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FACULTY OF OCCUPATIONAL SAFETY

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SCIENCE, INDUSTRY, EDUCATION
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ORIGINAL SCIENTIFIC PAPER

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ENVIRONMENTAL RISK OF MICROPOLLUTANTS: THE IMPACT OF REVISED EU DIRECTIVE ON URBAN WASTEWATER

Abstract: *Contamination of the environment by micropollutants has potentially adverse consequences, raising severe concerns. They were detected and identified in surface, ground, and drinking waters as well as in soils worldwide. Wastewater treatment plant (WWTP) effluents are recognized as the main source of the global increase of emerging contaminants. On 26 October 2022, the European Commission published a proposal for the revision of the Council Directive of 21 May 1991 on the treatment of municipal wastewater entitled "Urban Wastewater Treatment Directive – UWWTD". With the ongoing amendment of EU legislation on urban wastewater treatment, stricter requirements for pollutant removal are expected, driving the need for innovative environmental technologies. Diverse pollutants in urban wastewater, including macronutrients and micropollutants, require advanced treatment technologies that integrate biological, physical, and chemical processes. Advanced oxidation processes (AOPs) offer several advantages for the removal of micropollutants from wastewater. They facilitate the degradation of pollutants rather than their concentration, as is the case in membrane or adsorption systems, resulting in more thorough removal from wastewater. These processes also do not generate solid residues, reducing the need for additional waste management measures. AOPs have a small footprint, making them suitable for implementation in a variety of wastewater treatment facilities.*

Keywords: advanced oxidation processes, revised EU directive, micropollutants, sewage sludge, wastewater

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INTRODUCTION

Contamination of the environment by micropollutants (MPs) has potentially adverse impacts, raising severe concerns. Micropollutants were detected and identified in surface, marine, ground, and drinking waters as well as in soils world-wide (Hermabessiere, 2017). Wastewater treatment plant (WWTP) effluents are recognized as the main source of emerging contaminants, causing their global environmental impact. The use of new chemicals and compounds is driven by development, population changes, and efforts to improve the well-being of the population (Dogruel et al., 2020). The use of pharmaceuticals in animal and meat production, aquaculture, disposal of expired medicines, and hospital activities can cause severe environmental pollution, usually detected too late when enabled by sophisticated analytical techniques (Kümmerer, 2009). As a result, bacterial resistance (Sambaza & Naicker, 2023) to antibiotics due to adaptation and adjustment to the presence of antibiotics can occur (Irfan et al., 2025). Therefore, such pollutants need to be removed before disposal of wastewater (WW) into the environment. The improvement of detection and monitoring of substances in surface, ground, and wastewaters is also accompanied by the implementation of up-to-date legislation (Derco et al., 2024).

MICROPOLLUTANTS

Growing environmental problems include the widespread occurrence and presence of micropollutants and new emerging substances, collectively called "emerging pollutants" (EPs) in the aquatic and terrestrial environments (Kravos et al., 2024). Micropollutants are characterized by their adverse environmental impact even at very low concentrations (μg L^{-1} to ng L^{-1}). These effects include acute and chronic toxicity, bioaccumulation and bioconcentration in food chains, genotoxicity, or endocrine effects (Derco et al., 2024). Micropollutants enter the water environment mainly through their concentration in wastewater treatment plants, as current treatment technologies are not designed to remove them efficiently. Their presence in urban WWs is a consequence of using personal care products, cleaning agents, washing, use of toilets, and disposal of unused or excreted pharmaceuticals (Gomes et al., 2017). Due to the serious negative effects on the environment,

problems related to detection of low concentrations, and, in many cases, complex and variable chemical structure, the issue of MPs removal poses an urgent and current challenge to the development of treatment technologies for their removal, the investigation of their effects on the aquatic environment, and the potential of their possible penetration into groundwater (Lember et al., 2023; Derco et al, 2024).

NEW EU DIRECTIVE FOR URBAN WASTEWATER TREATMENT

On 26 October 2022, the European Commission published a proposal for the revision of the Council Directive of 21 May 1991 on the treatment of municipal wastewater "Urban Wastewater Treatment Directive – UWWTD" (European Commission, 2024). According to the revised directive, member states must collect and treat wastewater from all agglomerations above 1000 population equivalents (PE). All agglomerations between 1000 and 2000 PE need to be provided with collection systems and all sources of domestic wastewater need to be connected to these systems by 2035 (Derco et al., 2024). By 2039, the removal of nitrogen and phosphorus (tertiary treatment) will be mandatory for urban wastewater treatment plants larger than 150,000. For those urban wastewater treatment plants, by 2045, EU member states will have to apply additional treatment, known as quaternary treatment, to remove micropollutants (Table 1).

Table 1. *Groups of pollutants according to the EU directive proposal (EU, 2024).*

Group	Compound	Label	Function
I – Very easily decomposed	Amisulpride	AMI	Anti-psychotic
	Carbamazepine	CAR	Anti-epileptic drug
	Citalopram	CIT	Anti-depressant
	Clarithromycin	CLA	Antibiotic
	Diclofenac	DIC	Anti-rheumatic, analgesic
	Hydrochlorothiazide	HCH	Diuretic
	Metoprolol	MET	Beta blocker (heart)
	Venlafaxine	VEN	Anti-depressant
II – More easily removable	Benzotriazole	BZT	Anti-corrosive
	Candesartan	CAN	Anti-hypertension
	Irbesartan	IRB	Anti-hypertension
	4-methylbenzotriazole, 6-methylbenzotriazole 5-methylbenzotriazole	4MeBZT 6MeBZT 5MeBZT	Anti-corrosive

Producers of pharmaceuticals and cosmetics – the main source of micropollutants in urban wastewater – will need to contribute a minimum of 80% of the additional costs for the quaternary treatment, through an extended producer responsibility (EPR) scheme and in accordance with the 'polluter pays' principle (European Commission, 2024).

The new rules also introduce an energy neutrality target, meaning that by 2045, urban wastewater treatment plants treating a load of 10,000 PE and above will have to use energy from renewable sources generated by the respective plants (European Commission, 2024).

The proposed EU directive requires individual member states to define areas in which the concentration or accumulation of micropollutants poses a risk to human life and/or the environment. The removal of micropollutants must be achieved by applying quaternary treatment. By 2035, all WWTPs larger than 100,000 PE must be equipped with a quaternary treatment, while at least 50% of WWTPs larger than 10,000 PE also must have quaternary treatment. By 2040, all WWTPs larger than 10,000 PE in the areas where micropollutants pose a risk to human health or the environment should also be upgraded to the quaternary treatment stage. For quaternary treatment, 80% removal efficiency of at least 6 of the 12 micropollutants from Table 1 is mandatory (Kardos et al., 2025).

ADVANCED OXIDATION PROCESSES (AOPs)

With the ongoing amendment of EU legislation on urban wastewater treatment, stricter requirements for pollutant removal are expected, driving the need for innovative environmental technologies (Derco et al., 2024). Diverse pollutants in urban wastewater, including macronutrients and micropollutants, require advanced treatment technologies that integrate biological, physical, and chemical processes. Advanced oxidation processes (AOPs) offer several advantages for the removal of micropollutants from wastewater. First, they boast fast reaction rates for most organic pollutants, ensuring efficient degradation in a relatively short time frame (Boševski & Žgajnar Gotvajn, 2023).

Table 2. *Groups of AOPs according to sources of hydroxyl radicals (Žgajnar Gotvajn et al., 2023).*

General name of AOP	Source of hydroxyl radicals
Photolysis	UV
Ozone-based processes	O_3 O_3/UV O_3/H_2O_2 O_3/H_2O_2/UV
Hydrogen-based processes	H_2O_2/UV H_2O_2/Fe^{2+} (Fenton) H_2O_2/Fe^{3+} (Fenton-like) H_2O_2/Fe^{2+}/UV (Photo-Fenton)
Heterogenous catalysis	TiO_2/UV $TiO_2/UV/H_2O_2$
Sonochemical processes	Ultrasound 20 kHz–2 MHz
Electrochemical oxidation	Electric current 2–20A Electrolysis in aquatic medium
Cavitation	Ultrasound Laser Hydrodynamic Particle

They facilitate the degradation of pollutants rather than their concentration, as is the case in membrane or adsorption systems, resulting in more thorough removal from wastewater. These processes also do not generate solid residues, reducing the need for additional waste management measures (Satyam & Patra, 2025).

AOPs have a small footprint, making them suitable for implementation in a variety of wastewater treatment facilities. They could even completely mineralize most contaminants and ensure their transformation into harmless by-products. However, AOPs have some disadvantages (Cuerda-Correa et al., 2020). They may produce unknown products during the oxidation process, which may require further analysis to ensure the safety of the treated water. The water matrix can reduce their efficiency causing different interferences and the presence of residual oxidants, which can be a problem that requires careful monitoring and pretreatment measures in order to mitigate their effects on treatment efficiency.

The term Advanced Oxidation Processes (AOPs) describes those oxidation processes (Figure 2) that are based on the high oxidative capacity of the hydroxyl radical (·OH). Other reactive oxygen species and radicals of other ions also contribute to the efficiency of the processes (Ribeiro et al., 2015). They differ from each other depending on the method of radical formation and whether a catalyst is used. They mostly involve the *in situ* formation of hydroxyl radicals, which react rapidly with most organic substances, with the exception of chlorinated alkanes. AOPs can be roughly divided into two groups: homogeneous and heterogeneous processes, further classified into those that require an external energy source (radiation, ultrasound, electricity) and those that do not (Mahmoodi & Pishbin, 2025).

Hydroxyl radicals are very suitable for use on an industrial scale because they meet three key criteria (Brillas et al., 2009):

- they do not form solid waste;
- they are non-toxic and have a very short lifespan;
- they do not directly cause corrosion.

In addition to the above, the reactions take place at atmospheric pressure and room temperature, so the oxidation technology with hydroxyl radicals can also be described as environmentally friendly. They rank second in terms of oxidation potential, immediately behind fluorine. On the other hand, a significant disadvantage of AOPs could be high cost due to the use of reagents (e.g. hydrogen peroxide) and energy (ozone or UV light generation). Both are necessary to produce an adequate amount of hydroxyl radicals for a sufficient treatment effect. The most important parameter is the dose ratio between the mass of oxidant and the mass of pollution. Despite their wide applicability, hydroxyl radicals also have their limitations. However, AOPs are considered as a group of sustainable water remediation techniques (Satyam & Patra, 2025).

Ozone-based AOPs

In aqueous solutions of organic substances, COD (Chemical Oxygen Demand) first begins to decrease during ozonation. As the oxidation of the organic molecule progresses and CO_2 begins to form, the TOC (Total Organic Carbon) of the aqueous solution also begins to decrease. Complete oxidation of pollutants in aqueous solutions, down to CO_2, water, and inorganic components (nitrite, nitrate, sulphate, phosphate, etc.) is usually uneconomical, and in some cases not even possible, because, for example, acetic acid (due to its molecular structure) does not react with ozone (Ribeiro et al. 2015). The main goal of ozonation is therefore mainly the oxidation or decomposition of organic matter to the point where it becomes biodegradable or at least less harmful to aquatic and terrestrial (micro)organisms (Gottschalk et al., 2010). This could be particularly valuable for persistent micropollutants (Mahmoodi & Pishbin, 2025).

Ozone reacts with substances in two ways: by direct reaction of dissolved ozone with the organic molecule or by indirect reaction via hydroxyl radicals. The extent of both mechanisms and the degree of decomposition of pollutants in the direct or indirect mode depend on several factors, the most important of which are the nature of the pollutant, the ozone dose, and the pH of the medium in which ozonation is carried out. In acidic conditions (pH < 4), direct reaction with ozone usually dominates, while at pH > 9, the most important oxidation pathway is indirect, i.e., with hydroxyl radicals (Cuerda-Correa et al., 2020).

AOPs FOR REMOVAL OF SELECTED PHARMACEUTICALS – A CASE STUDY

Test compound

The purpose of this study was to measure the effect of ozone dose on the reduction of COD (Chemical Oxygen Demand), TOC (Total Organic Carbon), and increased biodegradability of model urban wastewater containing levofloxacin (LVX). It is a non-biodegradable antibiotic from the group of fluoroquinolones (Gong et al., 2016). The sites of ozone attack of the LVX molecule are shown in Figure 1 (El Najjar et al., 2013).

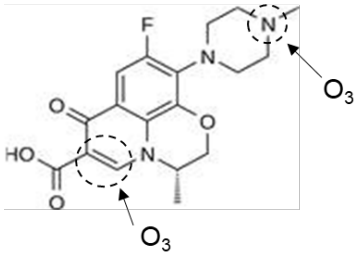


Figure 1. *Levofloxacin (LVX) with proposed sites for reaction with ozone (El Najjar et al., 2013).*

Levofloxacin is an antibacterial agent with a broad spectrum of activity against Gram-positive and Gram-negative bacteria and atypical respiratory pathogens. It is active against both penicillin-susceptible and penicillin-resistant bacteria.

MATERIALS AND METHODS

Ozone was led via a ceramic dispenser at the bottom of a bubble glass column with a volume of 3,500 mL (Žgajnar Gotvajn & Boševski, 2021). The water solution of LVX was pumped with a peristaltic laboratory pump through a column (1 mL s^{-1}) in a closed loop. Nominal ozone concentration in the gas phase was 140 g m^{-3} and the total capacity of ozone production was 7 g h^{-1}. Initial LVX concentration was 100 mg L^{-1}. At 15, 30, 45, 90, 120, 135, and 180 minutes, 30 mL of sample was taken to determine COD and TOC. For the purpose of the biodegradability test, samples were taken after 90 and 180 minutes of ozonation. Final samples were also used for determination of toxicity of activated sludge to microorganisms.

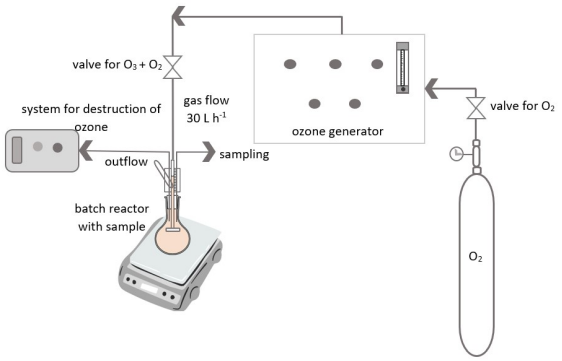


Figure 2. *Laboratory system for ozonation (Courtesy of N. Lekše, 2004).*

RESULTS AND DISCUSSION

LVX in concentration of 100 mg L^{-1} was not biodegradable (less than 10%). Samples after 90 and 180 minutes of ozonation were completely biodegradable. Both exhibited less than 2 days of lag phase; on day 7 more than 75% of biodegradability was determined. The ninety-minute ozonated sample completely biodegraded on day 22, while the 180-minute ozonated sample was completely degraded on day 17. No abiotic degradation was detected (less than 2%). Initial toxicity to microorganisms of activated sludge expressed as EC_{50} value was 1.115 ± 298 mg L^{-1} and it was reduced during ozonation (EC_{50} exceeded 5,000 mg L^{-1}). It can be concluded that ozonation efficiently degrades LVX to at least more biodegradable by-products without toxicity to microorganisms of activated sludge and thus enables further biological treatment of LVX-containing model wastewater. Treatment efficiency during ozonation of LVX according to COD and TOC is presented in Table 3.

Removal of COD was high, 74% (at an ozone dose of 0.40 mol_{ozone} mol $_{COD}^{-1}$), as was the reduction of TOC (47%). Longer ozonation or time-related higher ozone dose did not result in significant improvement in % of LVX removal. The difference in COD and TOC removal indicated the formation of by-products. LVX was oxidized, but not completely mineralized to carbon dioxide, water, and anions.

Table 3. *Treatment efficiency during ozonation of levofloxacin according to COD and TOC.*

Ozone dose (mol_{ozone} mol_{COD}^{-1})	Removal efficiency (%)	
	COD	TOC
0	0	0
0.1	65 ± 3	35 ± 3
0.2	65 ± 1	40 ± 2
0.3	67 ± 2	42 ± 1
0.4	74 ± 4	47 ± 1

However, pH decreased during oxidative treatment from 7.2±0.2 to 5.9±0.4 indicating the formation of simpler acidic products. This was also confirmed by the other toxicity and biodegradability studies (Urbanc, 2022). Reduction of pH could at the same time also shift the ozonation mechanism to direct ozonation rather than oxidation with hydroxyl radicals and thus reduce the oxidation potential of the system and decrease its non-selectivity. However, in the case of LVX it was proven that simple, non-catalytic ozonation is able to reduce its concentration in urban wastewaters.

CONCLUSION

New legislation mandating the monitoring of selected micropollutants in urban wastewaters and the implementation of quaternary treatment in wastewater treatment plants has forced future research and recommendations for effective removal of emerging contaminants. AOPs have a small footprint, making them suitable for implementation in a variety of wastewater treatment facilities. However, they have some disadvantages. They may produce unknown products during the oxidation process, which may require further analysis to ensure the safety of the treated water. The water matrix can reduce their efficiency, causing different interferences and the presence of residual oxidants can also be a problem. This requires careful monitoring and pretreatment measures to mitigate their effects on treatment efficiency. To fulfil the requirements of new legislation to prevent the impact on the environment and human health, numerous studies have yet to be conducted.

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REFERENCES

Bosevski, I., & Zgajnar Gotvajn, A. (2021). The impact of single step ozonation of antibiotics-contaminated waste sludge to biogas production. *Chemosphere*, 271.

Boševski, I., & Žgajnar Gotvajn, A. (2023). Biotreatability improvement of antibiotic-contaminated waters: high efficiency of direct ozonation in comparison to hydroxyl radical oxidation. *Acta Chimica Slovenica*, 70(1), 65-73.

Cuerda-Correa, E. M., Alexandre-Franco, M. F., & Fernández-González, C. (2020). Advanced Oxidation Processes for the Removal of Antibiotics from Water: An Overview. *Water*, 12(10).

Derco, J., et al. (2024). A Review About the Occurrence and Effectiveness of Conventional and Advanced Treatment Technologies of Persistent Organic Pollutants in Surface Water. *Reviews of Environmental Contamination and Toxicology*, 12(10).

Derco, J., Gulašova, P., Legan, M., Zakhar, R., & Žgajnar Gotvajn, A. (2024). Sustainability strategies in municipal wastewater treatment. *Sustainability*, 16(20), 1-40. https://doi.org/10.3390/su16209038.

Derco, J., Žgajnar Gotvajn, A., Gulašova, P., Šolzysova, N., & Kassai, A. (2024). Selected micropollutant removal from municipal wastewater. *Processes*, 12(5), 1-31.

Dogruel, S., et al. (2020). Ozonation in advanced treatment of secondary municipal wastewater effluents for the removal of micropollutants. *Environmental Science and Pollution Research*, 27(36), 45460-45475. https://doi.org/10.1007/s11356-020-10339-5.

El Najjar, N. H., Touffet, A., Deborde, M., Journel, R., & Vel Leitner, N. K. (2013). Levofloxacin oxidation by ozone and hydroxyl radicals: Kinetic study, transformation products and toxicity. *Chemosphere*, 93(4), 604-611.

EU. (2024). Directive (EU) 2024/3019 of the European Parliament and of the Council of 27 November 2024 concerning urban wastewater treatment. https://eur-lex.europa.eu/eli/dir/2024/3019/oj.

European Commission. (2024). Proposal for a Revised Urban Wastewater Treatment Directive. https://environment.ec.europa.eu/publications/proposal-revised-urban-wastewater-treatment-directive_en.

Gomes, J., Costa, R., Quinta-Ferreira, R. M., & Martins, R. C. (2017). Application of ozonation for pharmaceuticals and personal care products removal from water. *Science of The Total Environment*, 586, 265-283.

Gong, Y., Li, J., Zhang, Y., Zhang, M., Tian, X., & Wang, A. (2016). Partial degradation of levofloxacin for biodegradability improvement by electro-Fenton process using an activated carbon fiber felt cathode. *Journal of Hazardous Materials*, 304, 320-328.

Gottschalk, F., et al. (2010). Modeling the Environmental Impacts of Engineered Nanomaterials: Exposure Estimation for Nanoparticles Released from Products. *Environmental Science & Technology*, 44(10).

Hermabessiere, L. (2017). Occurrence and effects of plastic additives on marine environments and organisms: A review. *Chemosphere*, 182, 781-793. https://doi.org/10.1016/j.chemosphere.2017.05.096.

Irfan, M., et al. (2025). Systematic Review on Monitoring Antibiotic-resistant Pathogens in Wastewater. *Journal of Pure and Applied Microbiology*, 12(10).

Kardos, M. K., Patziger, M., Jolankai, Z., & Clemment, A. (2025). The new urban wastewater treatment directive from the perspective of the receiving rivers quality. *Environmental Sciences Europe*, 37(10).

Kravos, A., Žgajnar Gotvajn, A., & Prosen, H. (2024). Cardiovascular drugs as water contaminants and analytical challenges in the evaluation of their degradation. *Processes*, 12(10). https://doi.org/10.3390/pr12102177.

Kravos, A., Žgajnar Gotvajn, A., & Prosen, H. (2024). Utilizing Advanced Oxidation Processes (AOPs) to Understand the Complex Degradation Processes of Phenol, 2,4-Dichlorophenol, and Pentachlorophenol. *Environmental Analytical Chemistry*, 12(10).

Kümmerer, K. (2009). Antibiotics in the aquatic environment – A review - Part I. *Chemosphere*, 75, 417-434.

Kümmerer, K. (2009). Antibiotics in the Aquatic Environment—A Review—Part II. *Chemosphere*, 75, 417-434.

Lember, E., Kubliņa, A., Kokorīte, I., Putna, I., & Suzdalev, S. (2023). Recommendations for wastewater treatment plants for safe removal of pharmaceuticals and list of pharmaceuticals to be monitored. *Latvijas Vides, ģeoloģijas un meteoroloģijas centrs*, 6-56. https://videscentrs.lvgmc.lv/.

Mahmoodi, M., & Pishbin, E. (2025). Ozone-based advanced oxidation processes in water treatment: recent advances, challenges, and perspective. *Environmental Science and Pollution Research*, 12(10).

Ribeiro, A.R., Nunes, O.C. Pereira, M.F.R., Silva, A.M.T. (2015). *An Overview on the Advanced Oxidation Processes Applied for the Treatment of Water Pollutants Defined in the Recently Launched Directive 2013/39/EU.* Environ. Int. *75*, 33–51, doi:10.1016/j.envint.2014.10.027

Sambaza, S. S., & Naicker, N. (2023). Contribution of wastewater to antimicrobial resistance: A review article. *Journal of Global Antimicrobial Resistance*, 34, 23-29. https://doi.org/10.1016/j.jgar.2023.05.010.

Satyam, S., & Patra, S. (2025). The Evolving Landscape of Advanced Oxidation Processes in

Urbanc, T. (2022). *Primerjava katalitske in nekatalitske ozonacije za odstranjevanje antibiotikov iz odpadnih voda.* Master thesis. University of Ljubljana, Faculty of Chemistry and Chemical Technology, Ljubljana.

Wastewater Treatment: Challenges and Recent Innovations. *Processes*, 12(10).

Žgajnar Gotvajn, A., & Boševski, I. (2021). Reduction of environmental impact of antibiotic levofloxacin by ozonation of wastewater and sludge. *CRETE 2021: 7th International Conference on Industrial & Hazardous Waste Management*, 27th - 30th July 2021, Chania, Crete, Greece.

Žgajnar Gotvajn, A., Boševski, I. & Čehovin, M. (2023). *Napredni oksidacijski in hibridni procesi v postopkih čiščenja odpadnih vod*. 1. izd. Ljubljana: University of Ljubljana, Faculty of Chemistry and Chemical Technology, 1-65 (In Slovene).

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VIRTUAL REALITY APPLIED TO SAFETY TRAINING

Abstract: *According to the International Labour Organisation, approximately three million people die annually due to occupational accidents or diseases, with construction, mining, and manufacturing being the most affected sectors. One of the main contributing factors is the lack of adequate safety training programs, combined with poor safety knowledge. Literature suggests that immersive technologies, such as virtual and augmented reality (VR/AR), effectively enhance occupational safety training by allowing workers to experience hazardous scenarios in a controlled environment. This enables skills development without exposure to real-world risks. DigiRescueMe and STRIM European projects were designed with this principle in mind. DigiRescueMe focuses on miners' rescue training for professionals, while STRIM develops mining curricula with a special emphasis on occupational safety and health for students and mining professionals. The first phase of both projects involved identifying the most pertinent training content through focus group discussion and needs analysis. Then, realistic virtual scenarios were developed using Unity 3D, incorporating 3D-scanned objects via Peel3D technology to enhance realism. Currently, these scenarios are being tested by students and professionals, with feedback collected for further improvement.*

Keywords: immersive tools, safety engineering, occupational health and safety

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INTRODUCTION

Every year, around 3 million people die from occupational accidents or diseases, and 395 million workers sustain work-related injuries.[1] Data shows that about 63% of the fatal accidents are centred in just four sectors: agriculture, construction, forestry and fishing, and manufacturing. Taking a closer look at the European context, the scenario does not differ that much, with the construction sector at the top of the list with 22.9% of fatal accidents, and again the same sectors listed before, with transportation joining the list with around 15.6%.[2] Stress and mental health factors, fatigue, improper material handling, or use of inadequate personal protective equipment are some of the listed accident root causes, but, interestingly, a lack of safety programs is also mentioned in the literature (Barkhordari et al., 2019; Ivascu & Cioca, 2019; Mohandes et al., 2022). Particularly focusing on this latter issue, immersive tools have been paving their way through training agendas, especially occupational safety training. But what exactly are they? "Immersive tools" are computer-generated simulations with spatial and visual dimensions. Along the virtual continuum, virtual and augmented reality and their overlaps (Handa et al., 2012) allow programming of realistic (hazardous) scenarios that can be tested/used without actually putting the trainees in real-life threatening scenarios (Babalola et al., 2023). Despite their tremendous potential, it is important to note that these technologies are not here to replace traditional training methods but instead to complement them (Rey-Becerra et al., 2023).

LITERATURE REVIEW

A systematic literature research on immersive technologies as occupational safety training tools showed that, without surprise, construction is the sector investing more in safety training (Afzal & Shafiq, 2021; Al-Khiami & Jaeger, 2023; Alzarrad et al., 2024; Bao et al., 2024; Feng et al., 2024; Getuli et al., 2021; Rey-Becerra et al., 2023; Rokooei et al., 2023; Shringi et al., 2022; Xu & Zheng, 2021; Yu et al., 2022), followed by mining (Gürer et al., 2023; Pedram et al., 2020; Zujovic et al., 2021), manufacturing

[1] https://www.ilo.org/resource/news/nearly-3-million-people-die-work-related-accidents-and-diseases
[2] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Accidents_at_work_statistics

(Dhalmahapatra et al., 2021), transportation (Haj-Bolouri et al., 2024), and healthcare (Fujiwara et al., 2024). The analysed training domains can be easily divided into hazard identification and procedures training to improve safety awareness and decrease accident occurrence. To acquire a better perception of whether immersive tools are a better fit for safety training, control groups were used, whereby data showed that motivation and engagement, as well as overall training results, improved when compared to traditional classroom teaching methods (Al-Khiami & Jaeger, 2023; Alzarrad et al., 2024; Evangelista et al., 2025; Lu et al., 2022; Rey-Becerra et al., 2023; Rokooei et al., 2023). Nonetheless, it has to be mentioned that few studies provide long-term assessment to disclose the actual effectiveness of such training programs in long-term knowledge retention. The ones which did, however, obtained positive scores (Feng et al., 2024; Pedram et al., 2020; Stefan et al., 2024). Despite the said advantages of immersive tools, challenges remain. The cost of implementation and the resistance to adopting new technologies are notable barriers that cannot be ignored. Nevertheless, immersive tools present a transformative potential for occupational safety training, bridging theoretical knowledge with practical application.

DIGIRESCUE ME & STRIM PROJECTS

The *Standardization and Digitalization of Rescue Education in Mining* (STRIM) project, coordinated by the Faculty of Engineering of the University of Porto (FEUP), aims to develop an innovative digital curriculum for safety training in the mining industry, using virtual reality (VR) and augmented reality (AR). Funded by the Erasmus+ program No. 101083272, it involves institutions from Portugal, Angola, Mozambique, and Turkey. Activities include needs analysis, development of digital content, and validation of immersive tools for occupational safety training. The DigiRescueMe project, funded by the Erasmus+ program No. 2021-1-TR01-KA220-VET-000028090, aims to standardise and digitise mine rescue training. Coordinated by Dumlupinar University (Turkey), it involves FEUP and other European institutions. It focuses on creating modern curricula integrating technologies such as VR simulations and 3D techniques, promoting innovative educational practices in the mining sector. Both projects, STRIM and DigiRescueMe, stand out for their integration of immersive technologies, such as virtual and augmented reality, in the training of mining professionals. While STRIM focuses on occupational safety training, DigiRescueMe concentrates on mine rescue training. Immersive tools provide safe, realistic, and interactive learning environments, allowing trainees to acquire practical skills without exposure to real risks, reflecting a growing trend in professional education and industrial safety. This article aims to show how virtual reality, as an immersive tool, is being used to enhance safety training in these projects.

METHODOLOGY

The first phase of any training program is identifying the key content and materials. Therefore, a needs analysis was carried out for each project with this intent. Occupational health and safety technicians and mining professionals, as well as university educators and students, were interviewed and added to focus group discussions. It is important to bear in mind at this point that both projects encompass several institutions and, in their turn, are located in different geographical contexts and, therefore, cultures, which were also taken into consideration to draft the respective programs. Once the programs were drafted, the next step was to identify and draft computer-based scenarios that would allow building the immersive part of the training. Each scenario was thoroughly designed to consider every "real-life" bit that one would encounter in the real world using the Unity engine and C# in Visual Studio. Animations and sound effects were incorporated to stimulate the maximum number of senses and make the scenario as authentic as possible, creating a greater sense of immersion. Animations were created in *Unity*, using free *prefab* libraries-sourced objects. To enhance detail, additional objects were scanned using the *Peel3D* (Figure 1) scanner and incorporated into the scenarios.

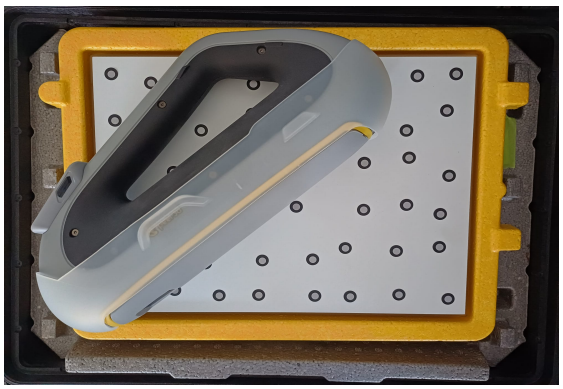


Figure 1. *Peel3D equipment*

The scenarios were built in a problem-based learning (PBL) approach, leading to the development of several *serious games*. By moving through each step of the way, the trainee has the chance to test their knowledge but also to learn the most appropriate action considering each learning outcome. To test the developed scenarios, the HTC VIVE equipment was used. It consists of one head-mounted display (HMD), two controls, and two sensors that require a minimum-distancing step up in order to function properly and, for the same reason, a maximum of 5.5 metres. The sensors have to be mounted at head height so they can pick up the signal emitted by the HMD. This means that the trainee also has to move exclusively within the radius of the equipment. Otherwise, the signal is lost, and the scenario blacks out. At the same time the scenarios were being built, a literature search was conducted to identify the most adequate questionnaires to test the developed materials. From the identified materials, two validated questionnaires stood out for their pertinence and adequacy to the testing phase: the System Usability

Scale (Brooke, 1996) and the Game Experience Questionnaire (GEQ) (Law et al., 2018). The SUS questionnaire is a 10-item questionnaire with answers on a 5-point Likert scale, used to evaluate the perceived usability of systems. It measures efficiency, effectiveness, and user satisfaction. It generates a score from 0 to 100 and is widely used for its simplicity, reliability, and general applicability. The GEQ is a multidimensional instrument for assessing the subjective experience of gamers. It also uses Likert scales to measure emotional, cognitive, and sensory factors. The GEQ questionnaire focuses on two moments: the "in-game", where the participant evaluates their performance and feelings during the *serious game*, and the "post-game", where the participants evaluate how they felt after the game. All the scenarios are currently undergoing testing by both students and professionals in the fields of mining engineering and occupational safety and health.

RESULTS AND DISCUSSION

The scenarios were made under the considerations detailed in the Methodology section. Three of those will be presented here, with the details discussed. The first one is a quarry scenario where the cardiopulmonary resuscitation (CPR) principles were tested (Figure 2). For this scenario specifically, the Automated External Defibrillator was digitised using the *Peel3D* and introduced in the *serious game*, as seen in Figure 2.



Figure 2. *Quarry scenario with CPR training*

As the scenarios were developed, subjects' feedback was gathered regarding their realness and proximity to reality, whereby small elements were added in the background to add a sense of reality to the quarry. This same exercise was later applied to every other scenario.

The second scenario propels users to take action upon the identification of an underground mining fire (Figure 3). The serious game development uses multiple-choice questions to guide the trainee throughout the scenario. In case the wrong answer is chosen, the box highlights in red colour, as seen in Figure 3. In case the user chooses the correct answer, the game moves on. Though real sounds were added to the scene, it is noted that, to increase the stress level as if in a real-life event, other aids could be used to improve the immersion experience, such as heating sensors, smoke machines, or camera effects (for example, changing colours or shaking/vibrating). However, that type of equipment would increase the overall step-up cost and would require a particular configuration room, contrary to the almost portable option of the HTC VIVE equipment, which has only the requirement for space for the free trainee movement.



Figure 3. *Underground mine fire scenario*

Finally, in scenario three, a worker is found unconscious, and the trainee is asked what the rescue operation actions would be (Figure 4). Considering the content complexity, even if the trainee provides the correct answer, the system "gives back" additional information to increase awareness of the subject, in this case – the need for an immediate response to improve the victim's chances.

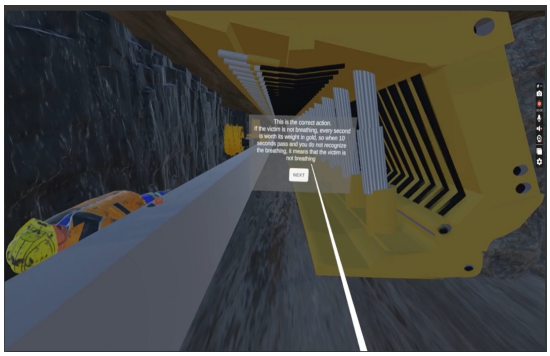


Figure 4. *Underground mine occupational accident scenario*

In this scenario, it is also quite complicated to increase the immersion level, taking the serious game to the next level instead of its being regarded as "just" a game.

Every scenario was created to incorporate real-life detailed dimensioning, exploitation, and technical principles. Nonetheless, it is important to mention that a severe limitation was encountered in the scenario development, as the relation between computer processing and the number of objects inside the scenario must be balanced for the computer to perform well. The users reported that the characters' movements "replicated well" real-life situations, enabling the player to act as they would in an authentic context. According to the feedback received so far, this tool is believed to help increase mining industry safety by providing training situations that empower workers to act.

CONCLUSION

Immersive tools such as virtual reality show great potential in occupational safety training, being explored in that direction by the STRIM and DigiRescueMe projects. The feedback gathered so far has led to the belief that using these tools, education on rescue operations (and overall safety) can be improved. With further investigation and proper development, hopefully, they will contribute to enhancing safety programs, raising awareness of mining-related hazards and accident reduction through training improvements.

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REFERENCES

Afzal, M., & Shafiq, M. T. (2021). Evaluating 4d-bim and vr for effective safety communication and training: A case study of multilingual construction job-site crew. *Buildings*, *11*(8). https://doi.org/10.3390/buildings11080319

Al-Khiami, M. I., & Jaeger, M. (2023). Safer Working at Heights: Exploring the Usability of Virtual Reality for Construction Safety Training among Blue-Collar Workers in Kuwait. *Safety*, *9*(3). https://doi.org/10.3390/safety9030063

Alzarrad, A., Miller, M., Durham, L., & Chowdhury, S. (2024). Revolutionizing construction safety: introducing a cutting-edge virtual reality interactive system for training US construction workers to mitigate fall hazards. *Frontiers in Built Environment*, *10*(April), 1–8. https://doi.org/10.3389/fbuil.2024.1320175

Babalola, A., Manu, P., Cheung, C., Yunusa-Kaltungo, A., & Bartolo, P. (2023). A systematic review of the application of immersive technologies for safety and health management in the construction sector. *Journal of Safety Research*, *85*, 66–85. https://doi.org/10.1016/j.jsr.2023.01.007

Bao, Q. L., Tran, S. V. T., Yang, J., Pedro, A., Pham, H. C., & Park, C. (2024). Token incentive framework for virtual-reality-based construction safety training. *Automation in Construction*, *158*(June 2023), 105167. https://doi.org/10.1016/j.autcon.2023.105167

Barkhordari, A., Malmir, B., & Malakoutikhah, M. (2019). An Analysis of Individual and Social Factors Affecting Occupational Accidents. *Safety and Health at Work*, *10*(2), 205–212. https://doi.org/10.1016/j.shaw.2019.01.002

Brooke, J. (1996). SUS: A "Quick and Dirty" Usability Scale. In *Usability Evaluation In Industry* (pp. 207–212). CRC Press. https://doi.org/10.1201/9781498710411-35

Dhalmahapatra, K., Maiti, J., & Krishna, O. B. (2021). Assessment of virtual reality based safety training simulator for electric overhead crane operations. *Safety Science*, *139*(February), 105241. https://doi.org/10.1016/j.ssci.2021.105241

Evangelista, A., Manghisi, V. M., De Giglio, V., Mariconte, R., Giliberti, C., & Uva, A. E. (2025). From knowledge to action: Assessing the effectiveness of immersive virtual reality training on safety behaviors in confined spaces using the Kirkpatrick model. *Safety Science*, *181*(October 2024). https://doi.org/10.1016/j.ssci.2024.106693

Feng, Z., Lovreglio, R., Yiu, T. W., Acosta, D. M., Sun, B., & Li, N. (2024). Immersive virtual reality training for excavation safety and hazard identification. *Smart and Sustainable Built Environment*, *13*(4), 883–907. https://doi.org/10.1108/SASBE-10-2022-0235

Fujiwara, A., Fujimoto, S., Ishikawa, R., & Tanaka, A. (2024). Virtual reality training for radiation safety in cardiac catheterization laboratories - an integrated study. *Radiation Protection Dosimetry*, *200*(September), 1462–1469. https://doi.org/10.1093/rpd/ncae187

Getuli, V., Capone, P., & Bruttini, A. (2021). Planning, management and administration of HS contents with BIM and VR in construction: an implementation protocol. *Engineering, Construction and Architectural Management*, *28*(2), 603–623. https://doi.org/10.1108/ECAM-11-2019-0647

Gürer, S., Surer, E., & Erkayaoğlu, M. (2023). MINING-VIRTUAL: A comprehensive virtual reality-based serious game for occupational health and safety training in underground mines. *Safety Science*, *166*(April 2021). https://doi.org/10.1016/j.ssci.2023.106226

Haj-Bolouri, A., Katende, J., & Rossi, M. (2024). Gamified immersive safety training in virtual reality: a mixed methods approach. *Journal of Workplace Learning*, *36*(7), 516–538. https://doi.org/10.1108/JWL-01-2024-0008

Handa, M., Aul, E. G., & Bajaj, S. (2012). Immersive Technology – Uses, Challenges and Opportunities. *International Journal of Computing & Business Research*, *6*(2), 1–11. http://www.researchmanuscripts.com/isociety2012/12.pdf

Ivascu, L., & Cioca, L.-I. (2019). Occupational accidents assessment by field of activity and investigation model for prevention and control. *Safety*, *5*(1). https://doi.org/10.3390/safety5010012

Law, E. L.-C., Brühlmann, F., & Mekler, E. D. (2018). Systematic Review and Validation of the Game Experience Questionnaire (GEQ) - Implications for Citation and Reporting Practice. *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play*, 257–270. https://doi.org/10.1145/3242671.3242683

Lu, S., Wang, F., Li, X., & Shen, Q. (2022). Development and validation of a confined space rescue training prototype based on an immersive virtual reality serious game. *Advanced Engineering Informatics*, *51*(December 2021), 101520. https://doi.org/10.1016/j.aei.2021.101520

Mohandes, S. R., Sadeghi, H., Fazeli, A., Mahdiyar, A., Hosseini, M. R., Arashpour, M., & Zayed, T. (2022). Causal analysis of accidents on construction sites: A hybrid fuzzy Delphi and DEMATEL approach. *Safety Science*, *151*(January), 105730. https://doi.org/10.1016/j.ssci.2022.105730

Pedram, S., Palmisano, S., Skarbez, R., Perez, P., & Farrelly, M. (2020). Investigating the process of mine rescuers' safety training with immersive virtual reality: A structural equation modelling approach. *Computers and Education*, *153*(September 2019), 103891. https://doi.org/10.1016/j.compedu.2020.103891

Rey-Becerra, E., Barrero, L. H., Ellegast, R., & Kluge, A. (2023). Improvement of short-term outcomes with VR-based safety training for work at heights. *Applied Ergonomics*, *112*(February), 104077. https://doi.org/10.1016/j.apergo.2023.104077

Rokooei, S., Shojaei, A., Alvanchi, A., Azad, R., & Didehvar, N. (2023). Virtual reality application for construction safety training. *Safety Science*, *157*(August 2022), 105925. https://doi.org/10.1016/j.ssci.2022.105925

Shringi, A., Arashpour, M., Golafshani, E. M., Rajabifard, A., Dwyer, T., & Li, H. (2022). Efficiency of VR-Based Safety Training for Construction Equipment: Hazard Recognition in Heavy Machinery Operations. *Buildings*, *12*(12), 1–23. https://doi.org/10.3390/buildings12122084

Stefan, H., Mortimer, M., Horan, B., & McMillan, S. (2024). How effective is virtual reality for electrical safety training? Evaluating trainees' reactions, learning, and training duration. *Journal of Safety Research*, *90*(February), 48–61. https://doi.org/10.1016/j.jsr.2024.06.002

Xu, Z., & Zheng, N. (2021). Incorporating virtual reality technology in safety training solution for construction site of urban cities. *Sustainability (Switzerland)*, *13*(1), 1–19. https://doi.org/10.3390/su13010243

Yu, W.-D., Wang, K.-C., & Wu, H.-T. (2022). Empirical Comparison of Learning Effectiveness of Immersive Virtual Reality–Based Safety Training for Novice and Experienced Construction Workers. *Journal of Construction Engineering and Management*, *148*(9), 1–13. https://doi.org/10.1061/(asce)co.1943-7862.0002337

Zujovic, L., Kecojevic, V., & Bogunovic, D. (2021). Interactive mobile equipment safety task-training in surface mining. *International Journal of Mining Science and Technology*, *31*(4), 743–751. https://doi.org/10.1016/j.ijmst.2021.05.011

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REVIEW PAPER

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TRADITION, ACTUALITY AND FUTURE PERSPECTIVES OF SOLAR ENERGY AT POLITEHNICA UNIVERSITY TIMISOARA

Abstract: *Politehnica University of Timișoara (UPT) has been at the forefront of solar energy research and applications in Romania, with a history spanning almost five decades, since its early beginnings in the 1970s. UPT has engaged in both thermosolar and photovoltaic (PV) projects, contributing significantly to the advancement of renewable energy technologies. In the first years, solar energy was studied by research teams with good positive impact on fields such as construction, thermotechnics, electromechanics, and electric and electronic fields. Different research teams performed measurements and simulations with good results on solar radiation, study of materials, different solar collectors, solar concentrators, a solar house, and many more.*

Keywords: solar energy, concentrated solar power, photovoltaics

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INTRODUCTION

This paper provides an insight into the work that has been performed at Politehnica University of Timisoara (UPT) for a period of more than 49 years, with added history, results, and perspectives on the use of solar energy. The main directions that were taken during this time frame are: actinometry, studies of the greenhouse effect, thermal collectors, solar concentrators, photovoltaic systems, industrial and home thermosolar setups, Fresnel lens, PV applications, and others. This paper focuses on the conception and building of a dedicated research laboratory and on the experimental results and simulations that allowed the development of industrial and home applications.

The activities related to solar energy have been performed during a long period of time within the Department of Fundamentals of Physics for Engineers at the Faculty of Electrical and Energetic Engineering, Faculty of Mechanics, and Telecommunications Faculty, and with the help of third-party collaborators and companies through projects or grants.

HISTORICAL OVERVIEW OF SOLAR ENERGY UTILIZATION AT UPT

Research in solar energy has been conducted from the early 1970s, when the first solar laboratory in natural conditions was built on the south-facing garage terrace, in the backyard of the then building of the Department of Physics, as shown in Figure 1.

Because it was difficult at the time to receive supplies and equipment from other countries, most of the building and maintenance work was done by 24 researchers-teachers and 7 technicians, and repairs were made in two workshops for electromechanics and electronics.

The main objective of the solar laboratory was to establish the weather-climatic database for the western part of Romania and to conduct theoretical and experimental research on the capture and use of solar energy for the supply of hot water and technological hot air, drying of ceramic and wood, fluidization of bitumen, concentration of radiation, obtaining of biomass, simulation of the physical phenomena involved in the thermo-conversion of solar energy, etc.

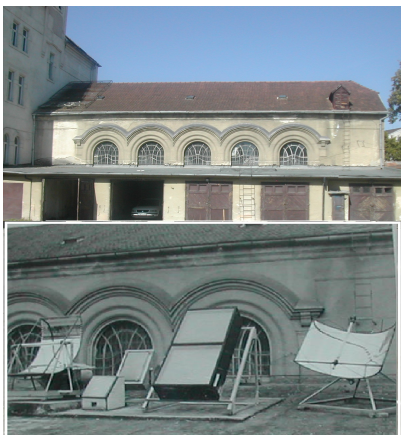


Figure 1. *First solar laboratory*

The first industrial application of solar energy technology ended up to be a hall for drying ceramic products, where the circulated air was heated by solar means. The cooperation between UPT and the Ceramic Plant from the city of Jimbolia began in 1976.

After many measurements and analysis, researchers concluded that clear window glass no thicker than 5 mm should be used for the best capture and conversion

of solar energy. Spinning panels with controllable orientation are also essential for a good water vapour evacuation without energy waste. Considering the 45-degree northern parallel, over which this city is situated, and considering environmental, climate, and building factors, a six-month period solar energy would be of good use. Details are shown in Luminosu, De Sabata, & De Sabata (2011).

In one of the first studies, tools to measure solar radiation were built, two devices specifically. The first one, Solaris 1, is a sensor with two thermally conductive plates painted in black. When the solar radiation falls on one plate, it heats it up until thermal equilibrium is reached, while the other plate is protected by the radiation with a silver-plated mirror, as shown in Figure 2 (Luminosu, De Sabata, & Ilie, 2013).

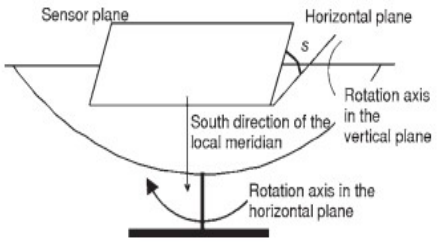


Figure 2. *Solaris 1*

The second one, Solaris 2 (Figure 3), a pyranometer, needed for measuring the global radiation in the horizontal plane, was built with a radiation sensor made from eight copper rings, as shown in Luminosu, De Sabata, & De Sabata (2010).



Figure 3. *Solaris 2*

Both devices were calibrated and compared to a standardized albedometer from the local weather station for Solaris 1, and for Solaris 2, the reference was a pyranometer from the National Meteorology and Hydrology from Bucharest. The results measured for solar radiation were highly accurate and are presented in detail in Luminosu, De Sabata, & De Sabata (2010).

In the following years, at the same department, an installation intended for measurement of the energy intake of diffuse radiation when conducting a thermal panel study was built.

In addition, over a period of many years, measurements and simulations were performed for solar radiation with locally built equipment. More in-depth details are presented in Table 1 and in Luminosu, De Sabata, & De Sabata (2010).

Table 1. *Solar radiation measured with built pyranometer*

Hour Month	09	10	11	12	13	14	15	16
Jan	73	102	154	188	190	174	104	36
Feb	106	169	247	291	282	210	165	84
Mar	190	286	336	384	380	345	293	214
Apr	330	374	508	512	470	412	352	280
May	480	580	610	615	605	590	512	384
June	590	704	745	807	810	720	629	431
July	475	681	771	801	778	693	602	504
Aug	416	612	691	704	701	646	538	426
Sept	312	414	487	538	543	476	413	279
Oct	183	276	334	364	367	315	273	127
Nov	97	163	231	261	252	182	116	44
Dec	46	94	137	158	146	107	82	14

Over a period of many years, this pyranometer has been used and compared to a later acquisitioned Kipp&Zonnen class A pyranometer. The results are remarkably accurate, thus proving the quality of the device. Table 2 shows the global solar radiation measured with Kipp&Zonnen pyranometer over a period of 3 years.

Table 2. *Solar radiation measured with Kipp&Zonnen pyranometer*

Hour Month	09	10	11	12	13	14	15	16
Jan	71	133	175	197	190	153	95	38
Feb	101	167	206	231	216	173	126	72
Mar	285	376	441	454	424	363	276	175
Apr	247	374	485	545	562	550	464	386
May	324	427	507	570	589	566	497	442
June	406	526	615	657	680	652	576	477
July	384	494	589	632	644	630	574	485
Aug	357	504	620	685	694	671	606	499
Sept	217	338	425	484	506	486	426	327
Oct	144	249	332	384	399	360	296	197
Nov	140	209	260	262	246	189	109	33
Dec	67	119	135	145	129	95	52	13

Thermosolar initiatives

In early 2000s, a thermosolar pilot system was built and integrated into the solar house. The solar house is shown in Figure 4. The building is still functional today, but was renovated. The thick brick walls are insulated with mineral wool and the roof is made of double reinforced concrete plates, insulated with bitumen. The building has two rooms, a lobby, and an access hall. All equipment for the thermal and solar installations is kept on the ground floor, including boilers, pumps, the control panel, etc.

The original building was constructed with a stone-filled tank for water and flat solar collectors (Figure 5), but during the following years, modifications were made.

The measurements made on the system with solar water collectors, air–water heat exchange, a heat accumulator bedrock, and a highly insulated building, resulted in the efficiency of the system of 30%, with solar energy accounting for 60% of the heating.



Figure 4. *Solar house, present view*

In addition, some of the first solar collectors built are shown in Figure 5. More details about the initial use and experiments made in the solar house with the initial destination are presented in Luminosu (2003).



Figure 5. *Flat solar collectors*

Nowadays, the solar house with the main side of the building orientated south has vacuum tube panels in front of the building, which are placed there for experiments, as shown in Figure 6. On top of the building, a concentrating solar thermal power installation was built and PV panels were installed this year.



Figure 6. *Vacuum tube panels*

In parallel with the research already ongoing for several years, in 2005 researchers from the department and from other faculties developed solar equipment for preheating bitumen. This system utilized solar energy to heat bitumen in industrial conditions, demonstrating an efficiency of 25-30% and achieving temperatures between 54-57°C, according to Luminosu, De Sabata, & But (2007).

Research on solar installations for heating bitumen was developed earlier in the 1980s at the physics department, and even then, researchers concluded that the process of passive solar heating may increase bitumen temperature up to 60-80°C. After many analyses, the use of solar energy for bitumen preheating has been regarded as reasonable.

Later on, as previously mentioned, pressurized thermal panels were installed on the south side, in front of the solar house. The panels were used for educational purposes and to produce hot water for the solar house, as shown in Figure 6 and Figure 7.

The solar house shown in Figure 4 has 3 circuits as follows:

Circuit 1: the capture area is 17.1 m^2; 3 pressurized panels, connected in parallel, and each panel equipped with 12, 18, or 24 tubes; the orientation of the panels is south; the inclination of the panels is 45°; there are two boilers with a capacity of 200 litres and 500 litres respectively and the surplus heat is transferred to an external tank.

Circuit 2: the capture area is 3.6 m^2; 1 panel equipped with 24 tubes; the orientation and inclination of the panel is variable and it is connected to 1 boiler with a capacity of 200 litres.

Circuit 3: the capture area is 3 m^2; 1 unpressurized panel, with natural circulation, equipped with 24 tubes; the orientation of the panel is south; the inclination of the panel is 45°.

These circuits are used for laboratory work for educational and demonstrative purposes.



Figure 7. *Pump and boiler connected to the thermosolar panels*

Photovoltaic (PV) developments

In parallel with the study of solar radiation in Timisoara for many years and with thermosolar research, in 2008 a PV installation consisting of 14 SOLWATT M220-60GET AK panels (Figure 8) with a 3 charging batteries system and with a total surface of 18.3 m^2 was built to be used for educational and practical applications for students, for public dissemination of information on solar energy, and as an uninterruptible power supply for local servers.

The system operated with an average efficiency of 12.66%, producing 1267.5 kWh/kWp annually. Details of the measurements, simulations, and conclusions are found in Toader et al. (2012).



Figure 8. *PV panels installed for educational purposes*

In addition, over a period of many years, measurements and simulations continued to be made for solar radiation with locally built equipment and acquisitioned through grants. More in-depth details, simulations, and mathematical models are shown in Luminosu, De Sabata, & De Sabata (2010), Luminosu, De Sabata, & De Sabata (2011), Luminosu et al. (2014), Jurca et al. (2011a and 2011b) and De Sabata et al. (2014).

Concentrated solar energy (Fresnel lens)

From 2010, for more than a decade, interest in concentrated solar energy, mainly Fresnel lens has emerged. Many setups have been built, through grants and partnerships and with financial help from the Research Ministry; numerous measurements were made with equipment that included Fresnel lens in combination with pressurized heat pipes, a Stirling engine, copper pipes with thermal agent, one-axis system, two-axis system, fixed inclination, etc.

Interest in this field and the results obtained led to a part of the prototypes being implemented in industry, with Energosophia Company as the beneficiary of this research conducted over the years.

Research on the design, testing, and certification of the two prototypes of solar collectors/concentrators with Fresnel lens was conducted over a period of 5 years, in order for the setup to be produced and used for internal and European market.

No fewer than 53 modules were built in order to determine the best possible option to obtain domestic hot water with minimal cost of investment and maximal efficiency.

The first prototype, LS01, has the most different units, which include lenses of different sizes with a focus spot and lenses with a linear spot of different sizes. Figure 9 shows some of the built units with 250x250 mm spot focus lenses, 22.5 mm focal length, whereas Figure 10 shows units with 320x400 linear focus lenses and a total focal depth of 62mm projecting on vacuum tubes.

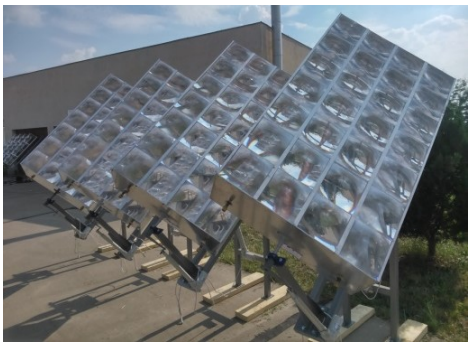


Figure 9. *LS01 prototype – units 6-9 (250x250 mm spot focus lenses, 22.5 mm focal length)*

More of the builds are shown in Figure 11 to Figure 14. Results were largely discussed and showed in (Șorandaru, 2013; De Sabata, 2013; Ilie, 2015; Ilie, 2017).



Figure 10. *LS01 prototype – units 16-18 (320 x 400 mm linear focus lenses, 62 mm focal length and vacuum tubes*)

Unit 19 of the LS01 prototype (Figure 11) is the only one with a gear-driven motor, but due to the cost involved for building and operation, only one setup was made.



Figure 11. *LS01 prototype – unit 19 (120x120 mm spot focus lenses, 120 mm focal length and driven by gear motors)*

Figure 12 shows an independent array where the lenses used for obtaining hot water are focusing on copper heat pipes, not on vacuum tubes, with a spot focus.

The second prototype, LS02, was intended to supply the Olympic swimming pool from Resita with warm water. The initial build was made in accordance with this request. Figure 13 shows the first unit from the LS02 prototype. Here the frame with the lenses follows the sun in the sky in order to keep its focal point.



Figure 12. *LS01 prototype – unit 20 (lenses with spot focus of 250x250 mm, focal length of 22.5 mm)*



Figure 13. *LS02 prototype – unit 1 (350x350 mm spot lenses, 32.5 mm focal length and copper tube)*

The second unit from the LS02 prototype (Figure 14) is fixed – only the top part with the lens follows the sun in the sky, driven by a chain to synchronize all units. This unit was the least feasible due to the height of the system, instability of the whole setup, and difficulty of manipulating the automatic system for following the sun in the sky.



Figure 14. *LS02 prototype – unit 2 (320x400 mm linear focus lenses, 62 mm focal length and vacuum tubes)*

A different experiment was conducted (Figure 15), which was the subject of a doctoral thesis. An overview of the experimental model of a solar thermoelectric power plant with a Fresnel lens and a beta-type Stirling engine, and the measuring devices used in the experimental determinations are shown.

The notations in the figure have the following meaning:

a – Fresnel lens, b – beta-type Stirling engine, c – electric generator, d – lens support frame, e – lower support frame, f – actuators, g – anemometer for measuring wind speed, h – pyranometer, i – actuator command and control module, j – insulated funnels, k – discs, l – voltmeter, m – ammeter, o – National Instruments module for data acquisition, p – standard resistor, q – variable resistor 100-1100Ω, r – laptop with LabView software, s – multimeter with temperature probe (hot zone), t – multimeter with temperature probe (cold zone), u – multimeter with temperature probe (hot zone), v – laser thermometer, and w – tachometer.



Figure 15. *Fresnel lens and Stirling engine prototype*

In-depth results of this setup, measurements, simulations, and applications are shown in Ilie et al. (2016), Ilie et al. (2017), and Maghet et al. (2018).

PRESENT AND FUTURE PROSPECTS

From 2014, UPT has a Research Institute for Renewable Energy ICER-TM, which was built over a period of 5 years. The research encompasses the following fields: photovoltaic piles, combustion piles, biogas production and use, wind power, nanomaterials and nanotechnologies used in conversion of renewable energy, aerodynamics and vibrations, electronics for renewable energy conversion, digital equipment for renewable energy, and automatic and electrical equipment.

Alongside this institute, many research teams work on areas of solar energy in order to contribute to the development of new technologies and systems for obtaining electrical and thermal energy from the sun.

In addition, it may be economic to use solar energy to reduce reliance on imported oil, particularly if Romania has a good solar potential, as shown in Luminosu, De Sabata, & Ilie (2013), Luminosu et al. (2019), and other studies.

Likewise, a prospective doctoral thesis that focuses on the use of PV cells in all types of conditions, from rough environments to local conditions is currently under way. Many results have been presented in papers found in the list of references below.

Figure 16 shows a small initial setup of the ongoing work for the aforementioned thesis, with a note that it is scaled to a 63.7 kWp on-grid PV park with 309.3 m^2 installed PV panels and with 140 PV modules.

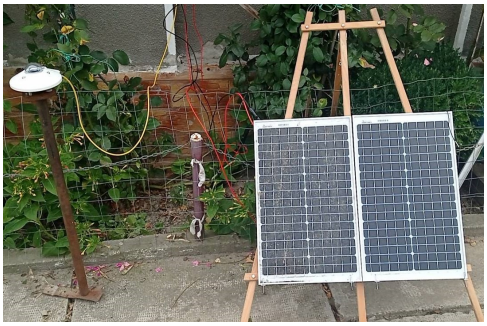


Figure 16. *Small PV setup*

CONCLUSION

Local solar conditions that apply to the western part of Romania, mainly where Politehnica University of Timisoara is located, offer the opportunity for multidisciplinary studies and applications of solar energy. Now, in 2025, Politehnica University of Timisoara is in the process of establishing a photovoltaic laboratory designed as a microgrid. This facility will integrate energy production, storage, and management, providing students with hands-on experience in simulating real-world energy scenarios.

This paper presented an ongoing work spanning half a century and experimental studies of solar energy in multiple fields. With Romania making significant strides in developing large-scale photovoltaic projects with over 880 large-scale PV power plants, with a cumulative capacity of more than 46600 MW, we believe that Politehnica University of Timisoara can make a significant contribution in this direction.

REFERENCES

De Sabata, A., Luminosu, I., & Ilie, S. (2013). *Study on the applicability of Fresnel lens concentrators in the Timişoara region*. Installations for Constructions and Environmental Comfort, AIIR, Edition 22, pp. 160-165.

De Sabata, A., Luminosu, I., Mărgineanu, D., Ilie, S., Jovanović, D., & Krstić, D. (2014). *Economics of a Small-Scale, Grid-Connected PV System in Western Romania: an LCoE Analysis*, 11th International Symposium on Electronics and Telecommunications, Timişoara, pp. 13-16. https://doi.org/10.1063/1.3647083

Ilie, S., Barvinschi, F., Toader, D., Greconici, M., Luminosu, I., & De Sabata, A. (2016). *Combined Simulations of Heat Transfer and Thermodynamic Cycle Processes Inside a Beta Stirling Engine by Using Two Different Softwares*. Global Conference on Applied Physics and Mathematics, pp. 159-160.

Ilie, S., Luminosu, I., Toader, D., De Sabata, A., & Zamfir, T. (2015). *Design and construction of a thermosolar installation with Fresnel lens and Stirling engine.* The scientific bulletin of UPT, *Mathematics - Physics Series*, 60(74), Issue 2.

Ilie, S., Maghet, A.E., Tatai, I., Mares, O., & Iovanovic, D. (2023). *Impact of dust on the performance of monocrystalline solar photovoltaic (PV) systems.* PES2023.

Ilie, S., Tatai, I., Sorândaru, C., Greconici, M., Toader, D. (2017). *System for supplying electric energy with zero CO_2 emissions*. PES2017 Conference, Nis, Serbia.

Ilie, S., Toader, D., & Barvinschi, F. (2016). *Modern Education on Renewable Energies by Using Numerical Finite Element Method of a Solar Powered Stirling Engine with Heat Transfer Simulations.* ISETC, pp. 137-140.

Ilie, S., Toader, D., Luminosu, I., Greconici, M., & Barvinschi, F. (2016). *Numerical Simulation of Heat Transfer inside a Beta Type Stirling Engine Using Concentrated Solar Energy and Artificial Heat Source*. Global Conference on Applied Physics and Mathematics, Italy, pp. 147-148.

Jurca, T., Paulescu, M., Dughir, C., Lascu, M., De Sabata, A., Luminosu, I., De Sabata, C., & Tulcan-Paulescu, E. (2011a). *Solar Radiation Modeling and Measurements in Timisoara, Romania.* AIP Conf. Proc. 1387, pp. 253-258.

Jurca, T., Tulcan-Paulescu, E., Dughir, C., Lascu, M., Gravila, P., De Sabata, A., Luminosu, I., De Sabata, C., & Paulescu, M. (2011b). *Global Solar Irradiation Modeling and Measurements in Timisoara*. TIM-10, Volume 1387.

Luminosu, I. (2003). *Experimental studies and economic considerations on a thermosolar pilot system destined for house temperature maintenance.* Thermal Science, 7, 47-61.

Luminosu, I., De Sabata, A., & Ilie, S. (2013). *Comparative analysis of the solar potential in west region of Romania.* AIIR conference, 22nd edition, pp. 147-155.

Luminosu, I., De Sabata, A., Ilie, S., Jovanovic, D., & Krstić, D. (2014). *Characteristics of solar radiation in the region close to Timisoara*. Safety Engineering 4, 163-166.

Luminosu, I., De Sabata, A., Toader, D., Margineanu, D., & Ilie S. (2019). Conception of a master degree program in Solar Energy: Infrastructure, Structure and Results. *Environmental Engineering and Management Journal.*

Luminosu, I., De Sabata, C., & But, A. (2007). *Solar equipment for preheating bitumen.* Thermal Science, 11(1), pp. 127-136.

Luminosu, I., De Sabata, C., & De Sabata, A. (2010). *Research in solar energy at the "Politehnica" University of Timisoara: Studies on solar radiation and solar collectors.* Thermal Science, 14(1), pp. 157-169. https://doi.org/10.2298/TSCI1001157L

Luminosu, I., De Sabata, C., & De Sabata, A. (2011). *Solar energy based industrial applications at Politehnica University of Timisoara.* Thermal Science, 15(3), pp. 587-598. https://doi.org/10.2298/TSCI100127026L

Maghet, A.E., Ilie, S., Luminosu, I., De Sabata, A., & Toader, D. (2018). *Experimental model of thermoelectric power plant with gamma Stirling engine.* ISFEE, Bucharest.

Șorândaru, C., Ilie, S., Zamfir, T., & Luminosu, I. (2013). *System for tracking the Sun in order to concentrate solar radiation with Fresnel lenses*., AIIR, Ed. 22, pp. 156-159.

Toader, D., Luminosu, I., De Sabata, A., & Negrea, D.M. (2012). *Educational PV system at Politehnica University of Timisoara.* IEEE. DOI: 10.1109/ISETC.2012.6

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OCCUPATIONAL HEALTH AND SAFETY MANAGEMENT: AN OVERVIEW OF FUNDAMENTAL PRINCIPLES AND PHILOSOPHY

Abstract: *Occupational health and safety (OHS) is generally defined as the science of predicting, recognizing, assessing, and controlling hazards and risks arising at or from the workplace, which could adversely affect the health and well-being of workers and other persons at work, considering the possible impact on the local community and the general environment. OHS principles are linked to the rights, responsibilities, and obligations of stakeholders who have certain expectations. These include moral, social, legal, and economic issues. The need for OHS is permanent. The philosophy of OHS begins with the basic need or requirement of safety, its fundamentals, cause analysis and assessment, identifying unsafe conditions and actions and the sequence of events leading to accident occurrence. It examines the principles and methodologies for the prevention of accidents and the prompt implementation of control measures. The OHS philosophy critically studies the basic principles and concepts of this field as an integral part of business management, while also emphasizing their practical application to promote a safe and healthy work environment. Based on the theoretical research, the paper presents an overview of the fundamental principles and philosophy of OHS management and provides guidelines for future specific research.*

Keywords: fundamental, philosophy, principles, occupational health and safety.

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INTRODUCTION

Occupational health and safety (OHS) has emerged as a crucial issue from economic, ethical, and legal standpoints. Companies are attempting to remain profitable in an ever more competitive global economy. For many companies, addressing safety, health, and environmental issues goes beyond good business practice - it can be essential to their very survival (Friend, Kohn, 2007).

The OHS management system is part of the overall system dedicated to the management of health risks associated with the organization's business activities. The system includes the organizational structure, planning, responsibility, practice, procedures, processes, resources for the development, application, implementation, review and maintenance of the organization's health and safety policy (Palačić, Mudri, 2014). Therefore, the OHS management system can be different between organizations and between countries.

The human, social and economic costs of work-related accidents, injuries and illnesses and major industrial disasters have long been a concern at all levels, from individual workplaces to national and international. Measures and strategies intended to prevent, control, reduce or eliminate hazards and risks in workplaces have been developed and applied continuously over the years to keep pace with technological and economic changes. However, despite gradual progress, work-related injuries and illnesses are still far too common and their cost in terms of human suffering and economic burden remains significant (Alli, 2008).

The management systems and characteristics required for success in OHS are the same as those required for success in any other area of industrial or commercial activity. Indeed, those organizations that are successful in business are usually those that have high standards of OHS (Cox, Tait, 1998).

Therefore, the purpose of OHS is to create safe conditions for the prevention of injuries at work, occupational diseases, and accidents at work. In the theoretical definition of the term occupational safety and health, there is no single position on what occupational safety and health is. Although various authors provide different definitions, it can be said that no definition contradicts the other, and in essence, they complement each other. The science of OHS aims to find measures and procedures that will eliminate the causes that lead to injuries and occupational diseases. Injuries and occupational diseases in modern society lead to major harmful consequences, primarily evident in the suffering experienced by injured workers or the

families of deceased workers, followed by major economic losses to society due to lost workdays, medical costs, recovery, etc.

The state of safety at work, in other words, the efficiency and effectiveness of the prevention of injuries at work and occupational diseases, depends on the success of the implementation of occupational safety in relation to the existing risks at work. Therefore, the key precondition for the planning and implementation of occupational safety is the assessment of occupational risks, and further and continual management of occupational risks.

From all the above, it is clear that OHS has its own principles and philosophy.

OHS principles are linked to the rights, responsibilities and obligations of stakeholders who have certain expectations. These include moral, social, legal, and economic issues.

The philosophy of OHS is rooted in the fundamental need for safety, its fundamentals, cause analysis and assessment, identifying unsafe conditions, unsafe actions, and examining the underlying reasons and the sequence of accident occurrence. It searches for the principles and methods of accident prevention and speedy control.

The need for OHS is permanent.

METHODOLOGY

Aim and tasks of the research

The problem that has been recognized in this area is the lack of understanding of the importance and relevance of OHS management in business. The importance and relevance of OHS management derive from its fundamental principles and philosophy.

Regarding the identified problem, the aim of the research is to provide an overview of the basic principles and philosophy of OHS management.

According to the set aim, the research tasks are:

- to analyse and present the fundamental principles of OHS management
- to analyse and present the fundamental philosophy of OHS management
- to encourage further empirical research into the principles and philosophy of OHS management.

Research methodology

Different scientific methods are used in the analysis, and their combination and sequence make up the research methodology. The principles and philosophy of OHS management were analyzed using the method of studying the content of scientific literature. A combination of deductive and inductive analysis is used to classify and summarize the theoretical foundations of the research subject. The content analysis method is used to analyze theoretical assumptions. The description method describes the fundamental principles and philosophy of OHS management. A combination of deductive and inductive analysis is applied in order to classify and summarize the basics of the research subject. After the analysis and comparison, essential properties are synthesized and conclusions are drawn.

RESULT AND DISCUSSION

Occupational health and safety management

Occupational health and safety (OHS) is a term that has been used for many years to describe health and safety related to work. OHS is a set of policies, processes and practices designed to protect workers from injury and occupational hazards. So, OHS is a way of protecting the health of employees. It is a responsibility that every employer has towards their employees. Employers are legally obliged to provide a safe workplace for their employees (Tajuddin, 2023).

Occupational health and safety is a field of public health that focuses on trends in illness and injury in the workplace. Professionals in the field use this knowledge to develop and implement policies and regulations aimed at reducing risks that could lead to physical or mental harm now or in the future. The scope of occupational health and safety is broad and encompasses a variety of disciplines (Corell, 2023).

OHS is a key aspect of any workplace, encompassing policies, procedures and practices that protect the health, safety, and well-being of employees. Whether it is an office, factory, construction site, or any other work environment, occupational health and safety is essential to ensure that workers can carry out their tasks without the risk of injury or illness. Therefore, OHS management is extremely important (Terrey).

OHS refers to a multidisciplinary approach to preventing accidents and injuries at work by identifying potential hazards, assessing risks, and implementing controls to mitigate those risks. It also involves integrating different fields, including health, safety, psychology, engineering, and law, to create a holistic framework that promotes a safe and healthy work environment (Karanikas, Pryor, 2021).

Occupational health and safety (OHS) is often terminologically equated with occupational safety. However, after careful consideration, it can be concluded that terminologically these two concepts cannot represent and mean the same thing (Palačić, 2021).

OHS is generally defined as the science of predicting, recognizing, assessing, and controlling hazards and risks arising at or from the workplace, which could adversely affect the health and well-being of workers and other persons at work, considering the possible impact on the local community and the general environment. This area is very broad and encompasses many disciplines and numerous hazards in the workplace and the environment. Therefore, a wide range of structures, skills, knowledge, and analytical capacity is needed to coordinate and implement all the elements that make up OHS systems to protect workers as effectively as possible (Alli, 2008).

OHS is integrated into the organization and execution of work processes and is achieved by performing occupational safety and applying the prescribed, as well as agreed-upon and recognized rules of occupational safety and employer's measures and instructions. So, the OHS management system is very important for business (Katić, Palačić, 2024).

The employer is responsible for the organization and implementation of OHS on the basis of objective responsibility, regardless of whether it has hired an occupational safety expert, organized an occupational safety service, or has contracted cooperation with an authorized person for occupational safety, an institution, or company for occupational safety. The management of OHS goes beyond the minimum requirements defined by the regulations in this area (Palačić, 2011).

According to some authors, occupational health and safety is an interdisciplinary scientific and professional field (it comes out of the domain of the existing structure of basic sciences and scientific disciplines) as well as a multidisciplinary field (because it forms a new field in which there are many scientific disciplines that touch and overlap). This multidisciplinary field is characterized by work organization, technique, technology, occupational medicine, ergonomics, anthropology, occupational health and safety law, pedagogy and andragogy, psychology, ecology, sociology, economics, etc. (Kacian, 1998).

The OHS management system is a continuous, adaptable process consisting of a series of related activities, phases, elements, and procedures that enable the normal flow and functioning of business processes and systems in which all persons participating in the organization's business processes must be included. OHS management is one of the more complex and responsible jobs in an organization that requires a lot of activity, attention and thinking from the organization's management. Optimum processes are created through the OHS management system through constant improvement, in which all factors that can make their contribution participate. Through thoughtful application and guidance in the OHS management system, hazards are eliminated, i.e., the risks of basic hazards that occur in the business process are reduced (Katić, Palačić, 2022).

The consequences of ineffective OHS management are directly related to the reasons why employers care about occupational safety and health. These consequences include, but are not limited to, the following:

- injury or illness to members of the workforce
- loss of credibility as a responsible company
- liability for failure to address safety and health
- loss of productivity
- loss of employees due to hazards, risks, injuries, illnesses, deaths, or unsafe/unhealthy work environments
- decreased employee morale
- damage to or loss of capital investments (e.g. equipment or facilities)
- decreased reputation and integrity of the company
- the perception that the company does not demonstrate good business practices
- loss of profits (Rees 2019).

There are several approaches to defining OHS management systems. As noted by Gallagher et al. (2001), the existence of various definitions has inhibited discussion about OHS management systems and contributed to a lack of consensus about how to evaluate their effectiveness. Furthermore, it has been asserted that OHS management systems definitions "have been watered down, making it more likely that organizations can claim to have a system, but less likely that it will be effective" (Gallagher et al., 2003). OHS management systems are often defined in simple terms such as "An OHS management system is a coordinated and systematic approach to managing health and safety risks" (WorkSafe Victoria, 2020).

Given that the successful implementation of an OSH management system has been identified as the foundation of an effective approach to OSH risk management (Sinclair, 2012) and a top priority for organizations (Mohammadfam et al., 2016), many researchers have been discussing the evaluation of OSH management systems for decades and whether OSH management systems positively impact OSH outcomes (e.g. Robson et al., 2007; Yorio et al., 2015; da Silva and Amaral, 2019; Madsen et al., 2020).

Any organization is responsible for making every effort to operate in a safe environment and introduce a safety management system, primarily for three key reasons recognized within the field of occupational safety and health. These include moral, financial, and legitimate reasons (Center for International Private Enterprise, 2022).

Fundamental principles

The fundamental philosophy of OHS is that "those who create risks must manage risks". However, decisions and actions at other levels of the system have a significant impact on the configuration and management of OHS risks. To ensure positive outcomes, every decision and action that affects health and safety must be guided by fundamental principles. Any lack of guiding principles for such decisions and actions creates dilemmas in risk management and can exacerbate the burden of harm and risk control (Pandey, 2024).

Several key principles underpin the field of OHS. These principles and provisions of international labour standards are designed to achieve a key goal: to work in a safe and healthy environment (Alli, 2008).

OHS principles are linked to the rights, responsibilities and obligations of stakeholders who have certain expectations. These include moral, social, legal, and economic issues. As stated earlier, the need for OHS is permanent.

OHS is an extensive multidisciplinary field that inevitably touches on issues related to scientific fields such as medicine, ergonomics, physics, chemistry, technology, economics, law, and other fields specific to different industries and activities. Despite this diversity, according to Alli (2008), certain basic principles are recognized, such as:

- All workers have rights. Workers, as well as employers and governments, must ensure the protection of these rights and must strive to establish and maintain decent working conditions and a decent working environment.
- OHS policies must be established. Such policies must be implemented at both the national and enterprise levels.
- A national OHS system must be established. The system must include all the mechanisms and elements necessary to build and maintain a preventive safety and health culture.
- A national OHS program must be formulated. Once formulated, it must be implemented, monitored, evaluated, and periodically reviewed.
- Social partners (employers and workers) and other stakeholders must be consulted.
- OHS programs and policies must be focused on prevention and protection. Efforts must first be focused on primary prevention in the workplace.
- Continuous improvement of OHS must be promoted.
- Information is vital for the development and implementation of effective programmes and policies.
- Health promotion is a central element of occupational health practice. Efforts should be made to improve the physical, mental, and social well-being of workers.
- Occupational health services covering all workers should be established.
- Compensation, rehabilitation, and curative services must be made available to workers who suffer occupational injuries, accidents, and work-related diseases.
- Education and training are vital components of safe, healthy working environments.
- Workers, employers, and competent authorities have certain responsibilities, duties, and obligations.
- Policies must be enforced. A system of inspection must be in place to secure compliance with occupational safety and health measures and other labour legislation.

Although these key principles form the foundation of occupational safety and health programs and policies, this list is not exhaustive. Specific special areas may have their own corresponding principles. Ethical considerations regarding issues such as individuals' right to privacy must therefore be considered when designing policies (Alli, 2008).

The responsibilities of governments, employers and workers should be complementary and mutually reinforcing in the common task of promoting occupational safety and health to the greatest extent possible within the limits of national conditions and practices.

Pandey (2024) concludes that from a systemic perspective, there are five OHS principles:

- utilise a system approach in decisions affecting the work systems
- a holistic and people-centric work system
- integrated lifecycle coverage
- inclusive process
- sustainable design.

The principles of OHS imply several different and broader perspectives. Regulatory frameworks, national policy instruments, or international conventions and recommendations are some of these perspectives. But at the core of all OHS activities, the primary objective is to prevent or protect against the risk of consequences.

Fundamental philosophy

The concept of philosophy is a branch of knowledge that investigates the elements, origin, source, causality, effect, reality and the means of their achievement and application in different fields. The concept of philosophy also includes science (Jadav, 2022).

As already mentioned, the need for safety is continuous and permanent. Safety is needed in all work activities. The goals of the OHS philosophy are to protect and serve people, to research, propose and implement safe ways of behaviour, human action, safe working conditions, and a safe environment for the safety, health, and well-being of workers. This shows the utmost importance of the OHS topic. OHS did not arise today. It has existed since ancient times, but it has developed in parallel with the demands of civilization and industry.

As already stated, the fundamental philosophy of occupational safety is that "those who create risks must manage risks." The OHS philosophy entails a critical study of the basic principles and concepts of OHS as an integral part of business, while ensuring that an understanding of these principles and concepts is applied in a way that ensures a safe and healthy workplace.

The OHS philosophy expresses the reasons and logic that dictate the decision-making process regarding the methodology, elements, and applications that should be used to implement successfully and effectively all OHS requirements (Reese, 2017).

All this includes safety devices, equipment, techniques and measures, factors that hinder and permit safety, safety responsibilities and roles of various agencies and authorized companies, terminology, theories and mysteries of causation, prevention, and control of accidents.

OHS is directly related to science, technology, law, engineering, health, hygiene, toxicology, psychology, and management. The OHS philosophy tries to find and

coordinate common causes and measures to solve general and specific safety problems.

OHS philosophy, in addition to the above, considers the study of physical, physiological, psychological, and other factors that influence and enhance OHS. It studies the costs and types of accidents and their significance, as well as the type of safety management required. This includes ways and means of ensuring and maintaining safe working conditions, human actions that affect human health and safety and environmental safety. OHS philosophy touches on the origin, development and amendment of safety legislation and its innovations and all safety needs in the fields of industrial safety and occupational safety.

The field of OHS philosophy is unlimited, its scope is very wide and includes the entire subject of safety from its origins to research, latest developments and from causality and behaviour analysis. This scope also includes the modern concept of design, testing, reliability, hazard control technology, risk analysis, assessment and audit, emergency planning, awareness and stakeholder involvement programs and future developments.

In fact, the OHS philosophy is reduced to the study of reality and phenomena. It analyses, considers, and examines the original or fundamental concepts of science or assumptions. This same philosophy coordinates scientific results with human moral experience, language, and meanings, visualizes or evaluates knowledge, its roots, measure, and limitations. The OHS philosophy is considered the foundation of the structure of safety culture (Jadav, 2022).

At the organizational level, the causal analysis of workplace incidents and the strategies that are subsequently adopted to identify and control OHS risks are based on one of two competing philosophical ideologies. The first is the “safe person” or “safe act” philosophy, which promotes an egocentric model of OHS risk. This view is criticized by safety experts who advocate an alternative perspective, known as the “safe place” philosophy, which promotes an ergonomic model of risk management. Current OHS legislation around the world is based precisely on the “safe place” philosophy (O’Neill, 2010).

Management's philosophy, procedures, policies, and procedures regarding OHS place workers in situations where they must implement safety and health practices in the performance of their work tasks.

The way the OHS management system is approached and how it works depends heavily on the OHS philosophy.

CONCLUSION

Business decisions and actions at the business system level have a significant impact on the configuration and management of occupational health and safety risks. To ensure positive outcomes, every decision and action that affects health and safety must be guided by fundamental principles. OHS principles can be considered at the operative and systemic level, at the level of the organization, or the state. The principles of OHS imply several different and broader perspectives, such as: regulatory frameworks, national policy instruments or international conventions and recommendations of these perspectives.

The OHS philosophy critically studies the basic principles and concepts of this field as an integral part of business management, while at the same time ensuring that an understanding of these principles and concepts is applied in a way that promotes a safe and healthy workplace. The philosophy of OHS management is very complex. The principles of OHS are related to its philosophy. The philosophy of occupational health and safety (OHS) involves closely examining its core principles and concepts as a key part of doing business, while making sure this knowledge is put into practice to create a safe and healthy work environment.

It can be concluded that the objectives and tasks of this research have been fulfilled. The analysis was carried out and the fundamental principles of OHS and the fundamental philosophy of OHS were presented. The importance and relevance of OHS management derive from its fundamental principles and philosophy. A good understanding of the concepts and philosophy of OHS is necessary for the improvement of OHS management. It is undeniable that further empirical research into the concepts and philosophy of OHS management is needed.

REFERENCES

Alli, B.O. (2008). *Fundamental principles of occupational health and safety*. International Labour Organization. Geneva.

Center For International Private Enterprise. (2022). *Fundamentals of Occupational Safety and Health – Introduction and Implementation of Management System*. Tbilisi.

Corell, R. (2023). *What Is Occupational Health and Safety?*. Verywell Health. Retrieved from https://www.verywellhealth.com/what-is-occupational-health-and-safety-4159865

Cox, S., Tait., R. (1998). *Safety, Reliability and Risk_Management - An Integrated Approach.* Butterworth-Heinemann. Oxford.

da Silva, S.L.C., Amaral, F.G. (2019). Critical factors of success and barriers to the implementation of occupational health and safety management systems: A systematic review of literature. *Safety Science,* 117, 123-132.

Friend, M.A., P. Kohn, J.P. (2007). *Fundamentals of occupational safety and health*, Government Institutes. Linham.

Gallagher, C., Underhill, E., Rimmer, M. (2001). *Occupational health and safety management systems: A review of their effectiveness in securing healthy and safe workplaces*. National Occupational Health & Safety Commission. Sydney, NSW: Commonwealth of Australia. Retrieved from https://www.safeworkaustralia.gov.au/system/files/documents/1702/ohsmanagementsystems_reviewofeffectiveness_nohsc_2001_archivepdf.pdf

Gallagher, C., Underhill, E., Rimmer, M. (2003). Occupational safety and health management systems in Australia: Barriers to success. *Policy & Practice in Health & Safety*. 1(2). 67-81.

Jadav, N.T. (2022) Philosophy of Safety. Retrieved from https://www.linkedin.com/pulse/philosophy-safety-natverlal-t-jadav/

Kacian, N. (1998). *Osnove sigurnosti*. IPROZ. Zagreb.

Karanikas, N., Pryor, P. (2021). *OHS Management Systems. Australian Institute of Health & Safety*, Tullamarine.

Katić, T., Palačić, D. (2024). Risks and opportunities of digitization of the occupational health and safety management system. 19th International Conference Management and Safety 2024. ESSE. Stubičke Toplice and online. 82-91.

Katić, T., Palačić, D. (2022). Analiza utjecaja na poslovanje i procjena rizika od poremećaja u zaštiti na radu u upravljanju kontinuitetom poslovanja. 17th International Conference Management and Safety 2022. ESSE. Online Conference. 83-94.

Madsen, C.U., Kirkegaard, M.L., Dyreborg, J., Hasle, P. (2020). Making occupational health and safety management systems 'work': A realist review of the OHSAS 18001 standard. *Safety Science*, 129, 104843

Mohammadfam, I., Kamalinia, M., Momeni, M., Golmohammadi, R., Hamidi, Y., Soltanian, A. (2016). Developing an integrated decision making approach to assess and promote the effectiveness of occupational health and safety management systems. Journal of Cleaner Production, 127, 119-133.

O'Neill, S.M. (2010). *Accounting for Lost Time: Examining Corporate Accountability to Stakeholders for Occupational Health and Safety*. [Doctoral dissertation, RMIT University].

Palačić, D. (2021). Occupational health and safety risk management model. 16th International Conference Management and Safety 2021. ESSE. Online Conference. 52-63.

Palačić, D. (2011). *Sustavi upravljanja sigurnošću*. IPROZ. Zagreb.

Palačić, D., Mudri, M. (2014). Defining Policy for Management of Occupational Health, Safety at work and Environmental Protection in order to Manage the Crisis in a Business Organization, *Collegium Antroplologicum*, 38, Suppl. 1, 13-24.

Pandey, B.R. (2024). Rethinking occupational health and safety principles - a systems perspective, *Journal of the Royal Society of New Zealand*, DOI: 10.1080/03036758.2024.2333555

Rees, C.D. (2019). *Occupational Safety and Health - Fundamental Principles and Philosophies*. CRC Press. London.

Robson, L.S., Clarke, J.A., Cullen, K., Bielecky, A., Severin, C., Bigelow, P.L., Irvin, E., Culyer, A., Mahod, Q. (2007). The effectiveness of occupational health and safety management system interventions: A systematic review. *Safety Science*, 45, 329-353.

Sinclair, D. (2012). Corporate OSH management architecture in the Australian coal mining industry. *Policy & Practice in Health & Safety*, 10(2), 3-24.

Tajuddin, A. (2023). Understanding Occupational Health And Safety (OHS): What You Need to Know to Keep Yourself and Your Employees Healthy. Fafetynotes.net. Retrieved from https://www.safetynotes.net/occupational-health-and-safety-ohs/#:~:text=In%20general%2C%20occupational%20health%20and%20safety%20refers%20to,and%20other%20support%20when%20injuries%20or%20illnesses%20occur

Terrey, R. Understanding Occupational Health and Safety (OHS): A Comprehensive Guide. Blog. Retrieved from https://www.the-entourage.com/blog/understanding-occupational-health-and-safety-ohs-a-comprehensive-guide

WorkSafe Victoria. (2020). *Occupational health and safety management systems.* Retrieved from https://www.worksafe.vic.gov.au/occupational-health-and-safety-managementsystems

Yorio, P. L., Willmer, D. R., Moore, S. M. (2015). Health and safety management systems through a multilevel and strategic management perspective: Theoretical and empirical considerations. *Safety Science*, 72, 221-228.

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CONTEMPORARY PROBLEMS OF OCCUPATIONAL SAFETY AND HEALTH IN THE DOMAIN OF CHEMICAL POLLUTION

Abstract: *Chemical pollution in the workplace is not just a concern; it's a serious threat to workers' health, causing both acute and chronic diseases. The key issues at hand include exposure to hazardous chemicals, insufficient exposure monitoring, and improper use of protective equipment. Industrial solvents, fumes, dust substances, and particulate matter significantly increase the risk of cancer, neurological disorders, and diseases of the respiratory system, particularly in the construction, chemical, pharmaceutical, and agricultural industries. Many companies are not conducting regular air quality measurements or biological monitoring of employees, and existing legal regulations often do not address new chemical risks. This lack of control and inadequate training results in the improper use of personal protective equipment (PPE), leading to an increase in occupational diseases such as asthma, chronic obstructive pulmonary disease (COPD), dermatitis, and chemical poisoning. It's clear that better regulations are urgently needed to address these issues. New research indicates the potential health risks of nanoparticles, particularly in the electronics industry. While there are international standards (OSHA, EU REACH, ILO), their implementation is inconsistent, inspections are infrequent, and sanctions are lenient. To address these issues, urgent action is needed in the form of improved regulation, stricter control, and enhanced worker education.*

Keywords: chemical pollution, occupational diseases, nanoparticles, workplace safety

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INTRODUCTION

Chemicals are integral to almost all aspects of modern society and are indispensable in numerous industries worldwide. Their application is diverse and multi-useful — from the production of medicines and disinfectants to the increase of yields in agriculture and the development of high technology. In many cases, chemicals contribute to better human health, more efficient production, and improved quality of life. As the second largest in the world among production branches, the chemical industry records constant growth, and every year, an increasing number of new substances are introduced into circulation (K. Singh et al., 2011; Xie et al., 2023). Although economically beneficial, this trend brings significant challenges — many of these chemicals have dangerous properties that can endanger human health and cause serious environmental consequences.

Exposure to hazardous chemicals can cause acute effects such as poisoning, irritation, and burns, but also long-term consequences, including cancer, neurological disorders, and endocrine system disorders (Alagan et al., 2023; Ghosh et al., 2022; Proshad et al., 2017; Thompson et al., 2017). A particular challenge is posed by chemicals that degrade slowly, tend to bioaccumulate, and spread through waterways and air, causing permanent damage to ecosystems.

Despite the benefits of chemicals, their irresponsible development, application, and disposal can cause irreparable consequences for health and nature. Industrial accidents, inadequate storage, non-compliance with regulations, and weak controls often lead to catastrophic consequences in local communities and globally (Palacios et al., 2021). More than one billion workers worldwide are annually exposed to hazardous chemical substances in the workplace, including pollutants, dust, fumes, and gases (International Labour Organization, n.d.). Unlike the general population, workers are often exposed to higher concentrations of these substances for more extended periods, which increases the likelihood of developing illnesses and injuries.

According to United Nations data from 2018, every 30 seconds, a worker dies due to exposure to chemicals at work (International Labour Organization, n.d.). These

deaths most often occur because of serious diseases such as cancer, systemic poisoning, and respiratory diseases, but also as a result of explosions and fires caused by chemicals. In addition to deaths, the number of non-fatal but serious injuries that lead to disability and chronic diseases, such as occupational asthma, dermatitis, and neurological disorders, is enormous.

The importance of the cumulative effects of long-term exposure is often overlooked — workers develop symptoms only after years of working in a contaminated environment, when the health damage is already irreversible. Many chemicals do not leave immediate traces, further complicating the timely diagnosis and treatment of diseases.

Chemical pollution in the workplace is a growing global problem with serious consequences for occupational safety and health. Exposure to hazardous substances such as industrial solvents, gases, dust particles, and fumes is associated with many acute and chronic health problems. Despite international standards and growing awareness, many workplaces are still characterized by inadequate risk assessment, weak enforcement of safety measures, and insufficient regulation. This paper aims to investigate the contemporary challenges associated with chemical pollution in the working environment, examine their impact on workers' health, with special reference to Serbia, and propose measures to improve the current situation.

Chemical exposure and health risks

Workers in various industries, especially construction, chemical, pharmaceutical, agricultural, and electronics, are exposed to various chemical agents. These agents include solvents, pesticides, heavy metals, acids, bases, aerosols, and other toxic substances used in everyday industrial processes.

The mode of exposure may include:

- Inhalation of toxic fumes – for example, workers who use solvents or solders in confined spaces are often exposed to harmful fumes that irritate the respiratory tract and cause headaches, dizziness, and even loss of consciousness (J. Singh et al., 2021).
- Contact with irritating substances - there is direct contact with chemicals that cause burns, allergic reactions, and dermatological problems (Rustemeyer et al., 2012).
- Absorption through the skin - many chemicals can pass through the epidermis and enter the bloodstream, causing systemic effects such as liver, kidney, or nervous system damage (Anderson & Meade, 2014).

Long-term exposure can result in chronic diseases such as:

- Chronic obstructive pulmonary disease (COPD) (Elonheimo et al., 2022).
- Asthma caused by the workplace (Ha et al., 2021).
- Dermatitis (allergic or irritant).
- Neurological disorders - due to exposure to heavy metals such as lead, mercury or manganese (Koszewicz et al., 2021).
- Cancerous diseases - associated with work in refineries, paint, and rubber industries (Boniol et al., 2016).

A special challenge is the increasingly frequent use of nanomaterials, especially in electronics, pharmaceuticals, cosmetics and nanotechnology. Due to their dimensions of less than 100 nm, nanoparticles can penetrate biological barriers that larger particles cannot cross (Baranowska-Wójcik et al., 2020). This includes:

- Penetration through the alveolar-pulmonary barrier and reaching the bloodstream,
- Accumulation in organs such as the liver, kidneys, and brain,
- Induction of oxidative stress, inflammation, and changes in cellular DNA.

Due to their size, nanoparticles often pass unnoticed through conventional filtration systems, and currently, valid regulations do not always include specific guidelines for their detection and control. The insufficiently investigated long-term effect of exposure to nanoparticles requires urgent interdisciplinary research and adaptation of rules to cover this new risk category in the working environment.

Weaknesses in supervision and regulation

Globally, regulations related to chemical safety at work lag behind technological developments. Although many countries have adopted laws and regulations such as OSHA (Occupational Safety and Health Administration) in the United States, REACH (Registration, Evaluation, Authorization, and Restriction of Chemicals) regulations in the European Union, and International Labor Organization (ILO) guidelines, their implementation is uneven, especially in developing countries. There are serious deficiencies in inspection systems, a lack of trained personnel, and limited resources for law enforcement. REACH is a comprehensive regulation of the European Union that entered into force in 2007 (Imaizumi, 2016). This regulation aims to ensure a high level of protection of human health and the environment through better and earlier identification of the properties of chemical substances. According to REACH, manufacturers and importers are obliged to register the chemicals they produce or import in quantities greater than one ton per year, and they are obliged to provide information on their properties and safe use. Although REACH represents one of the most advanced legal frameworks in the world, there are often delays in risk assessment and slow updating of the list of prohibited and restricted substances.

In Serbia, although there are basic legal acts that regulate safety and health at work, the application of these regulations is often formal and ineffective. It is problematic that monitoring of exposure to chemical

agents is rarely carried out, and biological monitoring is almost non-existent in practice. There is a lack of specialized laboratories for the analysis of toxic substances and personnel with expert knowledge in industrial toxicology and chemical safety. A particular challenge is the lack of up-to-date and comprehensive databases on chemicals used in industry and their effects on health.

Inspection services are insufficiently equipped with personnel and technology, and companies often do not feel obliged to comply with the regulations because the penalties are mild and rarely applied. In addition, there is insufficient synergy between regulatory bodies, scientific research institutions, and health institutions, which makes it challenging to coordinate and adopt effective policies.

Improvement actions

At the global level, an additional challenge is the slow reaction of legislation to the emergence of new materials and technologies, especially in the field of nanotechnology. Although more and more attention is directed to the potential risks of nanoparticles, regulations that would precisely define their use and worker protection criteria are still in their infancy.

To solve the problem, urgent reforms are needed, including:

- Improving legal regulations, especially about new chemical agents and nanomaterials.
- Introduction of mandatory and continuous workers' education on risks and protective measures.
- Regular implementation of air monitoring and biological analyses.
- Investments in quality personal protective equipment and improvement of working conditions.
- Strengthen inspection services and introduce stricter sanctions for non-compliance with safety regulations.
- Improving cooperation between institutions, including inspection services, academic institutions, and the health sector.
- Develop national databases on chemical substances and standardize risk assessment procedures.

Problems with personal protective equipment

One of the key problems in protecting workers' health from chemical pollution is improper use and inadequate availability of personal protective equipment (PPE). In many work environments, PPE is not standardized or adapted to the specific risks of the workplace. Poor quality equipment is often used without the necessary certificates, which do not provide adequate protection against chemicals, especially gases, vapours, and nanoparticles.

Workers are often not trained to properly use PPE - masks are not appropriately sealed, gloves are not changed regularly, and protective clothing is not resistant to chemicals with which employees come into contact. In addition, employers sometimes neglect the obligation to provide the appropriate equipment and to replace it after a specific period of use. This practice leads to a false sense of security among workers, who believe they are protected while chronic exposure to hazardous substances occurs.

In more advanced industrial systems, despite the availability of high-quality PPE, the problem is poor supervision of its proper use. Also, the efficiency of the equipment is rarely analyzed about specific chemical risks. Insufficient education and the absence of a safety culture contribute to the systemic neglect of preventive measures.

The need for regulatory reform and education

Solving the problem of chemical pollution requires strengthening the legal framework and enforcement mechanisms. It is necessary to harmonize the legislation with modern challenges, including the risks of nanoparticles and the mandatory toxicological assessment of all industrial chemicals.

Mandatory and regular education of employees must become a standard, with a special focus on small business entities in Serbia. Modernization of the health surveillance system, using digital tools for exposure monitoring and early warning, would enable a more effective response. In parallel, investing in engineering measures such as improving ventilation and local extraction of harmful substances is necessary.

International cooperation also plays an important role. Serbia should strengthen the exchange of data and experience with the EU and neighboring countries to encourage harmonizing standards and improve the efficiency of inspection and preventive mechanisms.

Current global trends

World trends in regulating chemical pollution in the working environment increasingly tend towards a proactive approach that includes the precautionary principle, the integration of risk evaluation in all stages of the industrial process, and comprehensive databases available to regulators and the public. The increased use of digital tools for monitoring chemical substances, including exposure simulation software and digital registries, allows for more accurate risk assessments and better surveillance efficiency. There are a growing number of "green chemistry" programs that encourage the replacement of hazardous chemicals with safer alternatives.

CONCLUSION

Chemical pollution in the workplace remains a key occupational safety and health challenge. Although there have been efforts to improve regulations and standards, there are still serious deficiencies in supervision, workers' training, and the implementation of protection measures. Especially in Serbia, where

institutional capacities are limited, there is an urgent need for comprehensive reforms.

To effectively protect employees' health, it is necessary to improve laws, strengthen control mechanisms, invest in education and technology, and encourage the cooperation of all actors in the occupational safety and health system. Only with such an integrated approach can the number of occupational diseases be reduced and a healthier and safer working environment ensured.

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REFERENCES

Alagan, M., Chandra Kishore, S., Perumal, S., Manoj, D., Raji, A., Kumar, R. S., Almansour, A. I., & Lee, Y. R. (2023). Narrative of hazardous chemicals in water: Its potential removal approach and health effects. In *Chemosphere*. https://doi.org/10.1016/j.chemosphere.2023.139178

Anderson, S. E., & Meade, B. J. (2014). Potential Health Effects Associated with Dermal Exposure to Occupational Chemicals. In *Environmental Health Insights*. https://doi.org/10.4137/EHI.S15258

Baranowska-Wójcik, E., Szwajgier, D., Oleszczuk, P., & Winiarska-Mieczan, A. (2020). Effects of Titanium Dioxide Nanoparticles Exposure on Human Health—a Review. In *Biological Trace Element Research*. https://doi.org/10.1007/s12011-019-01706-6

Boniol, M., Koechlin, A., Świątkowska, B., Sorahan, T., Wellmann, J., Taeger, D., Jakobsson, K., Pira, E., Boffetta, P., La Vecchia, C., Pizot, C., & Boyle, P. (2016). Cancer mortality in cohorts of workers in the European rubber manufacturing industry first employed since 1975. *Annals of Oncology*. https://doi.org/10.1093/annonc/mdw061

Elonheimo, H. M., Mattila, T., Andersen, H. R., Bocca, B., Ruggieri, F., Haverinen, E., & Tolonen, H. (2022). Environmental Substances Associated with Chronic Obstructive Pulmonary Disease—A Scoping Review. In *International Journal of Environmental Research and Public Health*. https://doi.org/10.3390/ijerph19073945

Ghosh, A., Tripathy, A., & Ghosh, D. (2022). Impact of Endocrine Disrupting Chemicals (EDCs) on Reproductive Health of Human. In *Proceedings of the Zoological Society*. https://doi.org/10.1007/s12595-021-00412-3

Ha, T. T. T., Hanh, B. M., Van Son, N., Giang, H. T., Hai, N. T., Thuc, V. M., & Khue, P. M. (2021). The cotton dust-related allergic asthma: Prevalence and associated factors among textile workers in nam dinh province, Vietnam. *International Journal of Environmental Research and Public Health*. https://doi.org/10.3390/ijerph18189813

Imaizumi, Y. (2016). Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH). *Japanese Journal of Pesticide Science*. https://doi.org/10.1584/jpestics.w15-48

International Labour Organization. (n.d.). *Introduction to chemicals in the world of work and the environment*. https://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/instructionalmaterial/wcms_871790.pdf

Koszewicz, M., Markowska, K., Waliszewska-Prosol, M., Poreba, R., Gac, P., Szymanska-Chabowska, A., Mazur, G., Wieczorek, M., Ejma, M., Slotwinski, K., & Budrewicz, S. (2021). The impact of chronic co-exposure to different heavy metals on small fibers of peripheral nerves. A study of metal industry workers. *Journal of Occupational Medicine and Toxicology*. https://doi.org/10.1186/s12995-021-00302-6

Palacios, A., Mata, C., & Barraza, C. (2021). Historical analysis of accidents in the mexican chemical industry. *Revista Mexicana de Ingeniera Quimica*. https://doi.org/10.24275/rmiq/Proc1345

Proshad, R., Kormoker, T., Islam, M. S., Haque, M. A., Rahman, M. M., & Mithu, M. M. R. (2017). Toxic effects of plastic on human health and environment : A consequences of health risk assessment in Bangladesh. *International Journal of Health*. https://doi.org/10.14419/ijh.v6i1.8655

Rustemeyer, T., Elsner, P., John, S. M., & Maibach, H. I. (2012). Kanerva's occupational dermatology, second edition. In *Kanerva's Occupational Dermatology, Second Edition*. https://doi.org/10.1007/978-3-642-02035-3

Singh, J., Kaushik, R. D., & Chawla, M. (2021). Hazardous Gases: Risk Assessment on the Environment and Human Health. In *Hazardous Gases: Risk Assessment on the Environment and Human Health*. https://doi.org/10.1016/C2020-0-03127-0

Singh, K., Ihlenfeld, C., Oates, C., Plant, J., & Voulvoulis, N. (2011). Developing a screening method for the evaluation of environmental and human health risks of synthetic chemicals in the mining industry. In *International Journal of Mineral Processing*. https://doi.org/10.1016/j.minpro.2011.07.014

Thompson, L. A., Darwish, W. S., Ikenaka, Y., Nakayama, S. M. M., Mizukawa, H., & Ishizuka, M. (2017). Organochlorine pesticide contamination of foods in Africa: Incidence and public health significance. In *Journal of Veterinary Medical Science*. https://doi.org/10.1292/jvms.16-0214

Xie, S., Li, Z., & Zhang, W. (2023). Techno-Economic Analysis of Upgrading Corn Stover-Based Acetone, n-Butanol, and Ethanol to Higher Ketones and Alcohols: Fuels or Fine Chemicals? *ACS Sustainable Chemistry and Engineering*. https://doi.org/10.1021/acssuschemeng.2c07103

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UPCYCLED CARBON BLACK AS AN ELECTROCATALYST FOR HYDROGEN PEROXIDE GENERATION

Abstract: *Carbon black is used in many industries due to its versatility and low cost. In this work, a cost-effective and scalable method for upcycling carbon black to carbon black flash graphene (CB-FG) using the fast flash joule heating (FJH) technique is presented. Extensive morphological, structural, spectroscopic and chemical analyses show that the resulting CB-FG exhibits lamellar morphology, low oxygen content, and a turbostratic graphitic structure. These properties underpin its excellent electrochemical performance in the two-electron oxygen reduction reaction ($2e^-$ ORR) for the electrosynthesis of hydrogen peroxide (H_2O_2). CB-FG shows up to 95% selectivity and high activity in 0.1 M KOH, making it a strong candidate for practical H_2O_2 electrosynthesis applications. Overall, this study advances the development of sustainable, upcycled electrocatalysts for H_2O_2 production and contributes to a circular economy and global sustainability initiatives.*

Keywords: Flash graphene; Flash Joule heating; upcycling; electrochemical synthesis; sustainability

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INTRODUCTION

Hydrogen peroxide (H_2O_2) is an important industrial chemical whose market is expected to reach USD 4.5 billion by 2032 (Wen et al., 2024) . Currently, over 95% of global production is manufactured using the centralized, multi-step anthraquinone process, which includes organic solvents, anthraquinone derivatives, Pd-based catalysts, and energy-intensive purification steps (Campos-Martin et al., 2006). Alternatively, H_2O_2 can be produced via direct synthesis from hydrogen and oxygen, but it is considered dangerous and unsustainable.

A cleaner, safer, and more sustainable alternative to the production of hydrogen peroxide is the direct electrochemical synthesis from water and oxygen via the two-electron oxygen reduction reaction ($2e^-$ ORR). This method has attracted considerable attention due to its potential for decentralized, on-demand H_2O_2 production (Farinazzo Bergamo Dias Martins et al., 2023). However, its commercialization is hindered by the lack of efficient and selective electrocatalysts. Various catalysts have been investigated, including platinum group metals (PGMs), their alloys, and transition metals such as Co (Cui et al., 2023), Fe (Zhang et al., 2023) and Ni (Nosan et al., 2023). While these materials exhibit high activity and H_2O_2 selectivity of up to 98%, their high cost, scarcity, and susceptibility to poisoning and deactivation limit their wide application. This has led to a growing interest in carbon-based nanomaterials, which offer a promising combination of activity, selectivity, and stability for $2e^-$ ORR (Bardarov et al., 2024). In particular, oxidized carbon materials have been shown to perform well in H_2O_2 electrosynthesis (Lu et al., 2018). However, many carbon electrocatalysts require complex and time-consuming synthesis routes, limiting their scalability and commercial viability. In line with sustainable and cost-effective approaches, we explored the use of upcycled, low-cost carbon materials. Specifically, we have focused on carbon black as a precursor for the development of an efficient electrocatalyst for H_2O_2 production.

Carbon black is a fine powder consisting of nanoscale amorphous carbon particles, usually produced by the incomplete combustion of various precursors. It is often used as a reinforcing filler in rubber composites to increase durability and wear resistance. In addition, carbon black serves as a black pigment in inks, paints, and plastics, providing color depth as well as UV protection. Its high surface-to-volume ratio and good electrical conductivity also make it valuable in electronics and energy storage and conversion technology. In contrast, graphene-based carbon materials offer superior properties, such as exceptional mechanical strength and one of the highest known electrical conductivities. However, their commercial use has been limited by high production costs, scalability issues, environmental concerns and inconsistent product quality associated with conventional synthesis methods (Wyss, Beckham, et al., 2021). An important advance was made in 2019 when Tour and colleagues demonstrated that various

carbon sources can be rapidly converted to turbostratic flash graphene (FG) using flash Joule heating (FJH) (Luong et al., 2020). In this context, the upcycling of carbon black into graphene-like derivatives represents a promising route to both scalable graphene production and the development of efficient electrocatalysts for H_2O_2 electrosynthesis. This motivation builds on our previous work where we successfully upcycled carbon fiber composites (CFCs) into highly efficient electrocatalysts for H_2O_2 generation using the FJH method (Bardarov et al., 2025).

Flash Joule Heating (FJH) is a simple, cost-effective bottom-up method for producing graphene. It involves passing a high-energy electrical pulse through a partially conductive sample, causing the temperature to rise to over 3000 K within milliseconds. This extreme thermal shock causes the sample to atomize and reorganize into a thermodynamically stable turbostratic graphite structure during rapid cooling, resulting in a product with a carbon content of up to 99% by weight. The ultra-fast cooling is crucial as it prevents the formation of the Bernal stacking (AB) typical of graphite (Wyss, Beckham, et al., 2021). Instead, the resulting turbostratic graphene exhibits a rotational disorder between the layers, leading to a larger interlayer spacing and a weaker van der Waals interaction. These weaker π-π stacking interactions make the structure easier to exfoliate and disperse into individual layers of the so-called flash graphene (FG) (Wyss, Wang, et al., 2021). This improved processability makes FG particularly attractive for various applications, especially for electrocatalysis for the oxygen reduction reaction (ORR) (Bardarov et al., 2025) and the hydrogen evolution reaction (HER) (Wyss et al., 2022) .

This article presents a novel approach for the upcycling of carbon black (CB) into high-quality flash graphene (FG) using flash Joule heating (FJH). The resulting material - carbon black-derived flash graphene (CB-FG) - shows excellent electrocatalytic performance for the $2e^-$ ORR and exhibits high activity and selectivity for electrochemical H_2O_2 production. This cost-effective, scalable method not only upcycles CB, but also provides a sustainable route to advanced carbon materials with great potential for clean energy and green chemical synthesis applications.

MATERIALS AND METHODS

Synthesis of Carbon Black Flash Graphene (CB-FG)

Carbon black flash graphene (CB-FG) was synthesized from carbon black (Ketjenblack EC-300J). The high conductivity of CB makes it ideal for flash Joule heating (FJH), eliminating the need for conductive additives. Typically, 200 mg of CB yields ~80% CB-FG. Weight loss results from volatile release during pretreatment and physical loss during flashing. A custom lab-scale FJH system was built to produce <1 g batches. For safety, the setup was enclosed in a grounded metal box inside a ventilated fume hood. The control unit, including the charger and emergency discharge circuit, was placed in a safe distance. Experiments were conducted with the sash closed and appropriate light shielding. A voltmeter and signal light confirmed capacitor discharge before sample retrieval. The experimental setup includes a 168 mF capacitor bank (400 V), charged via a half-wave rectifier with a current-limiting resistor. A thyristor switch delivers pulse currents up to 16 kA for 10 ms, controlled by an Arduino. An oscilloscope tracks voltage and current in real time. A 12 VAC, 20+ A power supply is used for pretreatment, which removes volatiles and prevents pressure buildup.

Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) analysis

Material morphology was analysed using a Zeiss ULTRA Plus field emission SEM (FE-SEM). Samples were mounted on conductive carbon tape affixed to an aluminium stub and imaged at 2 kV with an SE2 detector at a 5.5 mm working distance. TEM analysis of CB-FG was conducted using a JEOL ARM 200 CF microscope at 80 kV. For TEM, CB-FG was dispersed onto a carbon-coated copper grid.

X-ray photoelectron spectroscopy (XPS)

XPS analyses were performed using a Versa Probe 3 AD system (PHI, Chanhassen, USA) equipped with a monochromatic Al Kα X-ray source, operating at 15 kV accelerating voltage and 13.3 mA emission current. Powder samples were mounted on double-sided Scotch tape and placed at the center of the XPS holder. Spectra were collected over a 200 × 200 μm area with the charge neutralizer enabled. Survey scans were acquired using a pass energy of 224 eV and a step size of 0.8 eV, while high-resolution spectra were recorded with a pass energy of 27 eV and a step size of 0.1 eV. To ensure a strong signal-to-noise ratio, each spectrum was averaged over a minimum of 10 sweeps. Energy scale calibration and charge correction were performed by referencing the C=C component of the C 1s peak at a binding energy (BE) of 284.5 eV. Spectral deconvolution was carried out using MultiPak 9.9.1 and CasaXPS software, with Shirley background subtraction applied to all spectra.

Powder X-ray diffraction (XRD)

X-ray diffraction (XRD) measurements were performed using a PANalytical X'Pert PRO MPD diffractometer equipped with Cu $K\alpha 1$ radiation (λ = 1.5406 Å). Data were collected over a 2θ range of 10°–60° with a step size of 0.034° per 100 seconds, using a fully opened X'Celerator detector. Samples were mounted on a zero-background silicon holder.

Raman spectroscopy

Raman spectra were acquired using a WITec Alpha 300 RAS system equipped with a 532 nm laser (P = 5 mW), a 50× objective with a numerical aperture; NA = 0.8, and an integration time of 1 second. The reported spectra represent averaged data obtained from large-area mapping over a 50 × 40 μm region, sampled at a resolution of 100 × 80 pixels.

Electrode preparation and electrochemical measurements

Electrochemical measurements of CB-FG were performed using a rotating ring-disk electrode (RRDE, AFE6R2GCAU, Pine Research) with a GC disk (0.2376 cm²) and a gold ring (0.2356 cm²). The electrode was polished with 9 µm and 0.05 µm diamond paste (MetaDi™ Supreme, Buehler) and rinsed with ultrapure water (18.2 MΩ·cm, Milli-Q). CB-FG ink (2.376 mg·mL^{-1}) was prepared by dispersing 17.2 mg of CB-FG in 5.79 mL ultrapure water, 1.39 mL IPA (99.999%, Sigma-Aldrich), and 61.88 µL PFSA ionomer (Aquivion D98-25BS, 25% in water, Sigma-Aldrich), followed by 1 h of sonication. A 10 µL aliquot (100 µg·cm^{-2} loading) was drop-cast onto the GC disk and dried under ambient conditions. RRDE experiments were conducted with a WaveVortex10 rotator and a PalmSens4 bi-potentiostat, using Ag/AgCl/3 M NaCl as the reference, a glassy carbon rod as the counter electrode, and 0.1 M $HClO_4$, 0.5 M NaCl, and 0.1 M KOH as the electrolyte. Collection efficiencies were determined prior to measurements using 10 mM $[Fe(CN)_6]^{3-}$ in 0.1 M KOH at 1600 rpm and 50 mV·s^{-1}: $N = 0.383$ for the Au ring.

RESULTS AND DISCUSSION

CB-FG was synthesized via a two-step process involving preheating and FJH on a device presented in **Figure 1 (a) and 1 (b)**. The method was optimized for consistent material quality. In the first step, compressed carbon black (**Figure 1 (c)**) was pretreated by resistance heating at 20 A for 5 seconds. In the second step, a 200 ms high-current pulse (up to 1000 A) was applied to furnish carbon black flash graphene (CB-FG) as shown in **Figure 1 (d)**. CB-FG shows visible morphological changes when compared to CB precursor.

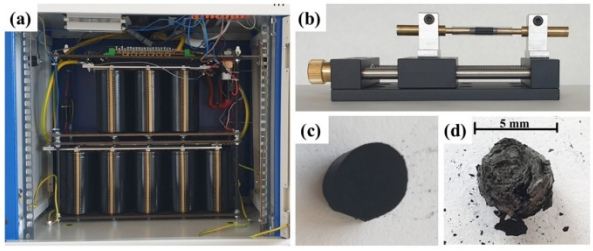


Figure 1. ***(a)*** *Flash Joule heating (FJH) setup showing the visible capacitor bank.* ***(b)*** *Sample holder with mounted precursor prior to preheating and FJH.* ***(c)*** *Compressed carbon black precursor before treatment.* ***(d)*** *Resulting carbon black flash graphene (CB-FG) after preheating and FJH.*

The morphology of the synthesized product was further investigated using electron microscopy (**Figure 2**). Scanning electron microscopy (SEM) revealed that the CB-FG exhibits a characteristic layered morphology, indicative of a turbostratic graphitic structure (**Figure 2 (a)**). The primary objective of transforming the amorphous, particulate morphology of carbon black (CB) into a graphitic-like structure was successfully confirmed by SEM analysis. Additionally, transmission electron microscopy (TEM) provided further evidence of this transformation, showing that the initially amorphous carbon black structure had been converted into a multilayered, turbostratic graphitic arrangement with noticeable wrinkling (**Figure 2 (b)**). The extremely rapid heating and cooling rates - on the order of milliseconds - impeded the formation of a fully crystalline graphitic structure typical of hexagonal graphite. Instead, these conditions favoured the development of short-range ordering and the emergence of curved, turbostratic graphitic layers. Such a structure is advantageous for subsequent material processing and facilitates easier exfoliation during the preparation of graphene-based electrocatalyst inks.

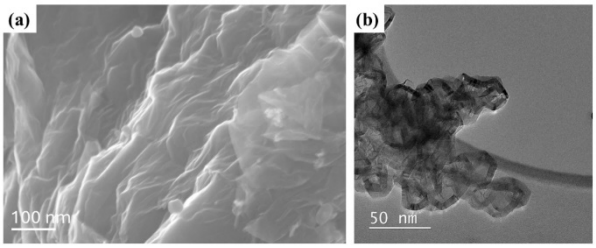


Figure 2. *Electron microscopy characterization of carbon black-derived flash graphene (CB-FG).* ***(a)*** *SEM image of CB-FG, illustrating its surface morphology, and* ***(b)*** *TEM image of CB-FG, revealing its internal microstructure.*

The structure was further characterized using X-ray diffraction (XRD) and Raman spectroscopy. XRD analysis revealed a highly crystalline structure, as evidenced by relatively sharp diffraction peaks. Notably, reflections corresponding to the (002), (101), and (004) crystal planes appear at 25.9°, 42.6°, and 53.5°, respectively (**Figure 3 (a)**). A minor peak at 35.7° suggests the presence of a small amount of SiC (111) as an impurity coming from a glass tube where flashing occurred. Focusing on the prominent (002) diffraction peak, the interlayer spacing $d_{(002)}$ was calculated to be 0.343 nm, which is larger than the typical value of 0.335 nm for highly crystalline hexagonal graphite with ABAB (Bernal) stacking. This increased interlayer distance is characteristic of a turbostratic, misaligned graphitic structure, corroborating observations made in TEM images.

Further confirmation of the turbostratic nature was obtained through Raman spectroscopy. The CB-FG sample exhibits distinct and sharper D and G peaks at 1337 cm^{-1} and 1570 cm^{-1}, respectively (**Figure 3 (b)**), in contrast to the broad and diffuse features typically observed in amorphous carbon black (CB) precursors. Additionally, prominent 2D, D+G, and 2D′ peaks are observed at 2700 cm^{-1}, 2914 cm^{-1}, and 3204 cm^{-1}, respectively, indicating a graphitic structure with multiple layers. To gain deeper insight into the structural order, we evaluated the I_D/I_G and I_{2D}/I_G intensity ratios. The I_D/I_G ratio of 0.67 suggests moderate structural disorder or a high density of edge sites, both consistent with a turbostratic morphology. The I_{2D}/I_G ratio of 0.68 further supports the formation of a few-layer, turbostratic graphene-like material, in agreement with the TEM and XRD findings.

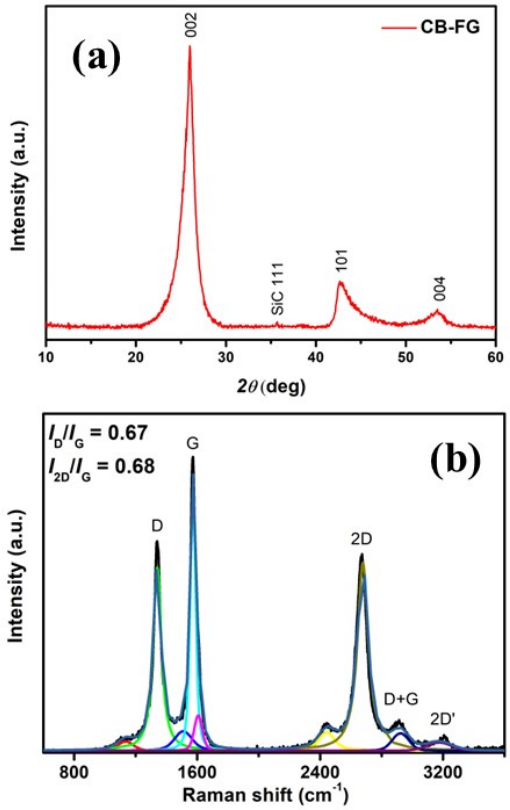


Figure 3. *Structural characterization of CB-FG.* ***(a)*** *XRD pattern of CB-FG, indicating high crystallinity.* ***(b)*** *Fitted Raman spectrum of CB-FG, highlighting the I_D/I_G and I_{2D}/I_G intensity ratios.*

To evaluate the chemical composition and surface functionalities of the synthesized material, X-ray photoelectron spectroscopy (XPS) analysis was performed. The survey spectrum revealed the presence of only two elements: carbon (99 at.%) and oxygen (1 at.%), as shown in **Figure 4 (a)**. This result demonstrates that the FJH process produces a highly pure carbonaceous product with a remarkably low concentration of oxygen-containing surface groups, indicating effective graphitization and minimal oxidation.

To gain deeper insight into the nature and distribution of surface functionalities, high-resolution C 1s core-level spectra were acquired and deconvoluted into five distinct components. The deconvolution identified peaks corresponding to: *sp²*-hybridized carbon at 284.5 eV, *sp³*-hybridized carbon at 285.0 eV, –C–O (epoxy or hydroxyl) at 286.5 eV, –C=O (carbonyl) at 288.0 eV, and –COO (carboxyl) at 289.3 eV, as illustrated in **Figure 4 (b)**. Quantitative analysis of the fitted peaks further supports the graphene-like nature of the material, with *sp²* carbon accounting for 94 at.% of the total signal, while only 1.3 at.% is attributed to *sp³*-hybridized carbon. The remaining oxygen-containing groups include –C–O (2.4 at.%), –C=O (1.0 at.%), and –COO (1.3 at.%), indicating the presence of minor surface oxidation.

These oxygen functionalities, although present in low concentrations, may play a significant role in the material's performance as an electrocatalyst. Specifically, surface-bound oxygen species can enhance electrocatalytic activity by modifying the electronic structure and increasing the density of active sites. However, they may also pose a disadvantage by potentially reducing the chemical and structural stability of the catalyst during prolonged oxygen reduction reaction (ORR) (Pavko et al., 2023).

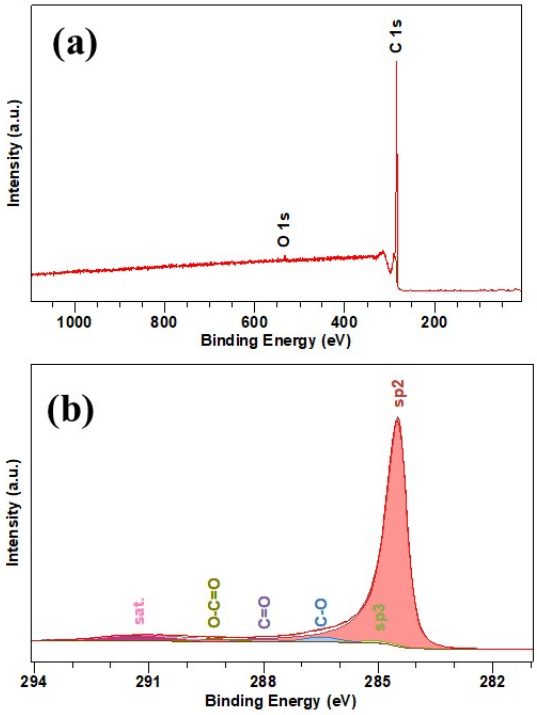


Figure 4. *XPS spectra of CB-FC.* ***(a)*** *survey spectrum and* ***(b)*** *fitted C 1s core level.*

In the final stage, the synthesized CB-FG was evaluated for its electrocatalytic performance toward the two-electron oxygen reduction reaction (2e⁻ ORR) in acidic (0.1 M $HClO_4$), neutral (0.5 M NaCl), and alkaline (0.1 M KOH) electrolytes. Carbon-based materials are known to favour the 2e⁻ ORR pathway, selectively producing hydrogen peroxide (H_2O_2) in acidic and neutral media, and hydroperoxide anions (HO_2^-) in alkaline conditions, while suppressing the competing four-electron pathway that reduces O_2 to water. Notably, in alkaline media, the pKa of H_2O_2 is 11.6, indicating that HO_2^- is the predominant species in alkaline electrolyte (**Eqn. (1)**).

$$O_2 + H_2O + 2e^- \rightarrow HO_2^- + OH^- \qquad \textbf{(1)}$$

ORR polarization curves (**Figure 5(a)** – lower graph) revealed that CB-FG exhibits the highest activity in alkaline electrolyte, moderate activity in neutral, and the lowest in acidic media. Specifically, the overpotential in neutral conditions was approximately 290 mV higher than in alkaline media at a current density of −0.1 mA, while the acidic medium required significantly higher overpotentials (681 mV higher than in alkaline media at a current density of −0.1 mA). The enhanced activity in alkaline media is attributed to reaction mechanism and the material's turbostratic structure and excellent electrical conductivity, both of

which facilitate efficient charge transfer. Rotating ring-disk electrode (RRDE) measurements were used to assess 2e$^-$ ORR selectivity (**Figure 5 (a)** – upper graph and **Figure 5 (b)**). CB-FG demonstrated over 90% selectivity in the range of 0.3–0.6 V vs. RHE in alkaline conditions, over 60% in the 0.0–0.3 V range in neutral electrolyte, and a maximum 10% at ~0.2 V in acidic conditions. The superior selectivity in alkaline media is linked to the presence of oxygen-containing functional groups and the increased interlayer spacing characteristic of turbostratic graphene, which create catalytically active sites in alkaline favourable for the 2e$^-$ ORR, as supported by density functional theory (DFT) studies (Perazzolo et al., 2015).

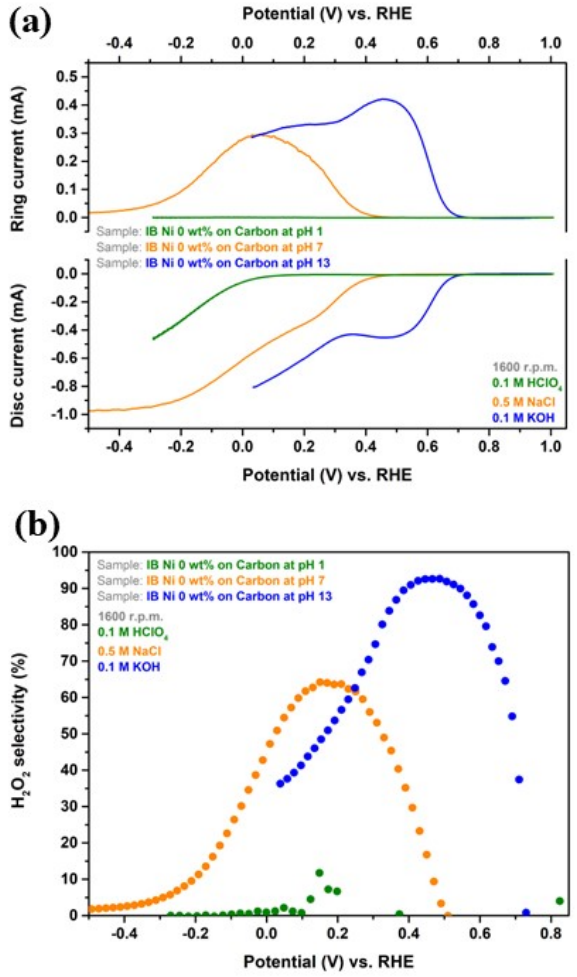


Figure 5. *Electrochemical characterization of CB-FG using RRDE. (a) Linear sweep voltammetry (LSV) polarization curves for the oxygen reduction reaction (ORR) recorded using a rotating ring-disk electrode (RRDE) setup. Simultaneous formation and detection of H_2O_2 species (HO_2^- in alkaline media) was achieved via the disk (formation - lower curves) and ring (detection - upper curves) electrodes. Measurements were conducted in O_2-saturated 0.1 M $HClO_4$, 0.5 M NaCl, and 0.1 M KOH electrolytes at a scan rate of 50 mV s^{-1} and a rotation speed of 1600 rpm. (b) H_2O_2 selectivity of CB-FG, calculated from the corresponding polarization curves, is presented for each electrolyte. The data illustrate the material's efficiency toward the 2e$^-$ ORR pathway across acidic, neutral, and alkaline environments.*

CONCLUSIONS

FJH has emerged as a highly efficient and scalable method for upcycling CB into CB-FG, effectively addressing many limitations of conventional graphene synthesis techniques. The process aligns with green chemistry principles, offering a sustainable route for transforming low-value materials into high-value, high-performance carbon nanomaterials. Electron microscopy reveals that CB-FG exhibits a lamellar-like morphology and a graphitic structure with a high specific surface area. Structurally, CB-FG possesses a turbostratic graphitic structure, as confirmed by Raman spectroscopy and XRD. XPS further shows that the material consists of 99 at.% carbon and only 1 at.% oxygen, highlighting the high purity achieved through the FJH process.

These combined structural and chemical characteristics underpin the material's excellent electrocatalytic performance in the 2e$^-$ ORR. In alkaline electrolytes, CB-FG achieves up to 95% selectivity for hydrogen peroxide production along with moderate catalytic activity. However, its selectivity and activity decrease in neutral conditions and are notably lower in acidic environments. Beyond its promising electrocatalytic potential, this approach also exemplifies how innovative materials science can contribute to circular economy goals and help mitigate environmental challenges through efficient upcycling strategies. Overall, CB-FG combines high catalytic activity with near-ideal selectivity in alkaline media, positioning it as a strong candidate for sustainable and efficient H_2O_2 electrosynthesis.

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REFERENCES

Bardarov, I., Apostolova, D. Y., Martins, P., Angelov, I., Ruiz-Zepeda, F., Jerman, I., Dular, M., Strmčnik, D., & Genorio, B. (2025). *Flash graphene from carbon fiber composites: A sustainable and high-performance electrocatalyst for hydrogen peroxide production.* Electrochimica Acta, 517. https://doi.org/10.1016/j.electacta.2025.145754

Bardarov, I., Apostolova, D. Y., Mathew, M. M., Nosan, M., Dias Martins, P. F. B., & Genorio, B. (2024). *Flash Graphene: a Sustainable Prospect for Electrocatalysis*. Acta Chimica Slovenica, 71(4), 541–557. https://doi.org/10.17344/acsi.2024.8794

Campos-Martin, J. M., Blanco-Brieva, G., & Fierro, J. L. G. (2006). *Hydrogen peroxide synthesis: An outlook beyond the anthraquinone process*. Angewandte Chemie - International Edition, 45(42), 6962–6984. https://doi.org/10.1002/anie.200503779

Cui, X., Zhong, L., Zhao, X., Xie, J., He, D., Yang, X., Lin, K., Wang, H., & Niu, L. (2023). *Ultrafine Co nanoparticles confined in nitrogen-doped carbon toward two-electron*

oxygen reduction reaction for H_2O_2 electrosynthesis in acidic media. Chinese Chemical Letters, 34(11). https://doi.org/10.1016/j.cclet.2023.108291

Farinazzo Bergamo Dias Martins, P., Plazl, I., Strmcnik, D., & Genorio, B. (2023). *Prospect of microfluidic devices for on-site electrochemical production of hydrogen peroxide*. In Current Opinion in Electrochemistry (Vol. 38). Elsevier B.V. https://doi.org/10.1016/j.coelec.2023.101223

Lu, Z., Chen, G., Siahrostami, S., Chen, Z., Liu, K., Xie, J., Liao, L., Wu, T., Lin, Di., Liu, Y., Jaramillo, T. F., Nørskov, J. K., & Cui, Y. (2018). *High-efficiency oxygen reduction to hydrogen peroxide catalysed by oxidized carbon materials.* Nature Catalysis, 1(2), 156–162. https://doi.org/10.1038/s41929-017-0017-x

Luong, D. X., Bets, K. V., Algozeeb, W. A., Stanford, M. G., Kittrell, C., Chen, W., Salvatierra, R. V., Ren, M., McHugh, E. A., Advincula, P. A., Wang, Z., Bhatt, M., Guo, H., Mancevski, V., Shahsavari, R., Yakobson, B. I., & Tour, J. M. (2020). *Gram-scale bottom-up flash graphene synthesis*. Nature, 577(7792), 647–651. https://doi.org/10.1038/s41586-020-1938-0

Nosan, M., Strmčnik, D., Brusko, V., Kirsanova, M., Finšgar, M., Dimiev, A. M., & Genorio, B. (2023). *Correlating nickel functionalities to selectivity for hydrogen peroxide electrosynthesis*. Sustainable Energy and Fuels, 7(9), 2270–2278. https://doi.org/10.1039/d3se00139c

Pavko, L., Gatalo, M., Đukić, T., Ruiz-Zepeda, F., Surca, A. K., Šala, M., Maselj, N., Jovanovič, P., Bele, M., Finšgar, M., Genorio, B., Hodnik, N., & Gaberšček, M. (2023). *Correlating oxygen functionalities and electrochemical durability of carbon supports for electrocatalysts*. Carbon, 215. https://doi.org/10.1016/j.carbon.2023.118458

Perazzolo, V., Durante, C., Pilot, R., Paduano, A., Zheng, J., Rizzi, G. A., Martucci, A., Granozzi, G., & Gennaro, A. (2015). *Nitrogen and sulfur doped mesoporous carbon as metal-free electrocatalysts for the in situ production of hydrogen peroxide*. Carbon, 95, 949–963. https://doi.org/10.1016/j.carbon.2015.09.002

Wen, Y., Feng, Y., Wei, J., Zhang, T., Cai, C., Sun, J., Qian, X., & Zhao, Y. (2024). *Photovoltaic-driven stable electrosynthesis of H2O2 in simulated seawater and its disinfection application*. Chemical Science. https://doi.org/10.1039/d4sc05909c

Wyss, K. M., Beckham, J. L., Chen, W., Luong, D. X., Hundi, P., Raghuraman, S., Shahsavari, R., & Tour, J. M. (2021). *Converting plastic waste pyrolysis ash into flash graphene*. Carbon, 174, 430–438. https://doi.org/10.1016/j.carbon.2020.12.063

Wyss, K. M., Chen, W., Beckham, J. L., Savas, P. E., & Tour, J. M. (2022). *Holey and Wrinkled Flash Graphene from Mixed Plastic Waste*. ACS Nano, 16(5), 7804–7815. https://doi.org/10.1021/acsnano.2c00379

Wyss, K. M., Wang, Z., Alemany, L. B., Kittrell, C., & Tour, J. M. (2021). *Bulk Production of Any Ratio 12C:13C Turbostratic Flash Graphene and Its Unusual Spectroscopic Characteristics*. ACS Nano, 15(6), 10542–10552. https://doi.org/10.1021/acsnano.1c03197

Zhang, Q., Zheng, L., Gu, F., Wu, J., Gao, J., Zhang, Y. C., & Zhu, X. D. (2023). *Recent advances in single-atom catalysts for acidic electrochemical oxygen reduction to hydrogen peroxide*. In Nano Energy (Vol. 116). Elsevier Ltd. https://doi.org/10.1016/j.nanoen.2023.108798

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ENHANCING OCCUPATIONAL SAFETY IN MINING: INSIGHTS FROM THE STRIM PROJECT

Abstract: *The project 'Safety Training with Real Immersivity for Mining' (STRIM) aims to enhance occupational health and safety training in the mining industry by integrating virtual reality (VR) and augmented reality (AR) tools. Given the high-risk nature of mining operations, effective training is essential to reduce workplace accidents and improve workers' preparedness. To identify key challenges and training needs, 26 semi-structured interviews were carried out with occupational health and safety professionals in Angola and Mozambique. These interviews explored their roles in occupational health and safety issues in their organisations and existing gaps in training. The findings revealed three priorities: 1) The need to create in-depth and well-founded training programmes across all levels of the industry, from mine workers to company managers and higher education institutions; 2) The need to strengthen the legislative framework on occupational health and safety regulations to be implemented in the extractive industry, and 3) The need to promote a more effective safety culture and to learn how to adequately perform risk analysis. The study concludes that adopting immersive technologies can significantly enhance learning experiences, strengthen regulatory compliance, and improve overall safety in the mining sector. Achieving these goals requires a collaborative effort involving industry professionals, policymakers, and educational institutions.*

Keywords: virtual reality, augmented reality, occupational health and safety, professional training.

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INTRODUCTION

The extractive industry is one of the sectors of activity with the most significant exposure to occupational risks, involving complex work environments, often underground, in which heavy machinery is used, explosives are handled, and geological conditions can be unstable. These aspects make health and safety issues in this context a priority for the sector.

In Angola and Mozambique, the mining sector plays a critical role in driving their respective national economies, contributing significantly to gross domestic product (GDP), job creation, and foreign exchange earnings (Caixao, 2021; Edwards et al., 2014). Both countries are rich in natural resources, including diamonds, gold, and other valuable minerals, making mining a cornerstone of their development strategies. However, despite its economic importance, the mining industry in these nations grapples with profound occupational safety and health (OSH) challenges that threaten worker welfare, operational efficiency, and sustainability (Moyo et al., 2017; Moyo et al., 2015). High rates of workplace accidents, limited access to specialized training, and inadequate implementation of safety regulations underscore the pressing need for systemic improvements in OSH practices (Moroe & Khoza-Shangase, 2022).

Gyekye and Salminen (2009) have developed a study on the impact of education on perceptions of workplace safety, concluding that "higher-educated workers recorded the best perceptions on safety, indicated the highest level of job satisfaction, were the most compliant with safety procedures and recorded the lowest accident involvement rate" (Gyekye & Salminen, 2009, p. 20). It is clear that education and training are fundamental in promoting occupational

safety and health. However, discussing what methodologies could promote better outcomes is still important. Traditional teaching methods — generally centered on expository lectures and printed materials — have proven insufficient to engage workers meaningfully, especially in high-risk environments, where practical experience and quick decision-making are essential (Burke et al., 2006). In this context, the STRIM project emerges as an innovative response, proposing the integration of virtual reality (VR) and augmented reality (AR) technologies into mining training programs. These technologies offer immersive experiences that simulate risk scenarios in a safe and controlled way, enabling active learning and the development of critical skills (Gonzalez-Franco & Lanier, 2017). Research indicates that virtual reality training can significantly increase knowledge retention and improve emergency response capacity (Lindgren et al., 2016). This article aims to discuss preliminary results on the challenges and main training needs of OSH in Angola and Mozambique.

METHODOLOGY

Considering that the STRIM project aims to improve occupational health and safety training in the mining industry by integrating virtual reality (VR) and augmented reality (AR) tools, it was relevant to identify specific training needs in Angola and Mozambique. To this end, four exploratory and 26 semi-structured interviews were carried out with a diverse group of agents involved in promoting occupational safety and health in the extractive industry in these two countries. The four exploratory interviews were carried out with the coordinators of African higher education institutions partnering with the project, with the following objectives: 1) understand the specific needs of these institutions concerning OSH in the mining sector; 2) identify existing training on the project's themes, at various levels of education; 3) collect existing data relating to current legislation for the area, accidents and incidents in the mining sector and risk assessment methodologies; 4) identify the topics on which there is a greater need for training.

The 26 semi-structured interviews were carried out with different professionals directly involved in occupational health and safety in the extractive industry, with 10 interviews relating to the Mozambican context and 16 to the Angolan context. This cohort includes mining engineers, health and safety managers, university educators, and government inspectors, providing a broad spectrum of perspectives on the industry's occupational safety and health (OSH) challenges. Most of these professionals were mining engineers and were responsible for the Health and Safety department in the workplace. These interviews aimed to 1) understand the training path of these professionals, particularly regarding OSH issues and the functions they currently perform, 2) understand the main problems associated with OSH in the organization in which they work, and 3) understand the primary training needs within the scope of OSH in the extractive industry. Through these interviews, valuable insights were gathered about the practical realities of OSH practices, the effectiveness of existing training programs, and the challenges posed by legislative frameworks.

A rigorous thematic analysis was employed, inspired by previous studies regarding the topic of the project, to process and interpret the data, allowing the identification of recurring patterns and key areas of concern (Safarpour et al., 2020; Tetzlaff et al., 2020; Tetzlaff et al., 2017). This approach revealed critical gaps in training, where the lack of standardized and specialized programs limits the preparedness of workers to handle industry-specific hazards such as explosives, heavy machinery, and mining-specific risks. Legislative deficiencies also emerged as a major concern, with regulatory enforcement and compliance gaps contributing to unsafe working conditions. Furthermore, accident patterns highlighted the prevalence of preventable incidents, often linked to inadequate training, poor risk management, and a lack of a safety-oriented culture within mining operations. The thematic analysis categorizes these challenges and underscores their interconnections, demonstrating how training deficiencies, weak legislative enforcement, and unsafe practices collectively perpetuate risk in the mining industry.

RESULTS AND DISCUSSION

The analysis of the interviews carried out within this project's scope revealed some gaps concerning the training of professionals in the area of occupational safety and health in the extractive industry in Angola and Mozambique. Three major axes stand out from these gaps and should be considered in framing the training to be developed in both countries. This section will present and discuss data from each of the identified axes.

1) The need to create in-depth and well-founded training programmes across all levels of the industry, from mine workers to company managers and higher education institutions

The data collected reveal some initial training in occupational safety and health offered by different types of institutions in Angola and Mozambique, with no concrete guidelines that respond to the complex needs of occupational safety and health in the extractive industry.

The analysis of the training path of interviewees working in occupational safety and health departments reveals three aspects:

a) Some professionals do not have occupational health and safety training or even mining engineering. In some cases, people playing the role of OSH manager combine it with other roles, such as organization manager or operations manager. In some cases, they feel it is unnecessary to undergo specific training in these areas. Some quotes substantiate these issues:

"I have a basic level of education, acquired in Zimbabwe. This is my first professional experience in a mining company, and I have been here for 12 years. Before that, I worked in a sugar company, in the area of occupational health and safety." (P18)

"Graduate in Environmental Management from the Higher Institute of Management, Commerce and Finance. Have 26 years of experience in managing safety, health, and environment in mines" (P15 - safety, health, and environment manager at the company).

"I have a master's degree in accounting, auditing, and management." (P16 – company manager and responsible for OSH)

"Q – Do you consider it necessary to have training in the area? A – Not really. I think this comes more in a way, from the basics that you learn at university and then with the combination of practice, seeing, and researching in a more autonomous way." (P8 – Mining Engineer, no formal training in OSH)

b) In cases where there are professionals with training, this was developed in other countries (with a special focus on training in Brazil and Portugal – due to linguistic approximation, but also in other African countries), as the next interviewee says:

"Also, remember that I completed some international certifications. I completed NEBOSH through the Safety Bridge Council in the U.K. I completed other training, some of which I had to travel to Portugal, I completed training at APQ, the Portuguese Quality Association, in terms of environmental legislation, in terms of quality, in terms of the European quality system, I also completed training in the implementation of integrated occupational health and safety systems by SGS, the Academy of Portugal. And I did other training through Bureau Veritas, also in Portugal." (P10)

c) In cases where training is provided, the organizations where the professionals work (mostly in multinational companies) offer it.

While international training offers access to advanced methodologies and standards, it is often inaccessible to most workers due to financial and logistical constraints, leaving a substantial portion of the workforce undertrained. Several interviewees reveal a lack of training:

"There is a lack of training, both for me and for all the members of the hygiene and safety team. And then the technicians, those who have higher education, advance a little further in terms of training, mainly in acquiring knowledge in terms of hygiene and safety management software, and also national and international standards in terms of this hygiene and safety matter. There is a lack of training. Training and improvement." (P8)

"So, if we have few occupational hygiene and safety engineers, it means that the level of knowledge in this chain of command is a little low compared to companies that don't have one. Just imagine, companies that only work with supervisors, people who have taken a basic course in occupational hygiene and safety. These people don't have enough experience to support the range of personnel that comes after them." (P9)

2) The need to strengthen the legislative framework on occupational health and safety regulations to be implemented in the extractive industry

Legislation is crucial in implementing and maintaining the extractive industry's occupational health and safety systems. In Angola and Mozambique, there are legal frameworks for regulating work and the mining industry, with references to guaranteeing the safety and health of workers. However, some gaps persist despite these efforts and some evolution and updating. According to some interviewees, these gaps are in the legal systems themselves; others are in applying the law. In some cases, as evidenced in the testimonies below, the interviewees, despite implementing safety and health systems at work, are unaware of the legislation.

"Honestly, I never had much time to study Angolan legislation in terms of safety and hygiene at work." (P9)

Another pattern that I noticed is that companies mostly use foreign legislation rather than Angolan legislation, because Angolan legislation in terms of health and safety at work is very limited, very small." (P10)

"Q – What OSH subjects/content would you like to see covered more?

R- Well... we'll get into that... the contents are generic, and I think that probably being more specific, the legislation itself should focus, since the aim is to... prevent accidents, it should be much more specific in terms of what aah... would be the exact measures to be dedicated to each job according to its specificity. We have to know in a general way, but specifically for that job, how it should be, or what the positioning of the section that looks after that job within the company should be. That's more or less it; the operating model or something like that, we need that." (P12)

"The technical safety and health regulations have a problem that should be improved as they oblige the employer to carry out medical examinations on workers before, during and after leaving work (retirement/resignation), however, it does not indicate the types of examinations specific and mandatory for each type of mining activity to be carried out, resulting in the presentation of identical medical certificates to companies for all areas of work." (P26)

The gaps identified point to the need to deepen legislation on safety and health at work in the specific sector of the extractive industry. However, they reveal the need for better training of professionals regarding understanding the legal framework in force and the conceptual issues that underlie the legislation.

3) The need to promote a more effective safety culture and to learn how to adequately perform risk analysis

Promoting an effective safety culture is essential to ensure compliance with occupational health and safety

protocols and promote proactive risk management. The interviews revealed important challenges to promoting a safety and health culture in the extractive industry. On the one hand, workers underestimate the importance of personal protective equipment and other safety measures, considering them optional and not essential. On the other hand, top management does not always get involved in safety initiatives or contribute to their prioritization compared to production prioritization.

Risk assessment in the extractive industry in Angola and Mozambique is generally characterized by reactive rather than proactive approaches. Companies that prioritize safety often implement measures such as daily safety briefings, bulletin boards to track accident statistics, and regular inspections of equipment and facilities. However, these practices are not uniformly adopted across the industry, leaving significant gaps in accident prevention. Large companies are more likely to have formalized risk management systems, while smaller operators rely on informal methods, increasing their vulnerability to security risks.

"We haven't carried out any risk assessments, as far as accident prevention is concerned, it's just day-to-day awareness-raising. Normally, when I'm here, I talk to the quarry manager to advise on what PPE to use and what CPEs to use. It's more of this kind of guidance. We have someone there who circulates throughout the quarry to make sure everything is going according to plan." (P8)

"There is no risk assessment as such, but all workers receive induction although there are always difficulties for workers to comply with the rules, for example, they can go down to the mine well dressed with personal protective equipment, but they can be surprised at the bottom of the mine without shirts, helmets, etc., claiming to feel hot due to the relatively high temperatures." (P19).

These results provide relevant insights for public policy in Angola and Mozambique. The identified gaps in training, the incipient enforcement of legislation, and the almost complete absence of a safety culture suggest the need for consistent interventions at the governmental level. It would be important for these countries to develop standardised OSH training programmes and review the legal framework to adapt it to mining risks. Investment in immersive technologies, such as VR and AR, to modernize safety education would also be an interesting avenue to explore (Gonzalez-Franco & Lanier, 2017; Lindgren et al., 2016). These measures can strengthen accident prevention capacity, improve compliance with legislation, and support the long-term sustainability of the mining sector (Moroe & Khoza-Shangase, 2022; Moyo et al., 2017).

CONCLUSIONS

The discussion developed in this article refers to the need to create a training strategy for occupational safety and health professionals in Mozambique and Angola that contributes to a rapid and overall improvement in safety and health conditions in the extractive industry. Therefore, it is considered necessary to:

- Standardized Curriculum: Develop a unified, nationally recognized curriculum for OSH training, with modules tailored to the specific risks of mining activities.
- Practical Learning Opportunities: Introduce hands-on training sessions, such as simulations and equipment demonstrations, to enhance workers' preparedness for real-world scenarios.
- Mobile Training Units: Deploy mobile training facilities to reach remote mining sites, ensuring that even small-scale operations can access high-quality OSH education.
- Capacity Building for Trainers: Invest in certifying and training a new generation of OSH instructors, focusing on mining-specific expertise.

All these improvement aspects can benefit from integrating virtual reality (VR) and augmented reality (AR) tools, which the STRIM project is creating and integrating into 2 courses to be implemented in both countries.

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REFERENCES

Burke, M. J., Sarpy, S. A., Smith-Crowe, K., Chan-Serafin, S., Salvador, R. O., & Islam, G. (2006). Relative effectiveness of worker safety and health training methods. Am J Public Health, 96(2), 315-324. https://doi.org/10.2105/AJPH.2004.059840

Caixao, J. Z. (2021). Mining industry in Mozambique. Mining Science and Technology (Russia), 6(2), 114-120. https://doi.org/https://doi.org/10.17073/2500-0632-2021-2-114-120

Edwards, D. P., Sloan, S., Weng, L., Dirks, P., Sayer, J., & Laurance, W. F. (2014). Mining and the African Environment. Conservation Letters, 7(3), 302-311. https://doi.org/https://doi.org/10.1111/CONL.12076

Gonzalez-Franco, M., & Lanier, J. (2017). Model of Illusions and Virtual Reality. Front Psychol, 8, 1125. https://doi.org/10.3389/fpsyg.2017.01125

Gyekye, S. A., & Salminen, S. (2009). Educational status and organizational safety climate: Does educational attainment influence workers' perceptions of workplace safety? Safety Science, 47(1), 20-28. https://doi.org/10.1016/j.ssci.2007.12.007

Lindgren, R., Tscholl, M., Wang, S., & Johnson, E. (2016). Enhancing learning and engagement through embodied interaction within a mixed reality simulation. Computers & Education, 95, 174-187. https://doi.org/10.1016/j.compedu.2016.01.001

Moroe, N. F., & Khoza-Shangase, K. (2022). Exploration of complexities in the management of occupational noise-induced hearing loss in the mining sector in sub-Saharan Africa. In K. Khoza-Shangase (Ed.), Complexities and challenges in preventive audiology: An African perspective [Internet] (pp. 107–124). AOSIS. https://doi.org/https://doi.org/10.4102/AOSIS.2022.BK311.07

Moyo, D., Zungu, M., Erick, P., Tumoyagae, T., Mwansa, C., Muteti, S., Makhothi, A., & Keletso Maribe. (2017). Occupational health and safety in the Southern African Development Community. Occupational Medicine, 67(8), 590–592. https://doi.org/https://doi.org/10.1093/occmed/kqx071

Moyo, D., Zungu, M., Kgalamono, S., & Mwila, C. D. (2015). Review of Occupational Health and Safety Organization in Expanding Economies: The Case of Southern Africa. Annals of Global Health, 81(4), 495–502. https://doi.org/https://doi.org/10.1016/J.AOGH.2015.07.002

Safarpour, H., Khorasani-Zavareh, D., & Mohammadi, R. (2020). The common road safety approaches: A scoping review and thematic analysis. Chin J Traumatol, 23(2), 113-121. https://doi.org/10.1016/j.cjtee.2020.02.005

Tetzlaff, E., Eger, T., Pegoraro, A., Dorman, S., & Pakalnis, V. (2020). Analysis of Recommendations from Mining Incident Investigative Reports: A 50-Year Review. Safety, 6(1). https://doi.org/10.3390/safety6010003

Tetzlaff, E., Pegoraro, A., Eger, T., Dorman, S., & Pakalnis, V. (2017). Thematic Analysis of Key Recommendations from Commissioned Occupational Health and Safety Reports in Mining. Diversity of Research in Health Journal 1, 139. https://doi.org/https://doi.org/10.28984/drhj.v1i0.65

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WORKPLACE INCIDENT INVESTIGATIONS AS A TOOL FOR SAFETY IMPROVEMENT

Abstract: *The safety and health of employees is not only a legal obligation, but also an essential need for enhancing productivity and economic progress of every company. Every company aims to continually improve workplace safety by implementing a range of control tools and measures designed to improve safety conditions. Improving safety is an open process that never ends; there is always room for improvement. A key control measure is the timely reporting of incidents and conducting a thorough investigation of incidents or injuries and implementing effective corrective measures. All injuries at work and significant events or potentially significant events (including near miss incidents) should be investigated to identify and implement corrective and preventive measures, thereby reducing the likelihood of future occurrences.*

Keywords: incident notification, incident investigation report, preventive measures, corrective measures

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INTRODUCTION

Timely and accurate reporting of work-related accidents, incidents, or potential incident conditions is an essential component of a successful Health and Safety Program.

Such reporting allows for a thorough investigation and the identification and implementation of effective corrective actions. Proper documentation of any investigation is essential for later use, if necessary. Furthermore, proper investigation, implementation of effective corrective actions and follow-up actions are key responsibilities of all responsible persons in a company. Incident reporting (including near misses) should be carried out as soon as possible. Additionally, each company should have a defined internal reporting that briefly describes:

- Date and time of the incident;
- Date and time of reporting the incident;
- Type of incident (incident/near miss);
- Work area where the incident occurred;
- Consequences of the incident (injury, loss of production, damage to equipment, environment, community, etc.);
- Description of the incident;
- Measures taken on site;
- Photographs (if possible).

After the reporting is completed, a thorough investigation of the incident is carried out to determine the causes of the incident.

A thorough investigation and analysis of work-related accidents and incidents is an essential part of health and safety management. The investigation should determine the underlying or root causes of the incident and identify preventive measures. There should be "Lessons Learned" from each investigation, i.e., what caused the incident and what we need to do to prevent it from happening again.

Conducting internal health and safety investigations provides a deeper understanding of the risks associated with specific work activities. Blaming individuals for an incident is extremely unproductive and ineffective. It also dispels the myth that incidents and accidents in some areas are inevitable and part of the work process. Well-designed risk control measures, combined with appropriate supervision, monitoring and effective management (i.e., risk management system), will ensure that work activities are safe. Health and safety investigations are an important tool in developing and refining" risk management system. An effective investigation requires a methodical, structured approach to information gathering, collation and analysis. The findings of the investigation should form an action plan to prevent the accident or incident from happening again and to "improve overall risk management". Findings will also indicate areas of risk assessment that need to be reviewed.

DEFINITION OF OCCUPATIONAL INCIDENTS/ACCIDENTS

Incident - occurrence arising out of, or in the course of, work that could or does result in injury and ill health

Note 1 to entry: An incident where injury and ill health occur is sometimes referred to as an "accident".

Note 2 to entry: An incident where no injury and ill health occurs, but has the potential to do so, may be referred to as a "near-miss", "near-hit" or "close call" (ISO 45001:2018(en)).

Note 3 to entry: Although there can be one or more nonconformities related to an incident, an incident can also occur where there is no nonconformity.

High Potential Incident – An incident that almost resulted in injury to a worker, damage to equipment, or an environmental incident.

First Aid (FA) – The first aid given in the event of an injury. Treatment can be provided by anyone trained in first aid or at a mine ambulance.

Medical Treatment Injury (MTI) – Assistance given in the event of an injury that requires treatment by a professional (doctor), but does not result in a lost-time accident.

Note: If an employee is taken to a hospital for an X-ray or consultation with a specialist and the scan shows no visible abnormalities and the employee returns to work the next day, the period of absence is considered a MTI.

Lost time injury (LTI) – An injury that occurs while at work that results in the inability to perform regular work duties on the following calendar day, including modification or limitation of work duties. In the LTI, both DI and FI are included, as well as other incidents that result in sick leave.

Disability Injury (DI) – A disability injury is an injury that results in the employee no longer being able to fully perform regular work tasks, performing either lighter or different work tasks.

Fatal Injury (FI) – Death of an employee as a direct result of an injury or illness at work.

Non-LTI Injuries – Includes injuries requiring first aid (FA), injuries requiring medical treatment (MTI) that do not require absence from work, as well as reports to the mine clinic for health issues that are and are not related to work (e.g., high blood pressure, etc.).

Risk: The level of risk is determined by a combination of the probability of a specific undesirable event occurring and the severity of the consequences (i.e., how often is it likely to occur, how many people could be affected, and how severe could the potential injury or health effects be?)

Risk control measures: Are precautions in place in the workplace to reduce the risk to a tolerable level?

Root cause: The initial event or failure from which all other causes or deficiencies arise. Root causes are generally failures in management, planning, or organization (Fact Sheet, 2016).

Underlying cause: the less obvious "systemic" or "organizational" cause of the occurrence of a negative event, e.g., checks on machines before start-up are not carried out by supervisors; the hazard is not properly addressed through an appropriate and sufficient risk assessment; production pressures are too great, etc.

Corrective action - action to eliminate the cause(s) of a nonconformity or an incident and to prevent recurrence.

THE CAUSES OF ADVERSE EVENTS

Adverse events have many causes. What may appear to be bad luck (being in the wrong place at the wrong time) can, on analysis, be seen as a chain of failures and errors that lead almost inevitably to the adverse event (this is often known as the Domino effect).

These causes can be classified as (HSE, 2004):

- immediate causes: the agent of injury or ill health (the blade, the substance, the dust, etc);
- underlying causes: unsafe acts and unsafe conditions (the guard removed, the ventilation switched off, etc);
- root causes: the failure from which all other failings grow, often remote in time and space from the adverse event (e.g., failure to identify training needs and assess competence, low priority given to risk assessment, etc).

Effective risk control measures must be implemented to address immediate, underlying, and root causes in order to prevent adverse events.

CHECKLIST FOR THE WORKPLACE INCIDENT INVESTIGATION PROCESS

To conduct a thorough incident investigation, it is essential to follow a proper checklist and ensure that all critical aspects of the investigation or incident analysis are addressed.

The checklist for the investigation process includes the following points:

- To determine an Investigation Team, i.e., those who will be involved in conducting the investigation;
- To collect documentation/information in the shortest possible time to prevent "spoilage" of the information;
- To interview the appropriate people to confirm the *FACTS* about the event and to discover the causative factors;
- To understand the *EXACT* details of the event, a timeline of events and conditions should be prepared;
- Determine which "protective mechanism" failed to prevent the event from occurring;
- Determine which factors - "human", "conditions" and "tasks" contributed to the incident;
- To determine which *PROCESS* (systems) can be improved to prevent recurrence;
- *CORRECTIVE ACTION* Determination Team;
- The outcome of the investigation is a top priority;
- Initiating *CORRECTIVE* and *PREVENTIVE* actions is a top priority.

Incident Cause Analysis

Incident Cause Analysis is a systematic process used to identify the underlying causes of incidents, going beyond the immediate events to understand the contributing factors. Figure 1 shows the steps for conducting an incident analysis. Insight into the causes is essential to prevent future (similar) accidents. Therefore, revealing all the causes leading up to an event of an accident is the basis of investigation and analysis. Accident causation models provide a theoretical basis for explaining how accidents at work occur (Reason, 1997). A well-known model used for accident analysis is the Swiss cheese model.

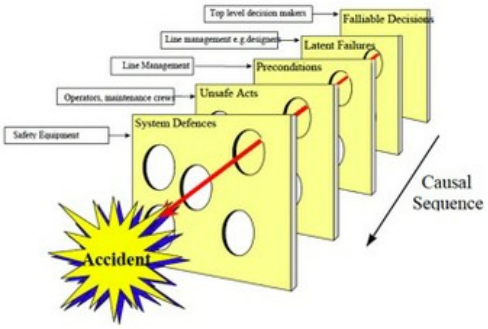


Figure 1. *Swiss cheese model (EU-OSHA, 2022)*

All work injuries and all significant events or potentially significant events (including near miss incidents) should be investigated so that corrective and preventive actions can be investigated, monitored and completed to prevent recurrence.

Analysis of the Human Factor as the Cause of the Incident

To thoroughly investigate an incident, it is important to begin by reviewing relevant personal records, such as work history, training documentation, time sheets, and medical information, as needed. Equally essential is identifying all individuals who may have knowledge related to the event and securing their statements promptly. Interviews should be conducted individually in a distraction-free environment to ensure accuracy and openness. Whenever possible, speaking with these individuals at the incident scene can provide valuable context and help verify details gathered during the investigation.

The following questions may be posed to interviewees to gather comprehensive and relevant information about the incident:

- Can you provide a full description of the work and conditions that led up to the event?
- Can you provide a full description of the sequence of events, from start to finish?
- Did you observe any unusual things before the event (sights, sounds)?
- What was their role in the sequence of events?
- What conditions influenced the event (weather, time, equipment, etc.)?
- How did people influence the event (activities, emergency response, etc.)?
- What is their opinion about what caused the event?
- How could it have been prevented?
- Did you give a list to other witnesses?.
- Were they under stress or due to a lack of time?
- How are they trained to do the job?

Analysis of the Conditions in the Work Environment as the Cause of the Incident

Examining the scene of the incident is crucial for gaining a clear understanding of the task being performed and the local environmental conditions at that moment. It is particularly important to recognize any sudden changes in the work environment, as these can significantly impact safety. Emphasis should be placed on the specific situation at the time of the incident rather than the usual or typical conditions, as this context provides critical insights into the factors that contributed to the event. It is important to determine:

- What were the weather conditions?
- Was a lack of cleanliness a problem?
- Was it too hot or too cold?
- Was noise a problem?
- Was there adequate lighting?
- Were there toxic gases, fumes, or dust?

In addition, it is important that when an incident occurs or a near-miss occurs, the conditions are not changed and the scene of the incident is immediately cordoned off so that a detailed investigation of the incident can be conducted.

Analysis of the Equipment as the Cause of the Incident

A careful inspection of the equipment involved in the incident is essential to understand its condition and any factors that may have contributed to the event. Attention should be given to any alterations or unusual signs, such as excessive strain, modifications, substitutions, distortions, or fractures. It is also important to identify potential design flaws, inappropriate components, or unclear labeling and markings. Ultimately, verifying that the equipment was suitable for the task at hand provides valuable insight into whether equipment-related factors played a role in the incident.

It is important to determine:

- Did an equipment failure occur?
- What caused the failure?
- Was the machine poorly designed?
- Are hazardous substances involved?
- Are they clearly identified?
- Was it possible to use a less hazardous substance and was one available?
- Were the raw materials substandard in any way?
- Should Personal Protective Equipment have been used?
- Was Personal Protective Equipment used?

- Were any safety devices removed from the machine?

Analysis of Procedures as the Cause of the Incident

A thorough review of the task includes examining the established work procedures and schedules to determine whether they may have contributed to the event. Additionally, it is important to evaluate the availability, suitability and use of these procedures, as well as the level of supervision required.

It is important to determine the following factors:

- Was a safe work procedure used?
- Are there written procedures?
- Was a Job Safety Analysis (JSA) prepared as part of the planning prior to the job?
- Has there been a change in conditions that made the normal procedure unsafe?
- Were appropriate tools and materials available?
- Were they used?
- Were lockouts used when necessary?
- Were safety devices in working order?
- Are workers adequately trained in the written procedures?
- Are the written procedures appropriate for the work tasks?

Analysis of the Organization as the Cause of the Incident

In this analysis, management has a legal responsibility for the safety of the workplace and the workforce. The role of supervisors and management must always be considered in the investigation of incidents.

- Are safety rules followed/understood by all employees?
- Are they enforced?
- Has there been adequate supervision?
- Have workers been trained for the job? When? Is the training still valid
- Have hazards been previously identified?
- Have procedures been developed to overcome hazards?
- Have unsafe conditions been corrected?
- Is the equipment regularly maintained?
- Are regular safety checks conducted?
- Are there any changes to equipment, environment, people or procedures?

ROOT CAUSE ANALYSIS IN INCIDENT INVESTIGATION

For root cause analysis in incident investigation, a tool known as a fishbone diagram, or cause and effect diagram (Ishikawa diagram, Figure 2), is often used in practice. It visually represents the problem as the “head” of a fish, and potential causes as “bones” branching off the “spine.”.

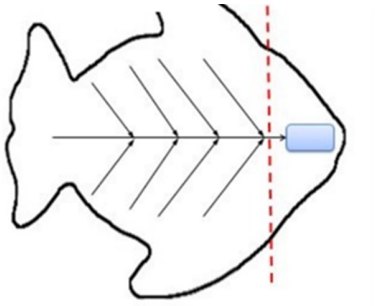


Figure 2. *The basic model of the Ishikawa diagram*

The Ishikawa diagram was popularized in the 1960s by Kaoru Ishikawa, who introduced quality management processes at Kawasaki shipyards, and in the process became one of the founders of modern management (Tague, 2014). It soon found widespread application in other industries, including risk management and occupational health and safety.

Fishbone diagrams visually represent various factors contributing to an issue, aiding in the identification of underlying causes. They are particularly useful for organizations that implement knowledge management. Collecting group ideas systematically can help management understand and diagnose the organization's problems. This method helps teams identify and analyze the root causes of incidents by brainstorming and categorizing potential causes (Sakdiyah, Eltivia, Afandi, 2022).

The following section explains how this method works, outlining its key steps processes (PetroSync, 2023):

1. Identify the problem: Start with the problem at the beginning of the fishbone diagram.
2. Brainstorm categories: Brainstorm and identify the main categories of potential causes (e.g., workforce, methods, materials, machines, measurement, environment).
3. Create the backbone: Draw a horizontal line like the backbone of a fishbone, connecting the problem to the categories.
4. Add the bones: Break away from the backbone to represent the categories of causes, forming the fishbones.
5. Brainstorm causes within each category: Brainstorm and list specific causes that contribute to each category.
6. Analyze and prioritize: Analyze the diagram, identify the most likely root causes, and prioritize them for action.
7. Implement solutions: Develop and implement solutions to address the identified root causes.

The following figure shows the practical application of the "fishbone" method for investigating the incident at the SASA Mine, Makedonska Kamenica, Republic of North Macedonia.

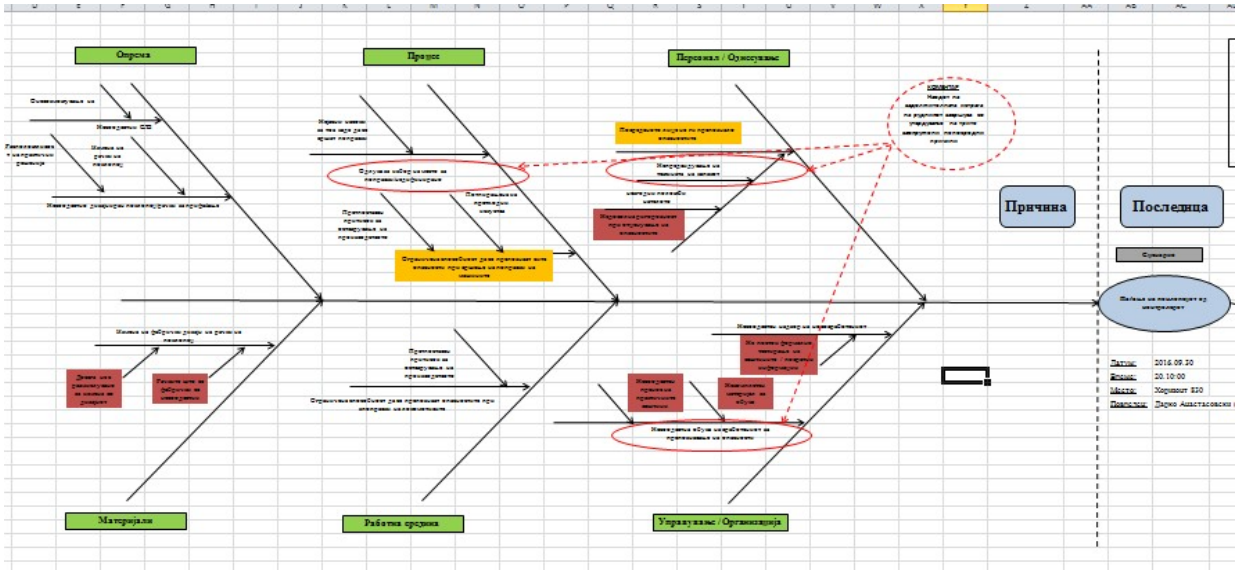


Figure 3. *"Fishbone" method with a practical example from an incident investigation* (Taskovski, 2024)

INCIDENT REGISTER

For an investigation to be effective, the control measures taken (preventive and corrective) should be completed in a timely manner. It is very important to keep records of all incident investigations as well as appropriate records of the planned preventive and corrective measures, i.e., to create an appropriate incident register.

A register should contain:

- Date of the incident;
- Brief description of the incident;
- Classification of the incident;
- Corrective action taken;
- Responsible person for completion;
- Date of completion;
- Fact of completion;
- Steps for the corrective action.

The incident register should also monitor the effectiveness of corrective measures, i.e. whether the measures taken are effective. Corrective measures are effective if the same or similar incident has not occurred in a certain period.

If a register is not kept and the completion of corrective measures is not monitored, the investigation into the incident would not be productive and would be just a waste of time.

Keeping the register makes it possible, if an incident occurs, to check whether previous incidents that have occurred are of the same or different type from the previous ones and a comparison can be made in relation to the control measures taken.

CONCLUSION

The main objective of the investigation is to prevent recurrence. Therefore, incident investigations should focus on the following:

Identifying immediate/direct causes that contribute to and are related to conditions, personal factors or activities;

Determining the underlying causes (root causes) for the above-mentioned;.

Identifying organizational, systemic or inherent deficiencies or failures;

Reviewing and analyzing the causes and deficiencies identified to determine corrective measures and improvement actions.

To ensure the integrity of the investigation, the scene of the incident should be cordoned off and not disturbed until a detailed inspection by an appropriate commission has been conducted, except when immediate action is required to safely remove individuals from the area.

The investigation should be completed thoroughly and by experts in the relevant field in order to determine the true causes of the incident, as well as to take appropriate measures to prevent recurrence.

Every workplace contains hazards; consequently, risk control measures are implemented to minimize those risks to an acceptable level and to help prevent accidents and health issues.

The fact that an adverse event occurred suggests that the existing risk control measures were inadequate.

REFERENCES

EU-OSHA – European Agency for Safety and Health at Work (2022). *Accidents and incidents*. Available at: https://oshwiki.osha.europa.eu/en/themes/accidents-and-incidents

Fact Sheet (2016). *The Importance of Root Cause Analysis During Incident Investigation.* Available at: https://www.osha.gov/sites/default/files/publications/OSHA3895.pdf

HSE - Health and Safety Executive (2004). *Investigating accidents and incidents. A workbook for employers, unions, safety representatives and safety professionals. Series code: HSG245.* Available at: https://www.hse.gov.uk/pubns/hsg245.pdf

ISO 45001:2018(en). *Occupational health and safety management systems — Requirements with guidance for use.* Available at: https://www.iso.org/obp/ui/en/#iso:std:iso:45001:ed-1:v1:en

PetroSync (2023). *Fishbone Diagram: Steps and Methods to Find Root Cause.* Available at: https://www.petrosync.com/blog/fishbone-diagram/

Reason, J. T. (1997). Framework Models of Human Performance and Error: A Consumer Guide. In L. P. Goodstein, H. B. Andersen & S. E. Olsen (Eds.): *Tasks, Errors and Mental Models.* London: Teylor & Francis.

Sakdiyah, H. S., Eltivia, N., Afandi, A. (2022). Root Cause Analysis Using Fishbone Diagram: Company Management Decision Making. *Journal of Applied Business, Taxation and Economics Research (JABTER) Vol. 1, No. 6, 566-576,* DOI: 10.54408/jabter.v1i6.103.

Tague, N. (2014). *Seven Basic Quality Tools. Milwaukee,* Wisconsin: American Society for Quality.

Taskovski, S. (2024). file:///C:/Users/s.taskovski/Downloads/Root_Cause_Analysis_Using_Fishbone_Diagram_Company.pdf

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ORIGINAL SCIENTIFIC PAPER

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OCCUPATIONAL EXPOSURE TO FERTILIZERS AND ASSOCIATED HEALTH EFFECTS

Abstract: *Fertilizers are generally used to provide nutrients to crops, through increasing yields and soil fertility. They are mainly categorized into two groups, organic and inorganic. Inorganic fertilizers are synthetic nutrient-rich products used to supply essential minerals to plants, such as nitrogen, phosphorus, and potassium. Organic fertilizers are obtained naturally from either plant (compost and biosolids) or animal sources (manure, slurry, etc.). Although the use of fertilizers in the agricultural sector is inevitable for achieving high-yield crop production, their production and application can present health and safety hazards. Some professions are especially significant in terms of exposure to fertilizers, primarily those associated with agriculture and related industries. They include agricultural workers, those who work in fertilizer plants and researchers. Individuals living in the same residential area are also exposed to these substances. Agricultural workers face potential exposure during planting, fertilizing, and harvesting, as well as through equipment maintenance and cleaning. Fertilizer plant workers may be exposed to dust and fumes during production, packaging, and storage. Transportation and handling of fertilizers, whether in bulk or packaged form, also present risks of exposure. Occupational exposure to fertilizers, particularly during manufacturing and agricultural application, can lead to various health issues. These range from respiratory problems and skin irritation to more serious conditions like kidney and liver damage, and even neurological effects.*

Keywords: fertilizers, occupational exposure, health effects

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INTRODUCTION

The issue of global food production becomes increasingly important as the global population expands and the availability and productivity of arable land, crucial for food production, decline. Fertilizers, both inorganic and organic, play an essential part in modern agriculture by significantly increasing crop yields, thus ensuring crucial human nutrition, global food security, crop quantity and quality, and sustainable soil management. Fertilizers can be applied in several ways, broadly categorized as soil application (broadcasting and banding), foliar application, and fertigation. Each method offers specific advantages depending on the crop, soil conditions, and nutrient requirements. About 90% of fertilizers are applied as solids, in granulated or powdered form. The most widely used solid inorganic fertilizers are urea, diammonium phosphate and potassium chloride (Rashid, 2022). Liquid fertilizers contain anhydrous ammonia, aqueous solutions of ammonia, aqueous solutions of ammonium nitrate or urea. Advantages of liquid fertilizer are its faster reaction and simple coverage of the treated area. While fertilizers are crucial for boosting crop yields in agriculture, their manufacture and use pose environmental and health risks. Farmers, fertilizer manufacturers, and those involved in the storage, transportation, and application of fertilizers are all at risk of exposure to fertilizers and other agrochemicals. Exposure to fertilizers can occur through various routes, including inhalation, skin contact, and ingestion, and can lead to both acute and chronic health effects. Anhydrous ammonia is an efficient and widely used source of nitrogen fertilizer. Any contact with anhydrous ammonia can cause tissue dehydration, caustic burns, and frostbite. Exposure to high concentrations of liquid or vapour causes severe burns to the skin, eyes, upper airways and gastrointestinal tract. There may be permanent effects including visual impairment, and chronic pulmonary disease such as obstruction of small and large airways, bronchiectasis

and interstitial lung disease. In the respiratory tract, anhydrous ammonia can cause laryngeal edema, pneumonitis and pulmonary edema. Airway obstruction and respiratory insufficiency may be fatal (ILO, 2010). Inorganic phosphates are widely used and essential fertilizers in agriculture. Severe burns, including those to the skin, upper airways, and gastrointestinal tract, as well as pulmonary inflammation, can result from exposure to inorganic phosphates. These injuries are often accompanied by a systemic inflammatory response, potential for infection, and a risk of long-term complications like scarring and respiratory issues. Inorganic phosphates, when systemically absorbed, can cause multi-organ toxicity, affecting the liver (hepatotoxicity), kidneys (renal damage), gastrointestinal system, and cardiovascular system. This toxicity can manifest as a range of symptoms, from mild discomfort to severe organ failure (Tagkas, 2024).

METHODS OF FERTILIZER APPLICATION

Fertilizers, containing essential macronutrients like nitrogen, phosphorus, and potassium, are vital for plant growth. While beneficial for crop yields, over-application of fertilizers can have negative environmental consequences. Different fertilizer application methods offer various advantages for crop production, impacting nutrient availability, efficiency, and environmental impact. Methods like broadcasting, banding, foliar application, and fertigation have unique benefits and drawbacks (Barłog, 2023).

Broadcasting. Broadcasting fertilizer, which involves spreading it evenly across the soil surface, has both advantages and disadvantages. It is a quick and cost-effective method for covering large areas. However, it can lead to lower fertilizer use efficiency and potential nutrient losses compared to other methods (Barłog, 2023).

Banding. Fertilizer is applied in concentrated bands, either near the seeds during planting or alongside existing crop rows. Banding fertilizer offers several advantages over broadcasting. This method helps to concentrate nutrients where plants can access them most effectively. This targeted approach minimizes the amount of fertilizer that can be lost by fixation to soil particles, leaching, or volatilization. Banding can also be more environmentally friendly, as it reduces the potential for nutrient runoff and pollution (Barłog, 2023).

Foliar application. Foliar application, or spraying nutrients directly onto plant leaves, offers both advantages and disadvantages compared to traditional soil-based fertilization. While it allows for rapid nutrient absorption and can be particularly useful for correcting deficiencies, it's not always a complete replacement for soil fertilization and can be more expensive and weather-dependent (Barłog, 2023).

Fertigation. Fertigation is the process of applying liquid or soluble fertilizers through an irrigation system. It combines irrigation and fertilization, delivering nutrients directly to the plant's root zone along with the water. Fertigation can synchronize nutrient supply and crop nutrient requirement, which enhances water-use efficiency, nutrient-use efficiency, and yield, while also reducing nutrient losses via leaching, ammonia volatilization, denitrification and weed pressure (ILO, 2010).

OCCUPATIONAL EXPOSURE TO FERTILIZERS AND CONSEQUENTIAL HEALTH EFFECTS

There are many different careers in the fertilizer industry, including fertilizer production jobs, application jobs, agricultural specialists, and researchers who innovate new methods to apply fertilizer or develop more effective fertilizers.

Exposure to fertilizers can occur through various routes, including inhalation, skin contact, and ingestion, and can lead to both acute and chronic health effects.

Around 22% of ammonia emissions from agriculture come from fertiliser, and 75% from livestock systems (https://www.yara.co.uk).

Anhydrous ammonia is an efficient and widely used source of nitrogen fertilizer. Anhydrous ammonia is stored and transported as a liquid in pressurized containers (Figure 1). If it is released from the pressurized tank, anhydrous ammonia will instantly transform to a gaseous state and can result in respiratory toxicity.



Figure 1. A*nhydrous ammonia application (http://blog.caseih.com/equipment-technology/upgrade-your-fall-fertilizer-applications)*

Except anhydrous ammonia, mineral nitrogen fertilizers which directly contain ammonium (ammonium sulfate, ammonium sulfate nitrate, ammonium nitrate, calcium ammonium nitrate) or are converted to ammonium in the soil subsequent to spreading (urea), are subject to potential ammonia losses. The significant sources of ammonia emissions from agriculture include manure handling and storage, as well as the application of manure and slurry.

Ammonia emissions have a negative impact on human health; hence, it is important to reduce the volatilization of ammonia (Wyer, 2022).

Acute inhalation exposure to high levels of ammonia in humans can provoke irritation and significant burns in

the lungs, mouth, and eyes. Airway obstruction and respiratory insufficiency may be fatal. Short-term or accidental exposures to high concentrations of ammonia gases are quite rare due to occupational exposure limits and health and safety protocols in many workplaces. Chronic exposure to airborne ammonia can raise the risk of respiratory irritation, cough, wheezing, tightness in the chest, and impaired lung function in humans (Figure 2).

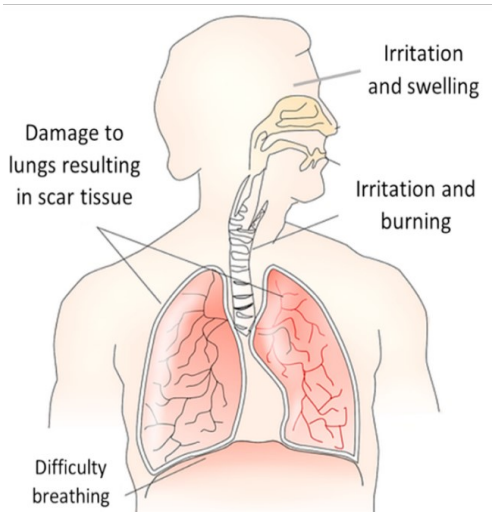


Figure 2. *The direct effects of ammonia on the respiratory tract (Wyer et al., 2022.)*

However, besides being toxic, gaseous ammonia is a precursor of secondary inorganic aerosols. It can react with NO_X or SO_2 to yield secondary fine particles ($PM_{2.5}$) comprising sulfates and nitrates. Although direct exposure to ammonia can be a possible risk for human health, when assessed as a precursor to $PM_{2.5}$, it has a considerable impact on human health. According to the World Health Organisation, $PM_{2.5}$ are particles which are small enough to penetrate deeply into the lung, causing irritation and corrosion of the alveolar wall, and consequently impairment of lung function (Lelieveld, 2015). As stated by the World Health Organization, more than 90% of the world's population is exposed to $PM_{2.5}$ concentrations that exceed the recommended guideline of 10 $\mu g/m^3$. Inhalable particulate matter (PM) has significant negative health impacts, primarily affecting the respiratory and cardiovascular systems. These effects include increased respiratory symptoms, exacerbation of asthma, higher rates of respiratory and cardiovascular hospital admissions, and increased mortality from respiratory, cardiovascular, and lung cancer. Adverse health effects can be exacerbated in vulnerable populations, including those with pre-existing lung or heart diseases, elderly people, pregnant women, and children (Table 1). When it comes to children, exposure to PM affects lung development, including reversible deficits in lung function as well as chronically reduced lung growth rate and a deficit in long-term lung function (World Health Organisation, 2013).

Table 1. *Influence of PM on the respiratory system*

Impact of PM on the respiratory system
Increases mortality
Increases the incidence of malignant tumors
Increases the incidence of chronic respiratory disease exacerbations
Increase or worsen overall respiratory symptoms
Reduce lung function growth in children
Causes temporary loss of lung function in normal people
Increases airway inflammation and increases airway hyperresponsiveness
Reduces pulmonary diffusing capacity in lung function

Dermal exposure to ammonia solutions or pressurized liquefied gas can lead to skin irritation and, depending on concentration, alkali burns. Liquefied ammonia, in particular, can also cause cryogenic burns due to the low temperature of the substance.

Ammonia can rapidly penetrate and damage the eyes, potentially causing temporary or permanent blindness. Even low concentrations of ammonia vapor can irritate the eyes.

Ingestion of ammonia solution causes rapid symptoms including pain in the mouth, throat and chest, excessive salivation and extensive alkali burns. In severe cases, perforation of the stomach or oesophagus may occur, resulting in issues such as cardiac injury and pneumonitis. Chronic oral exposure to ammonia has not been characterised in humans.

Farmers and agricultural workers may be exposed to ammonia during the application of fertilizers containing anhydrous or liquid ammonia, mineral nitrogen fertilizers, or manures high in ammonia (https://www.ncbi.nlm.nih.gov/books/NBK598711/). They are at an increased risk for inhalational exposure, due to high ammonia levels in the air. Ammonia emission attributed to volatilization from soils and plants due to the application of synthetic fertilizer and manure may rise with increasing global temperatures (Shen, 2020).

The nitrogenous fertilizer industry faces significant occupational and environmental health challenges due to ammonia exposure during production.

Bhat and Ramaswamy found that exposure to chemical fertilizers, specifically ammonia, urea, and diammonium phosphate (DAP), was associated with decreased lung function in fertilizer plant workers. Their study indicated that long-term exposure, particularly to diammonium phosphate, could potentially lead to restrictive lung disorders (Bhat, 1993).

Ramah and co-workers demonstrated that exposure to ammonia at higher amounts was related to an increased prevalence of respiratory symptoms and an acute depletion of lung functions among urea fertilizer factory workers (Ramah, 2007).

Based on research by Ballal et al., which included two urea fertilizer producing factories in Saudi Arabia, it was found that occupational exposure to ammonia is significantly related to an increase in respiratory symptoms and bronchial asthma. According to the authors, workers in factory A, who were exposed to higher levels of ammonia (2.0-130.4 mg/m^3), had a significantly increased risk of respiratory symptoms compared to workers in factory B, and the control group. The ammonia levels in factory B were below the threshold limit value -TLV (range 0.02-7.0 mg/m^3 of air). The authors recommend implementing engineering controls to reduce ammonia levels in Factory A, alongside occupational exposure monitoring. This includes measures like enclosing processes, improving ventilation, and using personal protective equipment. Monitoring aims to assess workers' exposure and ensure the effectiveness of implemented controls (Ballal, 1998).

The study conducted by Menadi and co-workers in order to evaluate the possible effects of chemical fertilizers (NPK 15.15.15) on occupational health included forty male participants, divided into two main groups. The first group consisted of 20 workers exposed to fertilizers in the fertilizer industry of Annaba (Algeria) for at least 6 years. The second (control) group included 20 participants with no history of exposure to any chemical fertilizer. Occupational exposure to NPK fertilizer dust in Annaba has been shown to cause significant alterations in biochemical parameters and oxidative stress status among workers. Specifically, studies have indicated increased levels of cholesterol and triglycerides, decreased erythrocyte count and hemoglobin concentration, and a significant decline in antioxidant enzyme activity (superoxide dismutase-SOD, glutathione peroxidase-GPx, and catalase- CAT). Additionally, there was an observed increase in malondialdehyde (MDA) levels, a marker of lipid peroxidation and oxidative damage. Authors concluded that, taken together, occupational exposure to chemical fertilizer can induce many adverse health effects, illustrated mainly by kidney and liver function impairments, and can also cause deleterious impacts on the biomarkers of oxidative stress status (Menadi, 2024).

A cross-sectional descriptive study was conducted in Ubon Ratchathani province, Thailand, in April 2016. Seventy-six chili farmers, directly contacting chemical fertilizers, participated in the study. Face-to-face interviews were performed to gather information about frequency and type of fertilizer used, participant characteristics, behaviours concerning chemical fertilizer use (the use of personal protective equipment and hand hygiene, symptoms occurring in work with chemical fertilizers). Descriptive statistics were used to describe information. All chili farmers used both chemical and organic fertilizers in chili farms. Most of them used chemical fertilizers 1-3 times monthly (80.3%). Urea fertilizer and NPK fertilizer (15.15.15) were generally used. Inappropriate behaviors related to chemical fertilizer use, such as handling chemical fertilizers without personal protective equipment, were found. About 26.3% of interviewees indicated the appearance of symptoms within 48 hours after using the fertilizer. Most common symptoms were coughing or sneezing (15.8%) and skin irritation or itching (14.5%). Based on the conducted research, the authors concluded that the prevalence of acute health effects related to chemical fertilizer exposure was relatively low. The study showed that the frequency of chemical fertilizer use (particularly more than three times per month), along with alcohol consumption and smoking habits, are significant risk factors for acute health effects associated with chemical fertilizer exposure. The study's authors recommended further research to investigate both acute and long-term health effects of fertilizer exposure and emphasized the need for farmers to adopt safer handling practices to minimize exposure (Nganchamung, 2017).

Exposure to nitrogen-based fertilizers can cause more severe skin reactions compared to other types of fertilizers. In a study of 132 farmers with contact dermatitis, 13% of cases were found to be caused by chemical irritants like fertilizers and pesticides. This highlights the significant role these substances play in causing skin problems for farmers (Kiec-Swierczynska, 2003).

In the work of Elmas et al., a case study of a 19-year-old strawberry picker is presented. He developed severe, itchy, and burning vesicular and bullous lesions on legs after working in a field where he had applied a nitrogen-based fertilizer. The lesions were limited to the areas of skin that contacted the leaves. It is important to note that the patient had no previous history of allergies or skin conditions. Histological examination showed epidermal damage and inflammation. The diagnosis was irritant contact dermatitis caused by nitrogen-based fertilizer. Authors point out that prioritizing the protection of workers from contact, especially with nitrogen fertilizers, is crucial for occupational safety and health in agriculture (Elmas, 2016).

Occupational exposure to nitrates primarily occurs through inhalation of dusts and dermal contact, especially in fertilizer and explosives industries. Workers in these fields, as well as farmers handling fertilizers, face potential risks (Tagkas, 2024; Martínez-Dalmau, 2021).

Ammonium nitrate fertilizer is a widely used high-nitrogen fertilizer, that provides plants with readily available nitrogen in both nitrate and ammonium forms (Ma, 2018). Short-term exposure to ammonium nitrate can lead to skin and eye irritation. Inhalation of this substance may cause irritation to the respiratory tract. Symptoms may include coughing, sore throat, and shortness of breath. At high temperatures, exposure to toxic nitrogen oxides (decomposition products) can quickly cause acute respiratory problems. Inhalation of large amounts of ammonium nitrate aerosol can lead to systemic acidosis and abnormal hemoglobin. High oral doses of nitrates can interfere with the ability of the

blood to carry oxygen, causing headache, fatigue, dizziness, and a blue color to the skin and lips (methemoglobinemia). Higher levels can cause trouble breathing, collapse and even death. When it comes to chronic exposure, small repeated oral doses of nitrates may cause weakness, depression, headache, and mental impairment (https://www.ncbi.nlm.nih.gov/books/NBK592476).

As previously mentioned, workers in the fertilizer industries and farmers handling fertilizers face potential risks due to occupational exposure to nitrates. In order to prevent or reduce those risks, protective measures are needed. They include enclosing operations, using local exhaust ventilation, and wearing appropriate personal protective equipment like gloves, clothing, and respirators.

CONCLUSION

Fertilizers play a crucial role in modern agriculture by significantly increasing crop yields and improving overall agricultural productivity. While fertilizers are essential for boosting crop yields and ensuring food security, their production and use introduce significant environmental and health risks. Farmers, fertilizer manufacturers, and those involved in the handling and application of these products are all susceptible to exposure. Occupational exposure to fertilizers can pose various health risks, including respiratory problems, skin and eye irritation, and potential long-term effects like cancer or endocrine disruption. Protective measures such as using personal protective equipment, proper ventilation, and safe handling practices are crucial to mitigate these risks.

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REFERENCES

Ballal, S. G., Ali, B. A., Albar, A. A., Ahmed, H. O., & Al-Hasan, A. Y. (1998). Bronchial asthma in two chemical fertilizer producing factories in eastern Saudi Arabia, The international journal of tuberculosis and lung disease: the official journal of the International Union against Tuberculosis and Lung Disease, 2(4), 330–335.

Barłog, P. (2023). Improving Fertilizer Use Efficiency-Methods and Strategies for the Future, *Plants*, 12(20), 3658. https://doi.org/10.3390/plants12203658

Bhat, M. R., & Ramaswamy, C. (1993). Effect of ammonia, urea and diammonium phosphate (DAP) on lung functions in fertilizer plant workers, *Indian journal of physiology and pharmacology*, 37(3), 221–224.

Elmas, O. F., Kızılyel, O., Metin, M. S., Bilen, H., et al. (2016). Occupational exposure to the nitrogen-based fertilizer: A severe case of irritant contact dermatitis, *Kafkas Journal of Medical Sciences*, 6(1), 62-63.

ILO, (2010). Diagnostic and exposure criteria for occupational diseases, Guidance notes for diagnosis and prevention of the diseases in the ILO List of Occupational Diseases (revised 2010)

Kiec-Swierczynska, M., Krecisz, B., & Swierczynska-Machura, D. (2003). Najczestsze przyczyny alergicznego kontaktowego zapalenia skory u rolnikow, na podstawie materiału Instytutu Medycyny Pracy w Lodzi [Most frequent causes of allergic contact dermatitis in farmers: based on material collected in the Nofer Institute of Occupational Medicine, Lodz], *Medycyna pracy*, 54(3), 237–243. DOI: 10.2478/v10001-006-0008-7

Lelieveld, J., Evans, J.S., Fnais, M., Giannadaki, D., Pozzer, A. (2015). The contribution of outdoor air pollution sources to premature mortality on a global scale, *Nature*, 525 (7569), 367-371, 10.1038/nature15371

Ma, L., Hu, L., Feng, X., & Wang, S. (2018). Nitrate and Nitrite in Health and Disease, *Aging and disease*, 9(5), 938–945. https://doi.org/10.14336/AD.2017.1207

Martínez-Dalmau, J., Berbel, J., & Ordonez-Fernandez, R. (2021). Nitrogen Fertilization. A Review of the Risks Associated with the Inefficiency of Its Use and Policy Responses. Sustainability, 13(10), 5625. https://doi.org/10.3390/su13105625

Menadi, S., Boubidi, F. S., Bouchelaghem, R., Messarah, M., & Boumendjel, A. (2024). Occupational exposure to the dust of chemical fertilizers (NPK 15.15. 15): effect on biochemical parameters and oxidative stress status among workers in Annaba, *Comparative Clinical Pathology*, 33(3), 437-444. DOI: 10.1007/s00580-024-03563-9

Nganchamung, T., Robson, M., & Siriwong, W. (2017). Chemical fertilizer use and acute health effects among chili farmers in Ubon Ratchathani province, Thailand, *J Heal Res*, 31. DOI: 10.14456/jhr.2017.53

Rahman, M.H., Bratveit, M., Moen, B.E. (2007). Exposure to ammonia and acute respiratory effects in a urea fertilizer factory, *Int J Occup Environ Health*, 13(2), 153-9. doi: 10.1179/oeh.2007.13.2.153 DOI: 10.1179/oeh.2007.13.2.153

Rashid, A. (2022). Applications of fertilizers for crop improvement, *Global Journal of Crop, Soil Science and Plant Breeding,* 9(2).

Shen, H. et al. (2020). Intense Warming Will Significantly Increase Cropland Ammonia Volatilization Threatening Food Security and Ecosystem Health, *One Earth*, 3(1), 126-134. https://doi.org/10.1016/j.oneear.2020.06.015

Tagkas, C.F., Rizos, E.C., Markozannes, G., Karalexi, M.A., Wairegi, L., & Ntzani, E.E. (2024). Fertilizers and Human Health-A Systematic Review of the Epidemiological Evidence. *Toxics*, 12(10), 694. https://doi.org/10.3390/toxics12100694

Wyer, K., Kelleghan, D., Blanes-Vidal, V., Schauberger, G., Curran, T. (2022). Ammonia emissions from agriculture and their contribution to fine particulate matter: A review of implications for human health, *Journal of Environmental Management*, 323, 116285. https://doi.org/10.1016/j.jenvman.2022.116285

World Health Organisation, (2013).

Toxicological Profile for Nitrate and Nitrite. Atlanta (GA): Agency for Toxic Substances and Disease Registry (US); 2017 Jul. 3, HEALTH EFFECTS. Available from: https://www.ncbi.nlm.nih.gov/books/NBK592476/

https://www.ncbi.nlm.nih.gov/books/NBK598711/

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EFFECTS OF ULTRAVIOLET RADIATION ON OCCUPATIONAL HEALTH AND SAFETY

Abstract: *Occupational exposure to ultraviolet (UV) radiation poses a significant health risk, particularly for workers in outdoor professions. Prolonged UV exposure is associated with a range of acute and chronic conditions, including erythema, photoaging, cataracts, and an increased risk of non-melanoma skin cancers. Despite growing awareness, protective behaviour among workers often remains inadequate. This paper examines the biological effects of UV radiation, identifies high-risk occupational groups, and discusses preventive strategies aimed at minimizing exposure. The emphasis is placed on the importance of implementing protection policies in the workplace, including the use of personal protective equipment (PPE), education campaigns, and organizational measures. Recognizing UV radiation as an occupational hazard is essential for safeguarding the health and well-being of exposed workers in light of climate change and ongoing ozone depletion.*

Keywords: UV radiation, occupational exposure, photoprotection, workplace safety

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INTRODUCTION

Ultraviolet (UV) radiation is a form of non-ionizing radiation, which constitutes a non-visible segment of the electromagnetic spectrum, characterized by wavelengths shorter than visible light. The main source of UV radiation that reaches Earth is sunlight. Some industrial processes, such as electric arc welding and plasma cutting equipment, germicidal UV lamps in hospitals and laboratories, mercury vapour lamps, metal halide lamps, etc., can also generate artificial (anthropogenic) UV radiation.

Ultraviolet radiation provides several important benefits, particularly in controlled or natural low-dose exposures. For most people, UV radiation from sunlight is the main source of vitamin D production. However, foods and supplements also contribute to circulating vitamin D. This process is essential for maintaining calcium homeostasis, bone health, and immune system function. Adequate vitamin D levels have been linked to reduced risks of osteoporosis, certain autoimmune diseases, and even some cancers (Ross et al., 2011). Vitamin D levels typically exhibit significant seasonal variation, particularly in regions located at higher latitudes. Research indicates that during the winter months, approximately 50% of the UK population may experience vitamin D insufficiency (Hyppönen & Power, 2007). In addition to these naturally significant roles, UV radiation has been used since ancient times to treat various diseases, and this phenomenon is scientifically grounded in the presence of numerous chromophores within various layers of the skin, which are capable of interacting with and absorbing UV radiation. Nowadays, in clinical and cosmetic practice, UV radiation is utilized for a wide range of purposes, including cosmetic tanning, the therapeutic management of several dermatological disorders, such as psoriasis, vitiligo, atopic dermatitis, and localized scleroderma, as well as in medical applications like photodynamic therapy (PDT) (Krutmann & Morita, 1999).

While UV radiation offers several recognized health and therapeutic benefits, it also poses significant risks to human health. According to the International Agency for Research on Cancer (IARC), all forms of ultraviolet radiation – UVA, UVB, and UVC, as well as solar radiation, are classified as Group 1 carcinogens, indicating confirmed carcinogenicity in humans, based on robust epidemiological and experimental evidence (El Ghissassi et al., 2009). Among the acute effects, UVB radiation in particular can trigger erythema, commonly manifested as skin redness, and may stimulate a compensatory increase in melanin production, particularly in individuals with lighter skin. On a molecular level, UV exposure can lead to genetic damage, including mutations in the p53 tumour

suppressor gene, which compromises its role in preventing malignant transformation. Additionally, ultraviolet radiation facilitates the generation of reactive oxygen species (ROS), which are closely linked to various stages of skin cancer development, from initiation to progression (Lee et al., 2020).

Given the potential health hazards associated with UV radiation, it is crucial to investigate its impact in terms of occupational safety, with special emphasis on worker safety. Addressing this issue involves identifying sources of exposure, evaluating associated risks, and implementing effective preventive measures to avoid negative health effects of UV radiation on employees.

UV RADIATION INTERACTIONS AND BIOLOGICAL EFFECTS

The ultraviolet radiation spectrum is conventionally divided into three bands based on their wavelengths and the interaction between the radiation matter and human cells (Figure 1):

- UVC – 100-280 nm wavelength
- UVB – 280-320 nm
- UVA – 320-400 nm

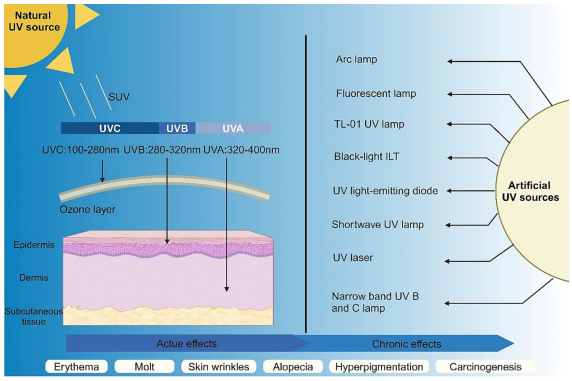


Figure 1. *Distribution of UV radiation. Source: Tang et al. (2004)*

Among the different types of UV radiation, UVC possesses the highest energy and poses the greatest potential risk to biological tissues. However, under natural conditions, UVC radiation is entirely absorbed by the stratospheric ozone layer, making it largely irrelevant as a health hazard except in the cases of accidental exposure to artificial sources (Trevisan et al., 2006). UVB radiation is also partially absorbed by the atmosphere, yet approximately 5% reaches the Earth's surface. Due to its shorter wavelength, UVB primarily affects the superficial layers of the epidermis and is associated with acute and chronic skin damage such as sunburns (Narayanan et al., 2010). UVA rays have the longest wavelength within the ultraviolet spectrum and constitute the majority of UV radiation that reaches the Earth's surface, between 90% and 95%. UVA radiation is minimally absorbed by atmospheric components and thus penetrates more deeply into the skin, reaching the dermal layer where collagen fibres are located. UVA radiation exerts harmful effects on both epidermal keratinocytes and dermal fibroblasts, contributing to progressive alterations in skin structure and function over time. Upon absorption of UVA photons by skin chromophores, ROS are generated, initiating oxidative stress. This oxidative imbalance and deeper penetration explain UVA's role in photoaging (Pittayapruek et al., 2016). The typical UVA to UVB ratio in solar radiation that reaches the ground is approximately 20:1, although this proportion fluctuates depending on geographic latitude, time of day, season, and atmospheric conditions such as cloud cover, which disproportionately attenuate UVB relative to UVA (WHO, 2016; Romanhole et al., 2015).

In addition to its damaging effects on the skin, UV radiation is also implicated in the development of several ocular disorders, including cataracts, macular degeneration, and premature aging of periocular tissues. Notably, cataracts account for approximately 48% of global cases of blindness.

Our experiments demonstrate that UV radiation affects certain naturally occurring biological compounds, including chlorophylls, bacteriochlorophylls, and porphyrins, with a particular emphasis on protoporphyrin IX. The data indicate that UV exposure induces degradation of these molecules, obeys a first-order rate, and is highly dependent on the used-energy input and the used solvents. These compounds may serve as biomarkers for UV-induced biological damage in humans. Additionally, these compounds can potentially be applied in fields such as cosmetology and PDT therapy (Zvezdanović et al., 2009; Lazarević et al., 2025).

The ozone layer within the stratosphere functions as an essential protective shield, filtering out a substantial portion of the sun's UV radiation, thus limiting its harmful impact on the Earth's surface. Over the past century, anthropogenic activities, particularly the release of chlorofluorocarbons (CFCs) and other ozone-depleting substances (ODSs), have led to considerable depletion of the ozone layer, consequently elevating the levels of UV radiation that penetrate the atmosphere and reach ground level (Bernhard et al., 2023). Climate change, characterized by rising global temperatures, also influences the levels of UV radiation exposure. Scientific studies indicate that with each 1 °C increase in ambient temperature, the carcinogenic potential of UV radiation may rise by approximately 5%, suggesting a compounding effect between thermal and UV-related environmental stressors (Umar & Tasduq, 2022).

WORKPLACE EXPOSURE TO UV RADIATION AND HEALTH RISKS

Although a slight recovery of the polar ice caps has been noted, the ozone layer continues to experience depletion. This ongoing deterioration has contributed to increased levels of UV radiation reaching the Earth's surface, accompanied by extended periods of elevated temperatures during summer months (Ball et al., 2019). From a primary prevention perspective, it is crucial to

identify occupations with a high risk of solar UV exposure, as well as to determine sectors where sun-protective behaviours in the workplace are notably inadequate.

Outdoor workers are particularly vulnerable to these adverse environmental changes and they are the ones who suffer the most. Ultraviolet radiation exposure among outdoor workers is not restricted only to bright, sunny conditions. Dosimeter-based studies reveal that on cloudy or overcast days, UV levels can still reach approximately 30% of those observed under clear skies. Moreover, during the spring season, when skin typically lacks protective thickening, UV intensity averages around 80% of that seen in the summer months. Prolonged occupational exposure to UV radiation is well documented as a risk factor for various adverse health outcomes, including squamous cell carcinoma, multiple actinic keratoses, cataract formation, and accelerated cutaneous aging (Wright et al., 2004; Schmitt et al., 2011). The World Health Organization has estimated that between 2 million and 3 million squamous cell carcinomas, 10 million basal cell carcinomas, and 200,000 melanomas are diagnosed globally each year, most of them among outdoor workers. It is estimated that about 15 million workers in Europe are exposed to solar UV, the vast majority of whom (90%) are generally male. Examples of occupations characterized by prolonged outdoor activities and consequently significant direct and indirect exposure to solar ultraviolet radiation UVR include construction workers, agricultural workers, gardeners, childcare providers, firefighters, police officers, lifeguards, athletes, street vendors, etc. (EU-OSHA, 2009).

The link between outdoor occupations and the incidence of skin cancers, as well as other dermatological conditions, is primarily connected with prolonged exposure to solar radiation, often combined with insufficient implementation of sun protection measures.

In industrial environments, UV radiation exposure primarily arises from artificial sources rather than natural sunlight. Common industrial applications involving artificial UV sources include electric arc welding, UV curing in the printing and textile industries, sterilization processes in pharmaceutical and laboratory settings, and photolithography in electronics manufacturing. Workers in these sectors may be regularly exposed to high-intensity UVA and UVB radiation, sometimes without adequate protective measures (Diepgen et al., 2012; WHO, 2016).

In addition to outdoor occupations and industrial environments, some indoor professions, particularly in the healthcare and cosmetic sectors, are also associated with notable exposure to artificial UV radiation. Healthcare workers may be exposed during procedures involving UV-emitting devices, such as phototherapy for dermatological conditions, UV disinfection systems, and in operating rooms or catheterization suites where UV-based sterilization is utilized. Similarly, workers in beauty salons and cosmetic clinics are often exposed to UVA radiation during procedures such as gel nail curing and skin tanning. Although these exposures are generally controlled and minimal, repeated exposure without appropriate protective measures may pose long-term risks to the skin and eyes (Marchbein & Campbell, 2022).

Prolonged or repeated exposure to artificial UV radiation can cause both acute and chronic health effects. These include erythema, photokeratitis ("welder's flash"), cataracts, photoaging, and an increased risk of skin cancers such as squamous cell carcinoma. Welding, in particular, is associated with intense UVC exposure, which, although typically filtered out by the atmosphere, poses significant hazards when generated artificially. To minimize these risks, it is essential to implement a combination of technical controls (e.g. shielding and enclosure of UV sources), administrative measures (e.g. training and restricted access), and personal protective equipment (e.g. UV-filtering goggles, gloves, and protective clothing). Regular monitoring of exposure levels and adherence to safety standards are crucial for preventing long-term health consequences among industrial workers (EU-OSHA, 2009; WHO, 2016; Modenese et al., 2018).

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has established a recommended exposure limit for artificial UV radiation affecting unprotected skin and eyes, set at 30 J/m² over an 8-hour work period. To assess compliance with this limit, effective irradiance (measured in W/m²) is calculated by weighting the spectral irradiance across the wavelength range of 180 to 400 nm using the ICNIRP action spectrum. The resulting value allows for the determination of the maximum permissible exposure duration, which is obtained by dividing the recommended maximum dose (30 J/m²) by the effective irradiance, under the assumption that exposure remains constant over time (ICNIRP, 2004).

PREVENTION OF OCCUPATIONAL UV DISEASES

Effective prevention of adverse skin and ocular diseases among outdoor and other workers exposed to UV radiation requires the implementation of a comprehensive set of preventive strategies. These include collective technical and organizational measures aimed at minimizing exposure, dissemination of targeted information, and provision of specific training programs for employees. Additionally, the consistent use of appropriate personal protective equipment (PPE), promotion of protective behavioural practices, and regular medical surveillance of exposed individuals are essential components of occupational health management in UV-exposed professions (Modenese et al., 2018). There are four main examples of preventive measures that can be applied to reduce UV exposure in the workplace, as follows (Modenese et al., 2018):

(1) *Collective Technical / Organizational measures*: These measures include both artificial and natural shading of workspaces, as well as scheduling structured breaks in UV-protected environments during peak radiation hours. Additionally, reorganizing work routines to limit or entirely avoid outdoor tasks during midday, initiating work earlier in the morning, or extending lunch breaks, can significantly reduce cumulative UV exposure, particularly during periods of elevated UV index values throughout the year (ICNIRP, 2010; Alfonso et al., 2017; Modenese et al., 2016).

(2) *Health and safety information and training*. Educational and informational initiatives should be introduced as early as possible, possibly in all schools preparing individuals for outdoor professions, as well as among all current outdoor workers.



Figure 2. *Typical signs used in the work environment to warn about UV risk exposure*

Supplementary preventive tools such as instructional fact sheets, warning signs, and visual reminders can encourage workers to avoid exposure when the UV index is high (Figure 2) and to consistently apply personal protective measures, including suitable clothing, wide-brimmed hats, UV-protective eyewear, and broad-spectrum sunscreen (ICNIRP, 2010; Alfonso et al., 2017; Modenese et al., 2016)

(3) *Personal protection*. Occupational sunglasses must comply with established safety standards regarding both the UV filtering capacity of the lenses and the physical design of the frames, with sufficiently large, close-fitting lenses and broadside arms to ensure comprehensive eye protection. Suitable protective clothing should consist of long-sleeved shirts and trousers made from tightly woven, UV-opaque fabrics such as cotton blends or technical synthetic fibres, preferably with a high UV protection factor (UPF), ideally rated 50+. Proper head protection includes wide-brimmed hats or helmets equipped with neck flaps and side guards to shield vulnerable areas from solar radiation (Figure 3). For exposed skin areas, broad-spectrum water-resistant sunscreens with a minimum sun protection factor (SPF) of 50+ should be applied at least 20 minutes before sun exposure. Reapplication is necessary at regular intervals, particularly every two hours, and more frequently in cases of excessive sweating or when the UV index is high (ICNIRP, 2010; Alfonso et al., 2017; Modenese et al., 2016).



Figure 3. *Welder with appropriate personal protective equipment*

(4) *Health surveillance*. Occupational health physicians should conduct periodic medical examinations of workers to effectively prevent long-term effects on the skin and eyes. Particular attention must be given to identifying individuals with heightened sensitivity to UV radiation, such as those with prolonged use of photosensitizing medications, existing wounds, suspicious skin lesions, or UV-sensitive dermatological conditions like psoriasis. Regarding ocular health, conditions such as lens opacities and corneal injuries may increase photosensitivity. Collaboration with dermatologists, ophthalmologists, and other relevant specialists is recommended for managing specific cases (ICNIRP, 2010; Alfonso et al., 2017; Modenese et al., 2016).

Exposure measurement

Measurement of UV radiation at workplaces is the first step in worker protection, and it can be measured at fixed locations using radiometers (Figure 4). There are several devices available for UV measurements. However, all of them mostly use two primary methodologies: chemical UV dosimeters, which utilize photosensitive plastic films that change their optical characteristics upon UV exposure, and electronic UV dosimeters, which rely on semiconductor-based sensors to detect and measure UV radiation levels. Both types of devices provide valuable data for assessing occupational and environmental UV exposure (Huang et al., 2021).



Figure 4. *PCE-UV34 Radiation Meter equipped with a Photodiode with a UV correcting filter*

CONCLUSION

Occupational exposure to UV radiation poses a significant health risk, particularly for outdoor workers and those operating near artificial UV sources. Prolonged and unprotected exposure can lead to acute and chronic dermatological and ophthalmological conditions, including skin cancers, photoaging, and cataracts. Because of the growing environmental challenges and increased solar UV radiation due to climate change and ozone depletion, along with growing industry, it is imperative that UV protection becomes a standard component of occupational health policies across all sectors involving outdoor work.

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REFERENCES

Alfonso, J. H., Bauer, A., Bensefa-Colas, L., Boman, A., Bubas, M., Constandt, L., ... & Giménez-Arnau, A. M. (2017). Minimum standards on prevention, diagnosis and treatment of occupational and work-related skin diseases in Europe–position paper of the COST Action StanDerm (TD 1206). *Journal of the European Academy of Dermatology and Venereology*, *31*, 31-43. https://doi.org/10.1111/jdv.14319

Ball, W. T., Alsing, J., Mortlock, D. J., Staehelin, J., Haigh, J. D., Peter, T., ... & Rozanov, E. V. (2018). Evidence for a continuous decline in lower stratospheric ozone offsetting ozone layer recovery. *Atmospheric Chemistry and Physics*, *18*(2), 1379-1394. https://doi.org/10.5194/acp-18-1379-2018

Bernhard, G. H., Bais, A. F., Aucamp, P. J., Klekociuk, A. R., Liley, J. B., & McKenzie, R. L. (2023). Stratospheric ozone, UV radiation, and climate interactions. *Photochemical & Photobiological Sciences*, *22*(5), 937-989. https://doi.org/10.1007/s43630-023-00371-y

Buys, D. G., & Brown, S. C. (2021). Radiation exposure protection: Small things matter. *Cardiovascular Journal of Africa*, *32*(5), 235-236. DOI: 10.5830/CVJA-2021-052.

Diepgen, T. L., Fartasch, M., Drexler, H., & Schmitt, J. (2012). Occupational skin cancer induced by ultraviolet radiation and its prevention. *British Journal of Dermatology*, *167*(s2), 76-84. https://doi.org/10.1111/j.1365-2133.2012.11090.x

El Ghissassi, F., Baan, R., Straif, K., Grosse, Y., Secretan, B., Bouvard, V., & Cogliano, V. (2009). A review of human carcinogens, part D: radiation. *The Lancet Oncology*, *10*(8), 751-752. https://doi.org/10.1016/S1470-2045(09)70213-X

European Agency for Safety and Health at Work. (2009). Outlook 1: New and emerging risks in occupational safety and health. Available online: https://osha.europa.eu/en/node/6842/file_view (accessed on 26 July 2018).

Huang, X., & Chalmers, A. N. (2021). Review of wearable and portable sensors for monitoring personal solar UV exposure. *Annals of biomedical engineering*, *49*(3), 964-978. https://doi.org/10.1007/s10439-020-02710-x

Hyppönen, E., & Power, C. (2007). Hypovitaminosis D in British adults at age 45 y: nationwide cohort study of dietary and lifestyle predictors. *The American journal of clinical nutrition*, *85*(3), 860-868. https://doi.org/10.1093/ajcn/85.3.860

International Commission on Non-Ionizing Radiation Protection. (2004). Guidelines on limits of exposure to ultraviolet radiation of wavelengths between 180 nm and 400 nm (incoherent optical radiation). *Health Physics*, *87*(2), 171-186.

International Commission on Non-Ionizing Radiation Protection. (2010). ICNIRP statement protection of workers against ultraviolet radiation. *Health Physics*, *99*(1), 66-87. *DOI:* 10.1097/HP.0b013e3181d85908

Krutmann, J., & Morita, A. (1999, September). Mechanisms of ultraviolet (UV) B and UVA phototherapy. In *Journal of Investigative Dermatology Symposium Proceedings* (Vol. 4, No. 1, pp. 70-72). Elsevier. https://doi.org/10.1038/sj.jidsp.5640185

Lazarević, A., Petrović, S., Cvetković, D., Stanojević, J., Anđelković, T., & Zvezdanović, J. (2025). Protoporphyrin IX response to ultraviolet and white light treatments in different mediums. *Monatshefte für Chemie-Chemical Monthly*, *156*(4), 431-442. https://doi.org/10.1007/s00706-025-03306-8

Lee, J. W., Ratnakumar, K., Hung, K. F., Rokunohe, D., & Kawasumi, M. (2020). Deciphering UV-induced DNA damage responses to prevent and treat skin cancer. *Photochemistry and photobiology*, *96*(3), 478-499. https://doi.org/10.1111/php.13245

Marchbein, D., & Campbell, C. (2020). "Is UV Light for Nails Safe? Dermatologists Weigh in on New Cancer Study." *Teen Vogue*. Retrieved from https://www.teenvogue.com/story/uv-light-for-nails-safety

Modenese, A., Bisegna, F., Borra, M., Grandi, C., Gugliermetti, F., Militello, A., & Gobba, F. (2016). Outdoor work and solar radiation exposure: Evaluation method for epidemiological studies. *Medycyna Pracy. Workers' Health and Safety*, *67*(5), 577-587.

Modenese, A., Korpinen, L., & Gobba, F. (2018). Solar radiation exposure and outdoor work: an underestimated occupational risk. *International journal of environmental research and public health*, *15*(10), 2063. https://doi.org/10.3390/ijerph15102063

Narayanan, D. L., Saladi, R. N., & Fox, J. L. (2010). Ultraviolet radiation and skin cancer. *International journal of dermatology*, *49*(9), 978-986. https://doi.org/10.1111/j.1365-4632.2010.04474.x

Pittayapruek, P., Meephansan, J., Prapapan, O., Komine, M., & Ohtsuki, M. (2016). Role of matrix metalloproteinases in photoaging and photocarcinogenesis. *International journal of molecular sciences*, *17*(6), 868. https://doi.org/10.3390/ijms17060868

Romanhole, R. C., Ataide, J. A., Moriel, P., & Mazzola, P. G. (2015). Update on ultraviolet A and B radiation generated by the sun and artificial lamps and their effects on skin. *International journal of cosmetic science*, *37*(4), 366-370. https://doi.org/10.1111/ics.12219

Ross, A. C., Manson, J. E., Abrams, S. A., Aloia, J. F., Brannon, P. M., Clinton, S. K., ... & Shapses, S. A. (2011). The 2011 report on dietary reference intakes for calcium and vitamin D from the Institute of Medicine: what clinicians need to know. *The Journal of Clinical Endocrinology & Metabolism*, *96*(1), 53-58. https://doi.org/10.1210/jc.2010-2704

Schmitt, J., Seidler, A., Diepgen, T. L., & Bauer, A. (2011). Occupational ultraviolet light exposure increases the risk for the development of cutaneous squamous cell carcinoma: a systematic review and meta-analysis. *British Journal of Dermatology*, *164*(2), 291-307. https://doi.org/10.1111/j.1365-2133.2010.10118.x

Tang, X., Yang, T., Yu, D., Xiong, H., & Zhang, S. (2024). Current insights and future perspectives of ultraviolet radiation (UV) exposure: Friends and foes to the skin and beyond the skin. *Environment International*, 108535. https://doi.org/10.1016/j.envint.2024.108535

Trevisan, A., Piovesan, S., Leonardi, A., Bertocco, M., Nicolosi, P., Pelizzo, M. G., & Angelini, A. (2006). Unusual high exposure to ultraviolet-C radiation. *Photochemistry and photobiology*, *82*(4), 1077-1079. https://doi.org/10.1562/2005-10-27-RA-728

Umar, S. A., & Tasduq, S. A. (2022). Ozone layer depletion and emerging public health concerns – an update on epidemiological perspective of the ambivalent effects of ultraviolet radiation exposure. *Frontiers in Oncology*, *12*, 866733. https://doi.org/10.3389/fonc.2022.866733

World Health Organization. (2016). *Radiation: Ultraviolet (UV) Radiation*. Geneva.

Wright, C., Diab, R., & Martincigh, B. (2004). Anatomical distribution of ultraviolet solar radiation. *South African journal of science*, *100*(9), 498-500.

Zvezdanović, J., Cvetić, T., Veljović-Jovanović, S., & Marković, D. (2009). Chlorophyll bleaching by UV-irradiation in vitro and in situ: Absorption and fluorescence studies. *Radiation Physics and Chemistry*, *78*(1), 25-32. https://doi.org/10.1016/j.radphyschem.2008.07.006

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MULTIMODAL ANALYSIS OF WORKERS' COGNITIVE AND PHYSICAL STRESS

Abstract: *In the modern contemporary environment, simultaneous monitoring of physical and mental strain is very important in order to improve ergonomic conditions and the health of workers. This research paper presents a multimodal approach to assessing the physical and mental strain of workers during assembly activities. The proposed model combines the RULA (Rapid Upper Limb Assessment) method for assessing ergonomic risk and the EEG (electroencephalography) method for evaluating mental strain. Through an experimental study conducted on a sample of 7 subjects, the implications of assuming certain body postures on the physical and cognitive state of the subjects were analyzed.*

The results indicated a significant association between the adoption of non-physiological and non-ergonomic body postures and increased mental effort, which indicates the need for an integrated assessment when designing ergonomic workplaces. The results obtained showed that the application of ergonomic principles contributes to the reduction of physical and mental strain. The results also confirm that high levels of physical strain lead to changes in the brain activity of the subjects that correspond to increased mental effort. The proposed approach can serve as a basis for the development of advanced systems for monitoring and optimizing worker performance and well-being.

Keywords: mental strain, multimodal approach, ergonomic, physical strain, RULA

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INTRODUCTION

In modern industrial systems, employees involved in assembling parts and components into a final product are increasingly exposed to physical and mental strain. Assembly tasks involve carrying out a sequence of precise and often repetitive operations, such as assembling parts, installing and positioning parts and components, testing, and final product adjustment. As such, assembly activities require a high level of attention and concentration, precision and coordination, as well as the ability to respond quickly to changing parameters in the production environment. These tasks can be both physically and mentally demanding, which necessitates the need to conduct ergonomic analyses and optimization in order to improve working conditions and increase productivity.

Holding unphysiological body postures for long periods of time and performing repetitive movements contribute to an increased risk of developing musculoskeletal disorders. On the other hand, mental overload and stress lead to a decrease in efficiency and effectiveness. Factors from the work environment can greatly affect the physical and mental ability of workers. For this reason, all ergonomic and organizational aspects need to be carefully considered in order to optimize working conditions, reduce the risk of work-related injuries and improve the efficiency of production processes. Traditional approaches to assessing workload often focus exclusively on one aspect - physical or cognitive - which can lead to an incomplete understanding of the real state. Therefore, there is a need for a multimodal approach to assessing the physical and mental workload of workers.

Physical and mental strain are two interrelated aspects that significantly impact the efficiency, health and well-being of employees. Although they are often viewed separately, numerous studies show that there is a clear correlation between physical exertion and increased mental strain, especially in conditions where work activities require a high degree of concentration, attention and coordination. Physical strain can lead to mental fatigue, reduced attention and an increased tendency to make mistakes, which directly affects worker performance. On the other hand, intense mental strain can intensify the experience of physical strain,

even when objective physical demands are low. This psychophysical interaction often leads to a deterioration in the health of workers, which indicates the need for a holistic approach to workplace design.

In this regard, there is a need for a multimodal approach that combines different measurement and assessment methods, in order to cover all dimensions of the load. In this paper, the multimodal approach is based on the application of the RULA method for assessing the ergonomic risk of musculoskeletal disorders and the EEG method for monitoring the mental state of workers in real time during the execution of an assembly task.

The aim of the research paper is analysis of data obtained by a combination of these methods to show the connection between the adoption of certain body postures and mental effort during assembly activities. The paper points to the importance of applying ergonomic principles when designing workplaces, optimizing the work environment and adapting working conditions to the needs of workers in order to reduce the physical and mental burden of workers, eliminate injuries at work and improve the general health and satisfaction of workers.

PROBLEM STATEMENT

Despite the growing trend of automation and the application of advanced Industry 4.0 technologies, in numerous modern industrial workplaces, full digitalization is not achievable, resulting in the continued reliance on repetitive and monotonous manual assembly tasks.

Assembly activities at industrial workstations are most often performed in ergonomically inadequate and non-physiological body postures for a long period of time, which leads to the occurrence of occupational diseases, most often musculoskeletal disorders, including carpal tunnel syndrome, tendonitis, etc. (Barr et al., 2004). Frequent performance of repetitive movements and performance of movements at high speed in non-physiological body postures for a long period of time increases the load on the tendons, muscles and nerves of the hand, joints of the forearm muscles and neck muscles, which further causes strain and pain in the muscles of the upper extremities.

The main risk factors for the development of musculoskeletal disorders in the literature are non-physiological body posture and inadequately designed workplace (Petreanu & Seracin, 2017). Also, given the frequent performance of repetitive activities, which leads to a decrease in attention and concentration, workers are exposed to mental strain and are more prone to making mistakes. In some situations, workers repeat the same work operation several thousand times during a work shift, which causes mental fatigue.

Mental strain is one of the most commonly used concepts in ergonomics and human factors and is a topic of increasing importance. As modern technology imposes ever-increasing cognitive demands, understanding the impact of mental strain on worker performance and well-being is increasingly important (Young et al., 2015). There is a growing need to investigate the causal relationship between physical and mental strain, especially in work environments where workers are exposed to high demands.

Mental workload is the level of cognitive effort a person puts into performing work tasks. Carrying out assembly tasks requires maintaining a high level of attention and concentration, focusing on work operations, remembering information, making decisions, and solving problem situations. Mental workload occurs when the demands of work tasks exceed or approach the cognitive capacities of the worker.

Mental strain depends on several factors - the complexity of work tasks, the duration of the activity, the work experience, motivation, and also the physical condition of the organism. Mental strain can negatively affect performance, lead to a decrease in productivity and efficiency, and an increase in the number of errors. Therefore, recognizing and monitoring mental strain is of great importance for effective workplace design, especially during tasks that require a high level of concentration and attention.

Lean philosophy is a modern approach to organizational management, derived from the Japanese Toyota Production System (TPS), aimed at the rational use of resources (time, space, effort) and the production of quality products that meet customer needs. In the lean concept, the focus is on performing only those activities that add value and eliminating all forms of loss and unnecessary waste. All activities that do not directly contribute to the creation of value for the end user are considered losses in the context of lean philosophy. According to (Suzaki, 1987), everything except the minimum amount of equipment, materials, parts, space and the minimum expenditure of employee time required to produce the necessary products is considered waste.

Special emphasis is placed on continuous improvement of the work process, redesigning workplaces and adapting to the individual characteristics of workers. In the context of ergonomics, the application of the lean concept involves improving workplaces in order to eliminate all problems that arise due to the inefficient arrangement of necessary parts, components, and tools, adopting non-physiological body postures, performing unnecessary movements, reducing physical and cognitive load, etc. (Santos et al., 2019).

The importance of incorporating ergonomic principles when designing a work environment in which repetitive assembly tasks are performed is also indicated by numerous scientific research papers (Neumann et al., 2002). The main goal of applying ergonomic measures is to tailor the work, tasks, and equipment to suit the needs of the workers through modification of the work environment, and equipment, and through minimizing poor posture and excessive muscle strain, in order to improve performance, reduce work injuries, and occupational diseases.

The RULA method is one of the most commonly used tools for assessing ergonomic risks related to upper body loads during work activities. This method allows for the quick and efficient identification of unfavorable positions and movements that can lead to musculoskeletal disorders. In the modern approach to ergonomics, digital modeling of working positions and movements is increasingly being applied as it enables detailed simulation and analysis in a virtual environment. Combining the RULA method with software solutions for digital modeling allows for more precise and comprehensive assessments of work processes, which contributes to the improvement of working conditions and the prevention of occupational injuries and occupational diseases.

Mental strain can be measured indirectly (via subjective questionnaires), by monitoring performance, or by analyzing physiological parameters such as electroencephalography (EEG). Modern research is increasingly focusing on multimodal methods of monitoring mental strain, in which objective data obtained through the application of psychophysiological methods are combined with subjective assessments, to gain a more comprehensive understanding of workers' cognitive strain.

The application of methods from the domain of neuroergonomics allows for deeper insight into the mental workload of workers (Ayaz & Dehais, 2019). As the authors point out (Trimmel et al., 2009), psychophysiological methods allow for objective quantification of cognitive state in real time. Monitoring brain activity provides insight into how people think, process information, solve problems, and make decisions in different situations (Gevins et al., 1995). This allows for monitoring changes in brain waves when a worker moves from simple to more complex cognitive tasks, helping to evaluate the mental effort required to complete work activities.

METHODOLOGY

In this research paper, a multimodal approach to assessing the physical and mental strain of workers while performing assembly activities is presented. The proposed model combines the RULA (Rapid Upper Limb Assessment) method for assessing ergonomic risk and the EEG (electroencephalography) method for evaluating mental strain.

The research conducted is based on an interdisciplinary approach that integrates ergonomic aspects, methods from the field of industrial engineering, and modern innovative technologies of Industry 4.0.

A total of 7 respondents participated in both scenarios. The respondents were undergraduate, master's and doctoral students at the Faculty of Engineering Sciences, University of Kragujevac, male, right-handed, aged between 18 and 30.

Experimental research was conducted in two scenarios: non-ergonomic and ergonomic. In a non-ergonomic scenario, the research was conducted on a traditional workstation, which was not aligned with ergonomic and lean principles. In the ergonomic scenario, the research was conducted on a proposed new workstation, designed in accordance with the "golden zone" standards, 5S, and ergonomic principles. The experimental procedure is described in detail in the research paper (Savković et al., 2023).

For the purpose of conducting complex research during the simulation of assembly tasks in the laboratory of the Faculty of Engineering of the University of Kragujevac, an industrial assembly workstation was designed and developed, which is aligned with ergonomic and lean principles and golden zone standards.

Industrial practice in this area reminds the organization of the importance of introducing ergonomics measures when designing installation workstations (Anghel et al., 2019). Designing assembly workstations requires careful consideration of the physical and cognitive abilities and limitations of workers. Special focus is placed on analyzing anthropometric characteristics, arm reach, and body posture to reduce physical strain and minimize the potential for work-related injuries (Figure 1.).

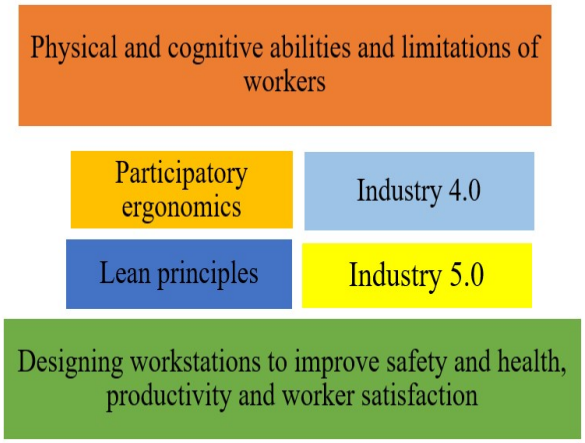


Figure 1. *A comprehensive approach to workstation design in accordance with ergonomic and lean principles*

Safety 4.0 represents a shift towards an approach to workplace safety based on big data analysis and the application of innovative technologies. In the context of Industry 4.0, a human-centered workplace is one that involves the application of advanced technologies in a way that assists workers in performing work activities rather than replacing them. In the era of Industry 4.0, ergonomics is of particular importance. The emphasis is on adapting advanced technologies to the needs and abilities of people and optimizing the interaction between people and other elements of the work system.

Industry 5.0 promotes a human-centered approach and places the worker at the center of production processes (which is represented in scientific research papers through the term Operator 5.0), with special attention paid to increasing their safety, health, satisfaction, and well-being at work (Aromaa et al., 2018).

Participatory ergonomics involves involving workers in the process of designing and improving the work environment. Respondents, in accordance with individual requirements and needs, provided direct information related to improving the workplace, tools and equipment, which contributed to reducing strain and increasing safety.

The new modular assembly workstation is displayed in Figure 2.



Figure 2. *Proposed modular workstation*

Unlike a traditional workstation, the new workstation is designed with ergonomic principles and the 5S principles in mind, and in accordance with the golden zone standards, taking into account the fact that the zones of the working space are different for each person (Savković et al., 2022). The proposed workstation is fully adapted to the worker's anthropometric characteristics, needs, abilities and limitations, thereby reducing bending and stretching of the body. At the proposed assembly workstation, the subjects performed work tasks within the golden zone. As a result, unnecessary movements such as reaching, stretching, and bending were reduced because all materials, components, and tools were positioned at waist level.

The RULA method and the EEG method were applied in the experimental research. The RULA method was used to assess physical strain. Using a combination of the RULA method and computer modeling, the workplace, work activities, and body movements and postures were analyzed, as well as the application of force, in order to determine which factors contribute to muscle strain, or which risk factors contribute to the development of musculoskeletal disorders.

RULA is one of the most cited and commonly used methods for assessing ergonomic risk in the workplace (McAtamney & Corlett, 1993).

A certain number of points is assigned for each body posture taken by the respondents. The scores obtained using the RULA method range from 1 to 7:

- Grades 1 and 2 indicate that the posture is considered acceptable if it is not maintained or repeated over a long period of time. These grades indicate that there is no significant risk of developing musculoskeletal disorders.
- Grades 3 and 4 (yellow): These grades indicate that further research is needed. Changes in the way work tasks are performed or in the work environment may be necessary in the future to reduce ergonomic risks.
- Grades 5 and 6 (orange) indicate an increased risk of occupational diseases, which means that changes need to be introduced in the near future. The current working conditions in which assembly activities are carried out can lead to serious health problems if changes are not introduced.
- A score of 7 (red) indicates the urgency of taking ergonomic measures to change working conditions in order to prevent musculoskeletal disorders and other occupational diseases.

Brain activity was monitored using electroencephalography during the assembly tasks. EEG is one of the most commonly used methods for measuring electrical brain activity in real time (Hogervorst et al., 2014).

Recently, the EEG method has been increasingly used in industrial environments, in ergonomics, in monitoring brain activity, assessing the cognitive state and mental load of workers, and determining whether a worker can maintain attention for a longer period of time (Infantolino & Miller, 2014). The authors (Gevins et al., 1995) believe that this method is particularly useful in measuring brain activity in workplaces that require high concentration from workers. This method allows the detection of subtle changes in mental state that are not necessarily visible to external observation.

An EEG cap with 24 electrodes was placed on the subject's head to measure the action potential of neurons. Brain activity was monitored in the frontal (AFz, Fz, Fp1, Fp2, F3, F4, F7 and F8), central (Cz, CPz, C3 and C4), temporal (T7, T8), parietal (CPz, Pz, P3, P4, P7, P8) and occipital (O1 and O2) regions and the midbrain region (M1 and M2). A SMARTING wireless 24-channel EEG system with a triggering frequency of 250 Hz was used to record the EEG signal. The EEG cap was connected to a mobile Smarting amplifier from mBrainTrain LLC (Belgrade, Serbia) with dimensions of 85 × 51 × 12 mm and a weight of 60 g.

RESULTS AND DISCUSSION

The results of the RULA analysis during assembly activities in a non-ergonomic scenario are shown in Figure 3. As can be seen in the figure, since at a traditional workstation the necessary components, parts and tools were not placed and arranged in accordance with the golden zone, lean and 5S principles, the subjects were forced to bend and stretch their bodies in order to reach them. Therefore, the total RULA analysis result for this position is 7, which is the maximum value and indicates that additional research and changes should be carried out immediately. A particular problem was the very limited possibility of changing the body posture during the work activity.

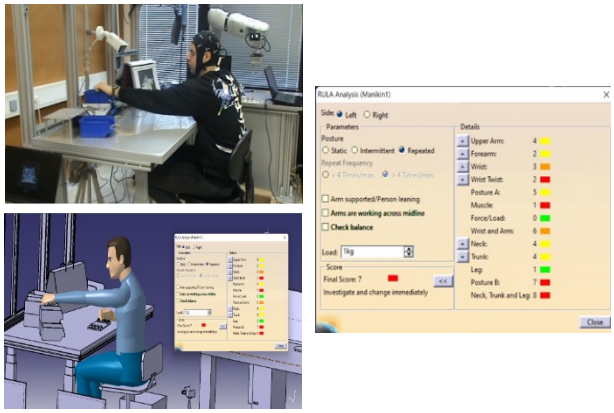


Figure 3. *Results of RULA analysis - non-ergonomic scenario*

At the new workstation, all necessary objects, materials and components were arranged and adapted to the needs, requirements and individual characteristics of the subjects, as shown in Figure 4. These changes contributed to the result after the RULA analysis for this position being 3 (which is a significantly lower value compared to the scores obtained in the non-ergonomic scenario). The subjects did not stretch their bodies to reach the necessary wires as in the non-ergonomic scenario because the cluster with wires was placed within the golden zone, and this significantly contributed to reducing the risk of developing musculoskeletal disorders.

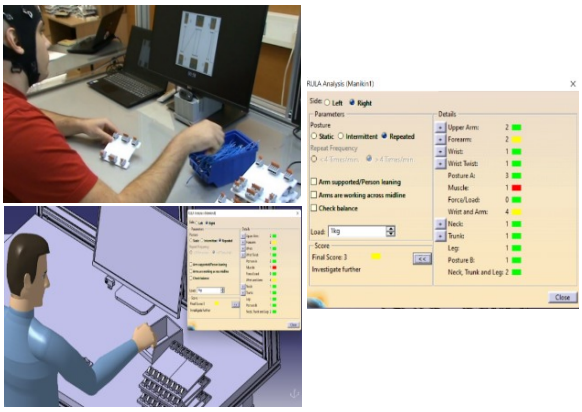


Figure 4. *Results of RULA analysis - ergonomic scenario*

The results of monitoring the mental workload of all 7 respondents using the mental workload index (MWLi) in non-ergonomic scenarios as shown in Figure 5.

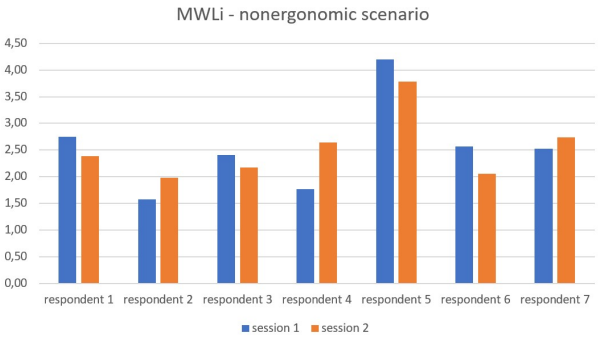


Figure 5. *Results of brain activity monitoring using the MWLi index in a non-ergonomic scenario*

Figure 6 presents the preliminary results of monitoring mental strain in an ergonomic scenario. The histogram does not show the results for respondent 2 in the first session due to technical reasons.

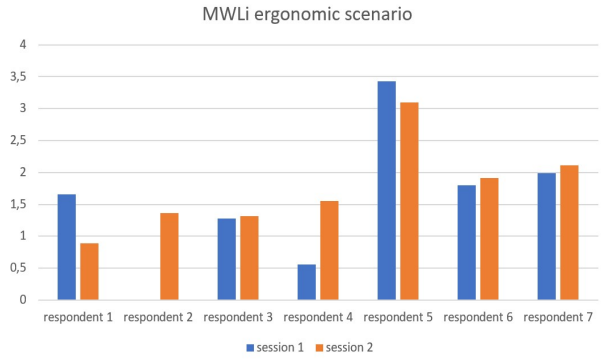


Figure 6. *Results of monitoring brain activity via the MWLi index in an ergonomic scenario*

As can be seen from the histogram, higher index values were recorded in the non-ergonomic scenario compared to the ergonomic scenario. The increased value of the MWLi index in the non-ergonomic scenario indicates that they are exposed to increased mental strain. The results showed that occupying static body postures for a longer period of time, performing repetitive movements, or performing activities in non-physiological body postures leads to a significant increase in mental strain. The reason for this can be found in the respondents' efforts to maintain concentration and accuracy despite physical exertion, which requires additional engagement of cognitive resources and causes mental fatigue. On the other hand, adapting the workplace to the respondents, by optimally organizing equipment, tools, and components based on their anthropometric and biomechanical traits contributes to reducing mental strain.

The obtained results indicate a significant correlation between physical and mental strain during assembly activities. The high value of the RULA analysis results in the non-ergonomic scenario indicates that the subjects performed activities in an unfavorable and

static body posture, which can lead to the development of musculoskeletal disorders if appropriate ergonomic measures are not taken.

The results showed that in the non-ergonomic scenario, the subjects were exposed to greater physical strain due to inadequate organization of the workspace, adopting inadequate body postures, and performing non-ergonomic movements because the tools, parts, and components required for assembly were placed on the work surface outside the subject's maximum reach zone. Frequent bending of the torso, bending of the neck and limited body mobility further contributed to the increase in physical strain in each subject. At the same time, in the non-ergonomic scenario, the subjects were exposed to greater mental strain compared to the ergonomic scenario, as shown by the results obtained by the EEG method. Results show that factors from the external environment greatly disturbed the respondents while performing assembly activities in a non-ergonomic scenario, which contributed to an increase in mental strain.

On the other hand, in the ergonomic scenario, the effects of these unfavorable factors were eliminated, which led to a significant improvement in working conditions. The optimal organization of the workspace and the elimination of external distractions resulted in a reduction in the physical and mental burden of the respondents. The results obtained clearly confirm the importance of applying ergonomic principles in workplace design.

CONCLUSION

Workers performing assembly activities at traditional workstations in real-world industrial environments are exposed to musculoskeletal disorders and other occupational diseases. Musculoskeletal disorders can occur as a result of adopting non-physiological body postures, performing repetitive movements, or chronic strain and overload, leading to pain, swelling, stiffness, and reduced functionality. Also, during the assembly of parts and components, workers are exposed to fatigue due to reduced attention and concentration.

This research paper presents a multimodal approach to the analysis of physical and mental strain of workers, combining the RULA method for assessing body position and the EEG method for monitoring brain activity. The results indicated that the subjects were exposed to high physical and mental strain when performing assembly activities in a non-physiological body posture in a non-ergonomic scenario. This was confirmed by a maximum RULA score of 7, as well as significant cognitive strain during task execution in the non-ergonomic scenario compared to the ergonomic scenario, as indicated by elevated mental strain index values.

The results obtained indicate the need for a systematic approach to load assessment that includes both physical and mental aspects. The results of the experimental research represent the basis for further ergonomic improvement of assembly workstations and the improvement of working conditions in order to prevent occupational diseases and increase the efficiency of production processes.

Future research should include different types of work tasks, as well as long-term monitoring of the effects of ergonomic measures, with the aim of developing personalized strategies for optimizing working conditions.

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REFERENCES

Aromaa, S., Liinasuo, M., Kaasinen, E., Bojko, M., Schmalfuß, F., Apostolakis, K. C., Zarpalas, D., Daras, P., Öztürk, C., & Boubekeur, M. (2018). User evaluation of Industry 4.0 concepts for worker engagement. In W. Karwowski & T. Ahram (Eds.), *Advances in intelligent systems and computing*: Vol. 876. Proceedings of the 1st International Conference on Human Systems Engineering and Design (IHSED 2018) (pp. 39–45). Springer. https://doi.org/10.1007/978-3-030-02053-8_6

Ayaz, H., & Dehais, F. (2019). *Neuroergonomics: The brain at work and in everyday life*. Elsevier. https://doi.org/10.1016/C2016-0-02196-4

Barr, A. E., Barbe, M. F., & Clark, B. D. (2004). *Work-related musculoskeletal disorders of the hand and wrist: Epidemiology, pathophysiology, and sensorimotor changes*. Journal of Orthopaedic & Sports Physical Therapy, 34(10), 610–627. https://doi.org/10.2519/jospt.2004.34.10.610

Gevins, A., Leong, H., Du, R., Smith, M. E., Le, J., Du Rousseau, D., & Libove, J. (1995). *Towards measurement of brain function in operational environments*. Biological Psychology, 40(1), 169–186. https://doi.org/10.1016/0301-0511(95)05105-8

Hogervorst, M. A., Brouwer, A. M., & Van Erp, J. B. (2014). *Combining and comparing EEG, peripheral physiology and eye-related measures for the assessment of mental workload*. Frontiers in Neuroscience, 8, 322. https://doi.org/10.3389/fnins.2014.00322

Infantolino, Z. P., & Miller, G. A. (2014). *Psychophysiological methods in neuroscience.* In R. Biswas-Diener & E. Diener (Eds.), Noba textbook series: Psychology. Champaign, IL: DEF Publishers.

McAtamney, L., & Corlett, E. N. (1993). *RULA: a survey method for the investigation of work-related upper limb disorders*. Applied ergonomics, 24(2), 91-99.

Neumann, W. P., Kihlberg, S., Medbo, P., Mathiassen, S. E., & Winkel, J. (2002). *A case study evaluating the ergonomic and productivity impacts of partial automation strategies in the electronics industry*. International Journal of Production Research, 40(16), 4059–4075.

Petreanu, V., & Seracin, A. M. (2017). *Risk factors for musculoskeletal disorders development: Hand-arm tasks,*

repetitive work. National Research-Development Institute for Health and Safety, Bucarest, Romania

Santos, J., Silva, F. J. G., Pinto, G., & Baptista, A. (2019). *Lean and ergonomics: How to increase the productivity improving the wellbeing of the workers.* In Lean manufacturing: Implementation, opportunities and challenges (pp. 189–224). Nova Science Publishers, ISBN: 978-1-53615-725-3

Savković, M., Caiazzo, C., Djapan, M., Vukićević, A., Pušica, M., & Mačužić, I. (2022). *Development of modular and adaptive laboratory set-up for neuroergonomic and human-robot interaction research*. Frontiers in Neurorobotics, 16, Article 863637. https://doi.org/10.3389/fnbot.2022.863637

Savković, M., Petrović, M., Caiazzo, C., Djapan, M., & Vukićević, A. (2023). *Determine muscle strain of assembly workers by applying advanced EMG measurement*. In Proceedings of the Quality Festival Conference 2023, Kragujevac, Serbia.

Suzaki, K. (1987). *The new manufacturing challenge: Techniques for continuous improvement*. The Free Press, New York, NY

Trimmel, M., Fairclough, S., & Henning, R. (2009). *Psychophysiology in ergonomics. Applied Ergonomics*, 40(6), 963–964. https://doi.org/10.1016/j.apergo.2009.02.003

Young, M. S., Brookhuis, K. A., Wickens, C. D., & Hancock, P. A. (2015). *State of science: Mental workload in ergonomics*. Ergonomics, 58(1), 1–17. https://doi.org/10.1080/00140139.2014.956151

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APPLYING NEW TECHNOLOGIES INSIDE SMART CITIES FOR CLEAN MOBILITY OF PUBLIC PASSENGER TRANSPORT

Abstract: *The application of modern technologies in combination with logistics centres in the public passenger transport system can contribute to reducing fuel consumption, preserving the environment, and increasing driving comfort. The door-to-door passenger transport model has been researched in this study as one of the ways for smart traffic management but also for increased driving comfort, primarily for people with special needs or requiring constant medical care. Modern technologies include the use of artificial intelligence and machine learning, vehicles powered by alternative fuels in city transport, and minibuses. The study shows that implementing a door-to-door transportation system with eco-friendly minibuses could reduce the number of passenger vehicles by up to 50% over six years in medium-sized cities, leading to lower CO_2 emissions and improved accessibility. The use of natural gas and electric vehicles, combined with intelligent management systems, significantly enhances energy efficiency and supports sustainability goals.*

Keywords: emission, door-to-door transport model, smart cities, vehicles

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INTRODUCTION

Passenger transportation in smart cities is becoming an increasingly important topic as technology evolves and urbanization continues to grow. Smart cities use innovation and technology to improve the quality of life of their citizens, and passenger transportation is a key part of that process. Here are some key aspects (Miron, Hulea, & Rusu, 2024):

- Smart Transportation Systems: In smart cities, transportation systems use sensors, data analytics, and applications to optimize traffic. This can include smart traffic lights that adapt to current traffic conditions or apps that help passengers find the fastest route.
- Electric and Autonomous Vehicles: Many smart cities are introducing electric buses and autonomous vehicles, which reduce CO_2 emissions and improve transport efficiency.
- Ride-Sharing Services: Car, minibus, bicycle, and scooter sharing services are becoming popular, allowing citizens to use transportation without owning a personal vehicle. This reduces congestion and pollution.
- Integration of Different Modes of Transport: Smart cities enable the integration of various transportation modes (public transport, cycling, walking, door-to-door model) so that passengers can easily switch from one to another.
- Data and Analytics: By using data collected from various sources, cities can better plan infrastructure, improve transport services, and adapt to the needs of citizens.
- All these innovations contribute to the creation of more efficient, sustainable, and user-friendly transportation in urban areas, leading to improved quality of life and a reduced environmental impact.

The management of municipal vehicles, especially garbage trucks and street cleaning vehicles, is also crucial for the efficient functioning of urban environments (Bošković et al., 2024):

- Telematics: The use of GPS and sensors to monitor vehicle efficiency, fuel consumption, and preventive maintenance.
- Route Optimization: Software solutions that enable the most efficient routes for waste collection or other municipal services, reducing time and costs.
- Automation: The introduction of autonomous vehicles for specific municipal services, which can reduce human error and increase efficiency.
- Resource Management: Centralized systems for tracking and managing vehicles, enabling better coordination and resource allocation.

Smart cities use technology to improve the quality of life for their citizens, reduce congestion, and increase

the efficiency of public services. Through innovation and the integration of smart solutions, cities can become more sustainable and more responsive to the needs of their residents.

In this way, technology contributes to the preservation of the environment by reducing the emission of harmful gases and noise from vehicles. Door-to-door transportation on demand using eco-friendly minibuses can significantly increase the comfort of passengers and persons with special needs (Milojević et al., 2024).

METHODOLOGICAL APPROACH

This paper is based on a qualitative and analytical approach, relying on the review and synthesis of relevant scientific literature, statistical data from the European Union vehicle fleet, and case examples from practice. The analysis includes a review of technological trends, environmental impact assessments, and transport system structures. A model-based evaluation of the door-to-door transport concept was conducted for a mid-sized city with 100,000 registered vehicles, assessing the potential for emission reduction and increased transport efficiency over a multi-year period. The aim is to identify effective strategies and technologies that can contribute to cleaner and more inclusive urban mobility in smart city environments.

MODERN TRANSPORT SYSTEMS IN SMART CITIES

Road transport emits one-fifth of the carbon dioxide (CO_2) emissions in the EU, which accounts for more than two-thirds of the total greenhouse gas emissions in the transport sector (Milojević et al., 2025).

Urban transport emits the largest share of emissions within the road transport sector. Moreover, by predominantly relying on fossil fuels in urban transport, we are responsible for air pollution in urban environments (Adikaram & Arambepola, 2025).

On the other hand, the mode of passenger transport (private and public, individual and mass) can significantly contribute to reducing the negative environmental impact. Priority is given to the use of alternative fuels alongside a parallel reduction in the use of fossil fuels. The main alternative fuels for propulsion and mobile systems are electric energy, hydrogen, and various types of biofuels. Synthetic fuels are still an option as a technology. Some of these technologies are very efficient, but their implementation cost remains high (Skrúcaný et al., 2018).

Another way to reduce emissions in the transport sector is the use of flexible passenger transport (such as door-to-door or on-demand systems), which enables a reduction in the number of cars and buses in urban areas, aiming to avoid traffic congestion and its negative environmental impact, as shown in Figure 1. Public urban transport and public transport in general, plays a special role in reducing dependency on fossil fuels. Along this path, the adoption of alternative propulsion technologies is necessary, as well as the development of a new public transport subsystem, along with the improvement of infrastructure and service quality (Milojević et al., 2025; Skrúcaný et al., 2018).

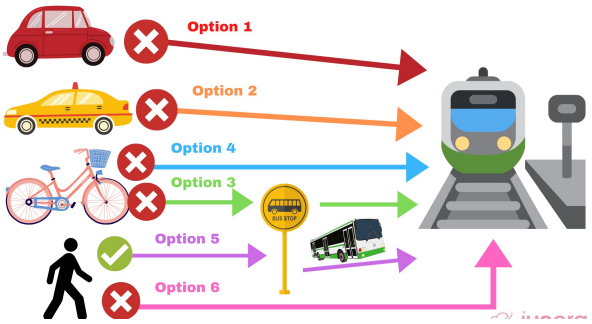


Figure 1. *Options for passenger transport over longer distances*

It is proposed that "on-demand" public transport be introduced, such as door-to-door services, primarily due to the comfort provided to passengers, which, in such cases, is comparable to the use of private cars (this especially applies to senior citizens, persons with disabilities, individuals undergoing regular medical treatments, etc.). The implementation of this transport system in cities reduces the excessive use of private vehicles, which in turn lowers traffic congestion and harmful gas emissions (Kluge et al., 2019).

The nature of mobility has changed over time, as has the way people travel; today, people travel long distances. Motor vehicles have gradually replaced non-motorized vehicles, giving preference to means of transport such as cars (Pooley & Pooley, 2022).

The use of motor vehicles (cars, motorcycles, buses, etc.) has simultaneously necessitated increasing amounts of energy, which mostly comes from burning fossil fuels. For this reason, fossil fuels remain the dominant energy resource in the transport sector today.

At the same time, due to the increasing energy demands in the transportation sector, there is a growing trend toward the application of alternative propulsion systems such as hydrogen-powered vehicles and electric vehicles (with electricity from renewable sources), which reduces the reliance on fossil fuels derived from oil (Milojević et al., 2024).

On the other hand, legal regulations set limits on the allowable emissions of toxic and harmful combustion products from motor vehicles and mandate the use of environmentally "cleaner" fuels.

Regarding the use of means of transport, people who live and work in rural areas, suburban settlements, and mountainous regions, as well as those working in isolated plants and inaccessible areas far from road networks, are forced to use their own cars, which contribute to congestion, the use of fossil fuels, and air pollution in urban environments.

In general, the reasons why the human population intensively uses cars for urban transport are numerous:

inconvenient public transport, residential areas not covered by public transit, inaccessibility (for people with children, the elderly, individuals with disabilities, etc.), inflexibility (breaking routine), the bad habit created by cheap fuel, and the increasing affordability of used (second-hand) vehicles, etc.

Urban traffic and traffic flow have the greatest impact on exhaust emissions and air pollution, especially in narrow streets, city centre zones, etc. The characteristics and types of roads also affect the cost of travel, safety, and passenger comfort. Furthermore, significant contributions to reducing exhaust emissions in urban traffic can be achieved through the application of various technologies and methods. Some of these can be very efficient and affordable and do not require additional costs, for instance (Milojević et al., 2024; Skrucany et al. 2019; Reji et al., 2025):

- The use of alternative fuels, biofuels, ethanol, natural gas, and hydrogen/electric energy, as well as other forms of "clean" propulsion energy, combined with the application of flexible transport, i.e. flexible transport systems that enable the reduction of the number of vehicles used in urban areas. This reduces congestion in city streets and downtown areas, thereby lowering fuel consumption and harmful exhaust emissions.
- Optimization and further improvement of the combustion process in internal combustion (IC) engines by using modern equipment and by reducing internal friction and mechanical losses, with the aim of reducing fuel consumption and exhaust emissions;
- Increasing vehicle reliability during operation and service life. An optimal approach to preventive maintenance of transport vehicles based on models that include planning processes, decision-making, logistics for supplying spare parts, skilled personnel for vehicle maintenance, etc.;
- Logistics for recycling vehicles at the end of their service life. Special attention should be paid to the logistics of dismantling and proper separation of rare materials from electric vehicles, such as neodymium or similar materials.

If the number of passenger cars in urban traffic were significantly reduced, significant results would be achieved in terms of lowering fuel consumption and environmental protection, which should contribute to a better-quality environment and social life. The following strategies, which are simultaneously real facts, can also serve as contributions to these trends:

- A significant increase in fuel prices on the market and limited supply;
- Penalties for exceeding permitted exhaust emissions.

Therefore, alternative ecological fuels, as well as modern propulsion systems for buses and other passenger transport vehicles, play an increasingly important role in the public transport system.

Essentially, it is necessary to implement transport systems that will enable higher-quality public transport services and comfort comparable to passenger cars while being accessible to potential users. Such optimal transport systems, which can complement conventional transport, can be applied in the following ways (Babić et al., 2022):

- Modern city buses or minibuses as suitable transport vehicles (introducing alternative fuels and technologies in public passenger transport);
- Introducing "door-to-door" transport models that will bring transport services closer to users, alongside appropriate information and communication systems as support, which should enable passenger information and "smart" and efficient management of the public transport system, as shown in Figure 2.

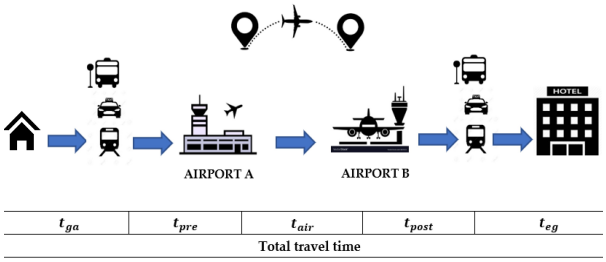


Figure 2. *Door-to-door passenger travel time*

A transport system for everyday fast public passenger transport over short distances, the so-called shuttle service, is one way to reduce the number of passenger cars on the roads. This type of transport has proven effective and inexpensive for users, easy to implement, and it contributes directly and indirectly to reducing fuel consumption and emissions.

Statistical data on the vehicle fleet in the EU

Concerning the number of vehicles and types of powertrains in the EU for the year 2023, the following characteristic data can be highlighted (Maniotis et al., 2023):

- A total of 96.4% of all trucks in the EU are diesel-powered, while gasoline vehicles account for 0.6% of the fleet. Only 0.1% of trucks on EU roads have a zero-emission powertrain;
- Diesel engine buses make up 89.2% of the EU fleet, with only 2.5% being electric and 2.2% hybrid-powered. However, a significant number of electric buses are found in the Netherlands (17.7%), Luxembourg (14.7%), and Ireland (13.5%);
- On average, there are 563 passenger cars and 83 commercial vehicles and buses per 1,000 inhabitants in the EU;
- Italy has the highest car density in the EU (694 per 1,000 inhabitants), while Cyprus has the highest density of commercial vehicles and buses (138 per 1,000 inhabitants). Conversely, Latvia has the lowest car density (381 per 1,000 inhabitants), as

well as the lowest density of commercial vehicles and buses (50 per 1,000 inhabitants).

- In Denmark, nearly 40% of households did not own a car, while 31% of French households had two passenger cars. The average annual distance travelled in the surveyed countries was 12,346 km.

Table 1 shows statistical data on the number of vehicles in the EU by vehicle type and powertrain.

Table 1. *Number of vehicles in the EU by vehicle type and powertrain*

Category of motor vehicles	M1	M2+M3	N1	N2+N3
Gasoline %	50	0.4	5.9	0.6
Diesel %	39.5	89.2	90.5	96.4
Electric vehicles, batteries %	1.8	2.5	1.1	0.1
Plug-in hybrid vehicles %	2.1	0.5	0.2	0.0
Hybrid powertrain %	3.2	2.2	0.2	0.1
Natural gas %	**0.6**	**4.2**	**0.5**	**0.8**
Liquefied petroleum gas (LPG) %	2.6	0.0	0.8	0.1
TOTAL	Passenger cars M1 (**248,824,542**)			
	Buses M2+M3 (**679,802**)			
	Vans N1 (**30,080,656**)			
	Heavy-duty vehicles N2+N3 (**5,998,915**)			

An analysis conducted in May 2025 showed an increase of 25% for battery electric vehicles and 16% for hybrid electric vehicles, while plug-in hybrid electric vehicles saw an increase of 46.9%.

By the end of May 2025, registrations of gasoline-powered cars had decreased by 20.2%, with the largest markets recording declines. France saw the biggest drop in registered vehicles at 34.3%, followed by Germany (-26.1%), Italy (-15.4%), and Spain (-13.3%).

With 1,305,525 newly registered cars, the market share of gasoline-powered vehicles dropped to 28.6%, down from 35.6%. The number of diesel-powered cars also declined by 26.6%, resulting in a market share of 9.5% in May 2025 since the beginning of the year. Year-on-year analyses compared to May 2025 indicate a decrease of 18.6% for gasoline and 27.6% for diesel vehicles.

Modern technologies aim to increase fuel efficiency and reduce harmful exhaust emissions, especially CO_2, whose emission is regulated by law, and any exceedance is penalized.

Alternative powertrain systems powered by natural gas

Natural gas as an engine fuel is gaining an increasing share in energy consumption, as evidenced by the fact that there are over 28 million natural gas vehicles (NGVs) worldwide.

Natural gas vehicles are powered by IC engines, and natural gas is stored on them under pressure either as compressed natural gas (CNG) or as liquefied natural gas (LNG). The main advantages of using natural gas as fuel for motor vehicles in traffic are as follows (Nylund et al., 2014; Spoof-Tuomi et al., 2022):

- Due to its low carbon (C) content compared to gasoline or diesel fuel, the combustion of natural gas produces lower amounts of CO_2, nitrogen oxides (NOx), and sulfur; emissions of particulate matter and smoke are also lower.
- Natural gas can be used in gasoline engines without major technical issues, while diesel engines require certain conversions.
- The production cost of natural gas is significantly lower compared to gasoline and diesel, and operating costs of NGV fuel are also lower, among other benefits.
- If biomethane is used, the amount of harmful substances in combustion products is further reduced.
- Natural gas has higher resistance to knocking (its octane number is about 105).

One example of a natural gas bus subsystem is the MAZ-BIK 203CNG-S bus, produced in Kragujevac (Figure 3). The use of such buses instead of conventional diesel-powered ones can significantly contribute to reducing noise emissions and harmful exhaust gases. From this perspective, the implementation of such buses has been initiated in larger cities (Milojević et al., 2025).



Figure 3. *Low-floor city bus powered by CNG MAZ-BIK 203CNG-S on bus route 74 in GSP Belgrade*

Such a propulsion system can also be applied to minibuses in the public passenger transport system, following the door-to-door model.

DOOR-TO-DOOR TRANSPORTATION MODEL IN SMART CITIES

The door-to-door transportation model for ecological and cleaner urban transport relies on modern information systems and may include several key components (Marinković et al., 2024):

- Integration of different modes of transport: Combining public transport, bicycles, walking, and electric vehicles to enable flexibility and easy access to various options;

- Travel planning applications: Developing mobile apps that allow users to plan their journeys using different modes of transport, with the option to choose more environmentally friendly alternatives;
- Bicycle and pedestrian paths: Building and improving infrastructure for cyclists and pedestrians to encourage citizens to use these modes of transport;
- Electric vehicles and car sharing: Promoting electric cars and vehicle-sharing services to reduce harmful gas emissions;
- Incentives for public transport use: Introducing subsidies or affordable fares for public transport users to encourage more people to choose it over private cars;
- Education and awareness: Organizing campaigns to raise awareness about the benefits of environmentally sustainable transport and its impact on the environment;
- Green corridors: Developing green corridors throughout the city exclusively for public transport, bicycles, and pedestrians, thus reducing congestion and pollution.

This model requires collaboration between local authorities, transport companies, and citizens in order to achieve sustainable urban transport solutions.

The essence of this transportation model includes main bus routes supported by auxiliary routes, where minibuses transport passengers to the main routes. The proposed system is flexible regarding the bus categories, as well as the number of secondary routes and passengers. The system can also be adapted for the use of electric-powered vehicles or autonomous vehicles, as shown in Figure 4 (Iclodean et al., 2020).

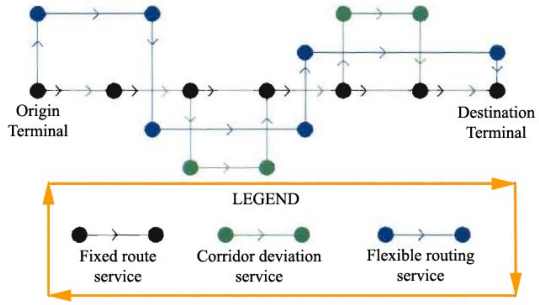


Figure 4. *Flexible routes in a door-to-door transportation system*

The goal of introducing such a transportation system is to reduce congestion on city streets, which should directly translate into lower fuel consumption and consequently reduce harmful gas emissions and noise pollution. Based on a medium-sized city with 100,000 vehicles, a 50% reduction in the use of passenger vehicles is expected by the sixth year of implementing the door-to-door transportation system.

CONCLUSION

In smart cities, the application of modern technologies is essential, as well as means of transportation whose management is based on artificial intelligence and machine learning methods.

The implementation of the door-to-door transportation model with eco-friendly buses should contribute to reducing the number of cars on the streets, thus lowering fuel consumption and exhaust gas emissions, as well as noise pollution.

The use of minibuses with alternative propulsion systems powered by natural gas and electricity also contributes to increased driving ergonomics and facilitates transportation for people with special needs.

REFERENCES

Adikaram, W. D. C. N., & Arambepola, C. (2025). Occupational hazard to on-road air pollution within passenger transport micro-environments: Evidence from traffic congested areas in Colombo, Sri Lanka. *BMC Public Health, 25*(1), 2253. https://doi.org/10.1186/s12889-025-23480-y

Babić, D., Kalić, M., Janić, M., Dožić, S., & Kukić, K. (2022). Integrated Door-to-Door Transport Services for Air Passengers: From Intermodality to Multimodality. *Sustainability*, *14*(11), 6503. https://doi.org/10.3390/su14116503

Bošković, G., Cvetanović, A. M., Jovičić, N., Jovanović, A., Jovičić, M., & Milojević, S. (2024). Digital Technologies for Advancing Future Municipal Solid Waste Collection Services. In F. Theofanidis, O. Abidi, A. Erturk, S. Colbran, & E. Coşkun (Eds.), *Digital Transformation and Sustainable Development in Cities and Organizations* (pp. 167-192). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3693-3567-3.ch008

Iclodean, C., Cordos, N., & Varga, B. O. (2020). Autonomous Shuttle Bus for Public Transportation: A Review. *Energies*, *13*(11), 2917. https://doi.org/10.3390/en13112917

Kluge, U., Paul, A., Urban, M., & Ureta, H. (2019). Assessment of passenger requirements along the door-to-door travel chain. In B. Müller & G. Meyer (Eds.), *Towards user-centric transport in Europe* (Lecture Notes in Mobility (pp. 255-276) Springer, Cham. https://doi.org/10.1007/978-3-319-99756-8_17

Maniotis, G., Spyropoulos, G., & Christopoulos, K. (2023). The Footprint of Road Transport Emissions: Electric Vehicles and Their Impact on Air Pollution Reduction in Greece. *Environmental Sciences Proceedings*, *26*(1), 146. https://doi.org/10.3390/environsciproc2023026146

Marinković, D., Dezső, G., & Milojević, S. (2024). Application of Machine Learning During Maintenance and Exploitation of Electric Vehicles. *Advanced Engineering Letters*, *3*(3), 132-140. https://doi.org/10.46793/adeletters.2024.3.3.5

Milojević, S., Glišović, J., Savić, S., Bošković, G., Bukvić, M., & Stojanović, B. (2024). Particulate Matter Emission and Air Pollution Reduction by Applying Variable Systems in Tribologically Optimized Diesel Engines for Vehicles in Road Traffic. *Atmosphere*, *15*(2), 184. https://doi.org/10.3390/atmos15020184

Milojević, S., Stopka, O., Orynycz, O., Tucki, K., Šarkan, B., & Savić, S. (2025). Exploitation and Maintenance of

Biomethane-Powered Truck and Bus Fleets to Assure Safety and Mitigation of Greenhouse Gas Emissions. *Energies, 18*(9), 2218. https://doi.org/10.3390/en18092218

Miron, R., Hulea, M., & Rusu, A. (2024). Integrated services for passenger transportation in smart cities based on blockchain. In J. Machado et al. (Eds.), *Innovations in industrial engineering III. ICIENG 2024. Lecture Notes in Mechanical Engineering* (pp. 381-391). Springer, Cham. https://doi.org/10.1007/978-3-031-61582-5_32

Nylund, N., Karvonen, V., Kuutti, H., & Laurikko, J. (2014). *Comparison of diesel and natural gas bus performance* (SAE Technical Paper 2014-01-2432). https://doi.org/10.4271/2014-01-2432

Pooley, C. G., & Pooley, M. E. (2022). Mobility change over time. In *Everyday mobilities in nineteenth- and twentieth-century British diaries* (Studies in Mobilities, Literature, and Culture (pp. 55-80). Palgrave Macmillan. https://doi.org/10.1007/978-3-031-12684-0_3

Reji, A. K., Das, B., Ray, T. K., et al. (2025). Assessment of compressed natural gas as an alternative transportation fuel in reducing CO2 emission: A case of Agartala city. *Environmental Development and Sustainability*. https://doi.org/10.1007/s10668-024-05777-x

Skrúcaný, T., Milojević, S., Semanová, Š., Čechovič, T., Figlus, T. & Synák, F. (2018). The Energy Efficiency of Electric Energy as a Traction Used in Transport. *Transport technic and technology*, *14*(2), 2018. 9-14. https://doi.org/10.2478/ttt-2018-0005

Skrucany, T., Semanova, S., Milojević, S., & Ašonja, A. (2019). New Technologies Improving Aerodynamic Properties of Freight Vehicles. *Applied Engineering Letters, 4*(2), 48–54. https://doi.org/10.18485/aeletters.2019.4.2.2

Spoof-Tuomi, K., Arvidsson, H., Nilsson, O., & Niemi, S. (2022). Real-Driving Emissions of an Aging Biogas-Fueled City Bus. *Clean Technologies*, *4*(4), 954-971. https://doi.org/10.3390/cleantechnol4040059

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HOW GREEN IS YOUR ALGORITHM? ASSESSING THE CARBON FOOTPRINT OF MACHINE LEARNING

Abstract: *The rapid advancement of machine learning (ML) and its extensive application across various fields have led to numerous innovative uses. However, large-scale ML systems require significant computational resources, energy usage, and result in associated carbon emissions, which have raised some concerns. ML can combat climate change with smart decision-making, but energy-intensive models like deep learning also impact the environment. In this paper, we applied the CodeCarbon, an open-source tool for estimating energy consumed and carbon dioxide (CO_2) emissions during the runs of ML models (Linear Regression, k-Nearest Neighbors Regressor, and Decision Tree Regressor). Both default and optimized models show low CO_2 emissions, with optimization resulting in slightly higher values. The impact of geographical locations related to the carbon intensity of electricity generation on emissions is also examined, along with the effects of utilizing the complimentary cloud service GoogleColab. Due to low emissions, applied ML algorithms are suitable for education, research, and practice. The increasing use of artificial intelligence (AI) highlights tracking of carbon emissions, even in lightweight ML algorithms, to introduce sustainable AI practices. The aim of this paper is to raise awareness of the energy and environmental cost of AI at all levels of research.*

Keywords: sustainable AI, carbon footprint, machine learning models, CodeCarbon, GoogleColab

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INTRODUCTION

Over recent decades, the increasing occurrence of extreme weather events (storms, droughts, wildfires, and floods) has underscored the destructive consequences of climate change. Global emissions of greenhouse gases (GHG) have continued to increase over the past several decades, despite widespread scientific agreement on the importance of reducing these emissions. Comprehensive response to tackle climate change involves both mitigation and adaptation strategies. Recent rapid scientific and technological developments have increased the application of artificial intelligence (AI) in various sectors to address climate change, including energy, transportation, industry, land use, and disaster resilience (Kaack, 2021). Machine learning (ML), a branch of AI, is increasingly used in predicting, classifying, approximating, and optimizing climate datasets for real-time monitoring, trend forecasting, and risk estimation (Olawade, 2024a). Although AI is widely recognized as an appropriate tool for achieving sustainability and net-zero emissions (Olawade, 2024b; Rolnick et al., 2019; Vinuesa, 2020), there is evidence that its role is twofold. ML training and a vast number of parameters tuning (as in deep learning and large language models) can be time and energy demanding. The iterative training and hyperparameter tuning of ML architectures are computationally intensive, leading to increased electricity consumption and higher GHG emissions (Strubell 2020). Many scientists suggest shifting the focus from achieving high accuracy to achieving high efficiency, due to the extensive use of AI with significant computational costs and large carbon footprints (Schwartz, 2020; Bergstra, 2011). According to the Intergovernmental Panel on Climate Change (IPCC) projections, limiting carbon emissions to 2 metric tons of CO_2 [1]equivalent per person per year is necessary to maintain the global temperature rise below 1.5°C (IPCC, 2023). Emissions of 100 megatonnes of CO_2 per year produced by data centers and high-performance computing (HPC) facilities could have a major impact on climate change in the future (Lannelongue 2021, Luccioni, 2023; Strubell, 2019, Lannelongue, 2023, Bannour, 2021, Dodge, 2022, Henderson, 2020). Energy consumption is linked

[1] The CO_2 equivalent or CO_2eq is a metric measure used to compare the emissions from various GHG based on their Global Warming Potential (GWP), by converting amounts of other gases to the equivalent amount of CO_2 with the same GWP.

to various activities, including the production of computer hardware, model development, data storage, data transfer, data processing, and cooling of large data centres. According to research, NVIDIA's new AI servers are projected to consume more energy than Argentina and Sweden by 2027 (Dayarathna, 2015; Xing, 2023). Since improvements in hardware, software and algorithms have significantly enhanced scientific research, there is an estimation of 9 billion hours spent on scientific computing in 2020, but the computational cost of such research activities and contribution of GHG emissions has not been completely explored (Extreme Science and Engineering Discovery Environment XSEDE). Also, to assess the AI environmental impact, it is important to know what kind of electricity is generated in a country − renewable or non-renewable. The uneven distribution of renewable and non-renewable electricity sources worldwide results in a significant AI carbon footprint for some countries (Electricity Maps). This raises a critical question: are we considering AI, on its current path, as sustainable? Concerns about the potentially huge negative environmental impact of AI in the future have established a new sustainable approach−green AI. As the name suggests, Green AI promotes performance/efficiency trade-off, reduction of computational cost, and reasonable use of resources (renewable energy sources) (Alzoubi, 2024; Schwartz 2020). Various tools can estimate GHG emissions during machine learning runs, including Green-Algorithms, CodeCarbon, Eco2AI, CarbonTracker, MLCO2, and Cumulator. Various studies summarise different methods for measuring energy consumption and emissions associated with computing activities (Bouza et al.). 2023, Lannelongue 2023).

This paper utilizes CodeCarbon to estimate the carbon footprint during the execution of three machine learning algorithms: Linear Regression, k-Nearest Neighbors Regressor, and Decision Tree Regressor. CodeCarbon is an open-source tool designed to estimate the amount of CO_2 produced by the cloud or personal computing resources used to execute the code (CodeCarbon). Since energy efficiency and carbon emissions have become a critical issue in ML research and deployment, our aim was to compare emissions from both default and optimized ML algorithms and support sustainable, energy-efficient AI practices, particularly in education, by tracking CO_2 emissions. The European Federation of Academies of Sciences and Humanities reports that the emission of CO_2 equivalents per scientist per year ranges from 1 to 30 tonnes (ALLEA 2022), accounting for emissions from computing, laboratories (LEAF framework), supply chains, conferences, and other related activities. Although ML algorithms commonly used in education (by students, academics, researchers, practitioners, etc.) have a low and moderate complexity (unlike deep learning and large language models with billions of parameters), the impact they may have in the future due to increasing use should be investigated. Although the results indicate that CO_2 emissions from some machine learning algorithms are significantly lower than those generated by GPT training (552 tCO_2eq) (Patterson, 2021), our objective is to raise awareness of the energy and environmental costs associated with AI tools at all levels of research. However, most ML applications in industry and education rely on simpler models like Linear Regression and Decision Trees. Their carbon footprint is often considered negligible and ignored. This paper aims to fill that gap by quantifying and analysing emissions from lightweight models using the CodeCarbon library.

METHODOLOGY

CodeCarbon is an open-source library simply implemented in Python code. This tool tracks the emission of CO_2 during the ML run. Emission of CO_2 is the product of the carbon intensity of electricity generation (a given country) and energy consumed. Carbon intensity is a known amount of CO_2 emitted for each kilowatt-hour (kWh) of electricity generated, calculated as a weighted average of the emissions from the different energy sources fossil fuels (coal, petroleum, natural gas) and renewable (solar power, hydroelectricity, biomass, geothermal, wind, nuclear, etc.) (Electricity Maps). Carbon intensity is measured as kilograms (or grams) of CO2 emitted per kilowatt-hour of electricity (kg/kWh). Energy consumed (quantified as kWh) is the amount of electrical energy used by the computational infrastructure (machine) during the execution of the code.

CO_2eq emissions (kg) = carbon intensity (kg/kWh) X energy consumed (kWh)

CodeCarbon uses global carbon intensity of electricity per country, representing average value from the previous year. Electricity in Serbia is primarily generated from non-renewable sources, leading to a carbon intensity of 0.671 kgCO2eq/KWh. This is higher compared to Norway and Switzerland, which have carbon intensities of 0.031 kgCO2eq/KWh and 0.037 kgCO2eq/KWh, respectively (Ember). Carbon intensity of electricity generation defines emissions, and for the same energy consumption ML application in Serbia produce more than 20 times higher emission than in Norway and Switzerland. Figure 1a) shows global carbon intensity of electricity generation in Europe for 2024, and 1b) annually carbon intensity values for Serbia during the period from 2000 to 2024. The values are shown in grams (g).

CodeCarbon measures energy consumption from three main hardware parts: Graphics Processing Unit (GPU), Central Processing Unit (CPU) and memory. Energy consumption by CPU can be estimated using two methods. The first method estimates energy consumption multiplying training duration by thermal design power – TDP, representing the maximum amount of power that CPU or GPU can dissipate when operating at maximum performance. The second method uses software integrated tool Running Average Power Limit (RAPL) which monitors and controls the

power usage of the processor and its components (Bouza, 2023). Efficiency of the computing facility or Power Usage Efficiency (PUE) is the efficiency coefficient of the data centre. Recommended PUE value for personal computers is 1. In this experiments ML training and testing are performed on the same hardware setup to ensure comparability. Training carried out with an Intel Core i5 processor (CPU), integrated GPU and 16 GB RAM (Table 1).

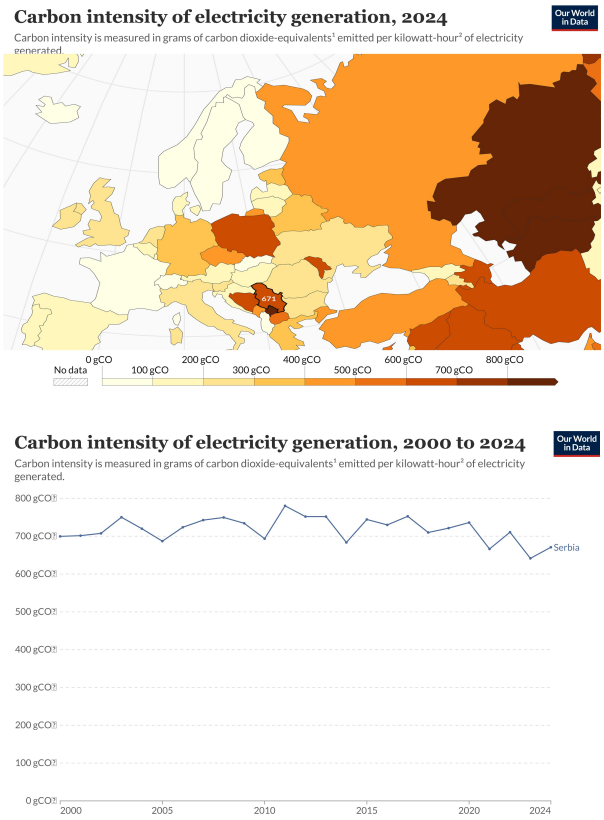


Figure 1. a) *Carbon intensity of electricity generation per country (average values for 2024). Carbon intensity for Serbia is 671 gCO2.eq/KWh. b) Carbon intensity for Serbia during the period from 2000 to 2024. Source: Ember (2025); Energy Institute - Statistical Review of World Energy (2024).*

Default and optimized version of three ML algorithms (Linear Regression, k-Nearest Neighbors Regressor, Decision Tree Regressor) is evaluated by CodeCarbon to assess CO_2 emission. In a regression model, the output as a dependent variable is obtained as a function of the independent input variable (Alpaydın, 2010). ML training is performed using supervised learning which is based on a dataset of input and corresponding output data. Training set consists of pairs of input and associated output data. ML algorithms reach a defined performance level when the difference between the actual output and the anticipated output becomes minimal.

Linear Regression is an easy, understandable, interpretable and applicable model with low computational complexity and fast training. Linear regression assumes a linear relationship between variables and usually does not perform well with complex, non-linear data. The fitting line is obtained using the least squares method (which minimizes the difference between the anticipated and the actual values). In an optimized linear regression model, generalization is enhanced, and overfitting is reduced, allowing minimal energy consumption.

The *k-Nearest Neighbors Regressor* is a non-parametric model, applicable for complex relationships. It is adaptable to different data types and easy easy-to-implement model. k-Nearest Neighbors predicts a value of new data based on its similarity to nearest data in the training set, e.g., assumes that nearest objects are similar (Altman, 1992). Its performance varies significantly with data size and dimensionality, and with large datasets algorithm can be computationally expensive. The optimization focuses on dimensionality reduction and efficient searching, which reduces inference time and memory usage, leading to lower energy demand of the optimized model.

Decision Tree Regressors uses a tree-like structure to make predictions by splitting data into subsets. A decision tree is composed of internal decision nodes and terminal leaves. A decision tree predicts responses to data by following the decisions in the tree from the root (beginning) down to a leaf node. A tree consists of branching conditions where the value of a predictor is compared to a trained weight. During the training number of branches and the values of weights are set (Alpaydın, 2010). Decision Tree Regressors can predict continuous values of variables and deal with non-linear relationships, but it is prone to overfitting and requires carefully selected data. Optimizations such as reducing, limiting maximum tree depth, and setting minimum sample thresholds per node effectively control model complexity, reduce training time, and enhance interpretability, contributing to a measurable decrease in energy usage.

Energy consumption during runs of default and optimized ML models, and during the optimization processes are compared. For all ML algorithms, optimized models have shown lower emission and energy consumption in comparison with the initial default models. In all cases, emissions during the optimization processes were higher by few orders of magnitude The optimization process sets the best parameters to maximize the accuracy of a ML model, but it is often time- and energy-intensive.

RESULTS AND DISSCUSSION

The database for supervised training was taken from the UC Irvine Machine Learning Repository site (archive) that represents a collection of continuous and ordinal data types. Linear Regression, k-Nearest Neighbors Regressor and Decision Tree Regressor are trained and optimized using this dataset. Data are used offline i.e. data are downloaded and stored locally, to avoid repetition and additional energy costs (from data transmission and data center compute loads).

To estimate the carbon footprint of machine learning runs, experiments were conducted using open-source Python software within the PyCharm environment, with the CodeCarbon library activated to monitor emissions. For our purpose CodeCarbon library is confirmed as the straightforward solution. Application of CodeCarbon tool was effortlessly, and the data are recorded in a separate file. CodeCarbon measurement starts simultaneously with the ML run and stops when ML run terminates. All ML runs were performed at hardware characteristics described in Table 1. Also, GoogleColab environment is used to compare CO_2 emissions.

Table 1. *Hardware characteristics*

CPU	Intel(R) Core(TM) i5-9500 CPU @ 3.00GHz
RAM	16GB
GPU	iGPU
Location	Serbia, SRB
OS	Windows-10-10.0.19045-SP0
Python_version	3.13.2
CodeCarbon version	2.8.2003
tracking_mode	machine

The hardware components that consume the most energy include: Central Processing Unit (CPU), Graphics Processing Unit (GPU), and RAM. Usually, a CPU uses more energy than RAM (Henderson, 2020). Contribution to GHG emission by other hardware elements, such as storage and network can be considered negligible. CodeCarbon tool cannot measure energy consumption of non-NIVIDIA GPUs. Estimation of energy consumption by hardware defined in Table 1, should be considered as a conservative (we assume that iGPU contribution is small). Results of energy consumed by hardware parts (CPU and RAM) during the Linear Regression runs (Figure 2) confirm the previous conclusion. The difference between CPU and RAM energy consumption is around one order of magnitude.

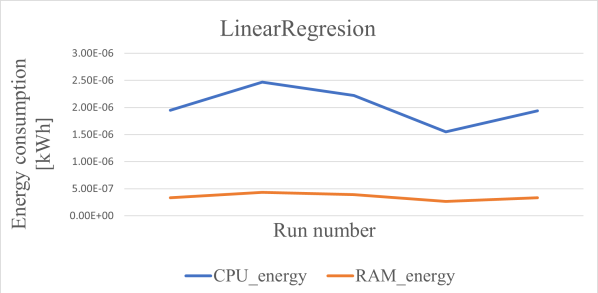


Figure 2. *Energy consumed by components during the Linear Regression run (values shown on the y axis in kWh). CPU energy consumption is around 10 times more than the energy consumed by RAM.*

Energy consumption during the run of default and optimized model, as well as the optimization process for the three applied ML algorithms are compared. To reach defined accuracy ML algorithm should be tailored to the problem that needs to be solved by tuning parameters.

Optimization process implies parameters adjustment to improve predictive performances, balance the bias-variance trade off, enhance generalization, and efficiency. Optimized models ensure stability and maintain efficiency in real-world applications. Generally, it performs faster and shows more sustainable features. However, the optimization process can be time and energy demanding. Is it worth to rise energy consumption to optimize ML models? It depends on the purpose. For intensive and long-term ML usage, optimization can be a more sustainable solution, because an optimized model in the long run can provide a smaller emission. If machine learning algorithms are intended for short-term use—such as in educational contexts like lectures or exercises—where high precision and extensive parameter tuning are not essential, it is worth considering whether model optimization is necessary or if the default configuration is sufficient to solve the given task.. ML algorithms with moderate complexity and small training set, and consequently negligible emissions, are very suitable for educational purposes, but there is no need to perform many iterations to achieve high precision.

Linear Regression is a simple ML model, easy to train. Energy consumption of Linear Regression training and testing is minor. In comparison of energy consumption by default and, optimized model, as well as the optimization process, it is obvious that the difference is not worthy of consideration. Negligible CO_2 emissions of Linear Regression make it very appropriate for multiple applications in different fields, regarding responsible and sustainable AI. It is appropriate for applications in education, industry, engineering, statistics, biostatistics, etc. In education, it is a core to statistics and introductory ML courses, and for teaching interpretability and inference models. Linear Regression has various applications in industry and engineering in forecasting, strategies, trend analysis, predicting system performance, control system modelling, thermal system modelling, stress-strain modelling in materials, etc. (Freedman, 2009; James, 2013). Also, it is applicable in high-dimensional biological and medical data.

Three parameters of the k-Nearest Neighbors Regressor are adjusted during the optimization process: n_neighbors, which determines model complexity; leaf_size, which controls the size of leaf nodes in tree-based neighbor searches; and p, which determines the distance metric used. The best performing model had values n_neighbors = 10 (the number of nearest neighbors), leaf_size = 20 (optimizes neighbor search efficiency without affecting accuracy), and p = 3 (Minkowski distance). Parameters n_jobs = 1 indicates runs on a single core (serial processing). The results obtained for both the default and optimized models indicate exceptionally low emissions (Figure 3). The accuracy of models with different parameters (default or the best) varies. The optimized model (with the best

parameters) provides significantly higher accuracy. As we expected (Figure 3), the emission of optimization (orange line) is higher due to retraining. The optimized model (grey line) exhibits the lowest emissions, with the least execution time and energy consumption. These results confirm that processes of parameter tuning can be more carbon intensive, but the optimized model has one order of magnitude lower emissions than the default model. This conclusion is significant for the training of deep learning and large language models, as their emissions can be higher (Lacoste, 2019; Henderson, 2020; Strubell, 2019).

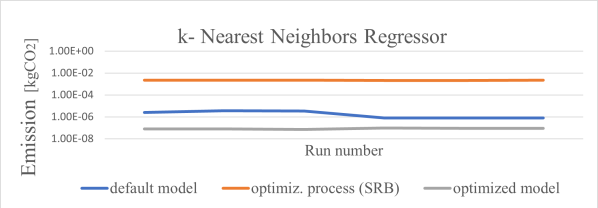


Figure 3. *k-Nearest Neighbors Regressor emissions of CO_2 during the runs of the default model (blue line), and optimized model (grey line), as well as during the optimization process (orange line).*

Bearing in mind that the k-Nearest Neighbors Regressor, produces negligible emissions, optimization for achieving high accuracy may be performed, without a meaningful impact on the environment. K-Nearest Neighbors is a straightforward algorithm commonly used in education, computational chemistry (for predicting molecular properties), medical imaging, remote sensing, nonlinear regression, and other fields. In education, it is suitable for teaching the concept of ML learning based on similarity, and for demonstrating overfitting and model complexity. The negligible carbon footprint of this algorithm encourages its applications in both industry and engineering for recommender systems, fraud detection, sensor data interpolation, and image processing.

Decision Tree Regressor follows the same pattern of emissions between default and optimized models and the optimization process (Figure 4). Parameters are adjusted to define a regularized, shallow decision tree that prioritizes robustness and generalization. The best suited parameters are criterion = absolute_error (the splitting criterion for evaluating the quality of a split, encourages robust predictions), max_depth = 2 (limits the maximum depth to 2 levels and reducing model complexity), and max_leaf_nodes = 3 (limits the number of terminal nodes and controls overfitting). This combination of parameters resulted in a straightforward and interpretable model that emphasizes robustness. The model with optimal parameters is significantly more accurate than the default model. The emission of the default model (blue line) is slightly higher than for the optimized model (grey line). As anticipated, the optimization process involves increased computational effort and results in higher emissions (represented by the orange line). Decision Tree Regressor optimization process shows a slightly higher emissions than k-Nearest Neighbors Regressor, but the accuracy of the optimized model is remarkably better than for the default. This algorithm requires adaptation to the problem by adjusting the parameters. Even though model optimization results in higher emissions, it should be optimized if the model is intended for long-term use. As previous ML models with negligible carbon emissions, this algorithm is also appropriate for education, especially for introducing concepts of model interpretability and as a base for learning more complex algorithms (for example, Random Forests). It is widely used across industries for purposes such as fault detection, performance prediction, medical diagnostics, ecology, and more.

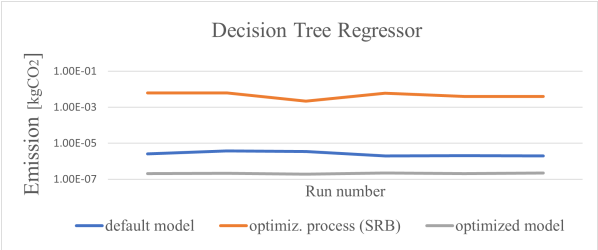


Figure 4. *Decision Three Regressor emissions of CO_2 during the runs of default model (blue line), and optimized model (grey line), as well as during the optimization process (orange line).*

Estimation of emissions and carbon footprint should draw attention to concerning current issue - the increasing use of AI in education, science, and in everyday life by millions of people. We usually approach computing resources as if they are limitless, but they are constrained in energy and environmental costs. This paper tracks the footprint of ML algorithms used to study basic principles of ML by solving specific tasks for a master's thesis. Emissions of default and optimized ML models are very small (< 1 μg CO_2eq), and the optimized models have one order of magnitude less emission than default, for both algorithms. Optimization processes for both algorithms (k-Nearest Neighbors and Decision Tree) perform more slowly, last longer, and show higher emissions (by several orders of magnitude). Higher emissions of optimization may have different origin that should be investigated (even if the model is lightweight, performing a large number of operations can extend runtime and memory usage, leading to higher overall energy consumption and emissions). If the optimization is run on a machine powered by a high-carbon-intensity grid (e.g., coal-heavy), even small increases in energy usage result in large increases in CO_2 equivalent emissions.

To compare emissions for different regions, we selected a country with a low carbon intensity value, Norway (Figure 5 and Figure 6). Figures 5 and 6 illustrate a decline in emissions by an order of magnitude when the location is changed from Serbia to Norway. The carbon intensity of electricity generation in Norway (0,031 kgCO2eq/KWh) is significantly lower than in Serbia (0,671kgCO2eq/KWh), primarily

due to the predominance of renewable energy sources. Used ML algorithms are simple, and their optimization may not have a major impact on emissions, but when we deal with complex hyperparametric ML architectures at high carbon intensity locations, optimization becomes a concerning issue.

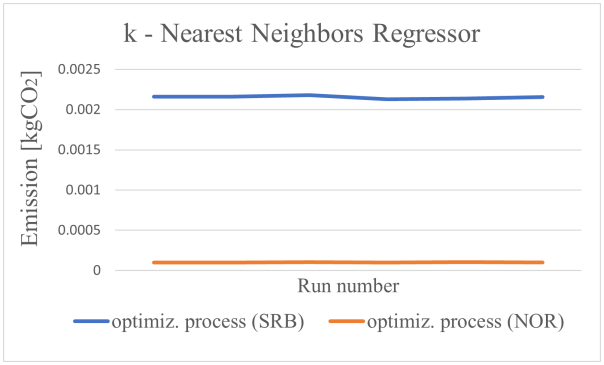


Figure 5. *Comparison of k – Nearest Neighbors Regressor emissions during the optimization processes at two selected locations: Serbia (blue line) and Norwegian (orange line).*

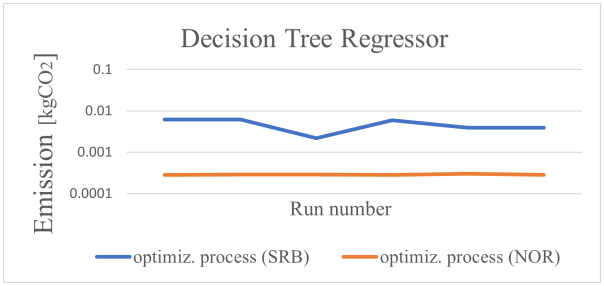


Figure 6. *Comparison of Decision Tree Regressor emissions during the optimization processes at two selected locations: Serbia (blue line) and Norwegian (orange line).*

Although energy consumption and emissions during the training and run of three applied ML algorithms are negligible, tracking carbon footprint is the first step toward fostering environmentally responsible AI. It should be kept in mind that the rapid development of computer technology and various algorithms can have notable environmental costs. In problem solving, scientists, practitioners, and other users typically emphasize accuracy without considering the energy expended during multiple iterations and trial-and-error processes. Each new run can be computationally intensive and energy demanding, particularly for complex algorithms with hyperparameters. Optimized models can be more accurate, and less energy intensive, but higher emissions during the optimization process are a critical issue. Complex algorithms may overfit, and optimization does not always guarantee improved accuracy. Numerous open questions regarding to parameter tuning, algorithm efficiency, and introduction of new ML practices require detailed analysis. Prioritizing cost-benefit or accuracy-efficiency issues is the first step in the responsible AI application. The AI life cycle's carbon footprint encompasses manufacturing, transport, distribution, dataset creation, transfer, and storage. Training AI models is just a small part.

To illustrate this statement GoogleColab is used as a cloud-based environment. GoogleColab is a widely used resource, with data centers located around the world. Cloud-based environments offer accessible platforms for ML experiments by supplying virtual machines in large-scale data centers. However, it is not possible to choose a server for data processing during the environment creation. In the GoogleColab environment, there are certain restrictions for the user (administrator rights, access to RAPL files, actual insight into hardware resources).

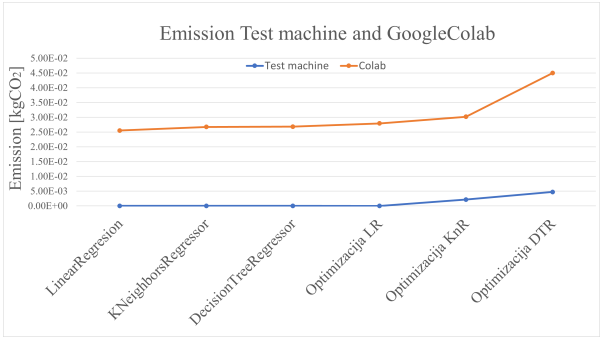


Figure 7. *Comparison of emissions for the test machine and GoogleColab during the runs of three ML algorithms and their optimizations.*

Emission report by GoogleColab includes energy consumption by full infrastructure: cooling, networking, data storage, etc. CodeCarbon estimates emissions based on actual energy consumption during the local execution of code, measuring CPU, GPU, and memory usage, along with execution time and regional carbon intensity of electricity (Lacoste et al., 2019). GoogleColab reports emissions for the entire duration that a virtual machine is distributed, regardless of the duration of actual computation runs. In our experiment, this virtual machine remains active for more than 40 minutes, even if the computation takes only seconds on the test machine. Decision Tree Regressor optimization took three times longer, and accordingly energy cost and emission had higher values. However, as shown in Figure 7, carbon emissions reported by GoogleColab are 2 orders of magnitude higher than those estimated by local tools CodeCarbon, even for short computations. This discrepancy is primarily due to different accounting, because GoogleColab estimates the true environmental cost of cloud resources, including both active and idle power usage. This estimation represents the hidden carbon costs of AI development and infrastructure (Strubell et al., 2019; Schwartz et al., 2020). A new sustainability challenge in ML practice is including emissions from passive infrastructure used in local measurements. It is of great importance, since data centers consume more electricity, accounting for 3% of global electricity supply and 2% of total GHG emissions, and this percentage is continuously growing (to 14% of the

world's emissions by 2040, according to estimation of Thangam et al., 2024 and IEA).

Numerous questions about AI use need to be answered in the future, including carbon footprint over the life cycle, encompassing manufacturing, transport, product use and recycling (Wu, 2021; Guo, 2022).

CONCLUSION

In this paper, we estimated CO_2 emissions associated with the training of three commonly used machine learning (ML) algorithms Linear Regression, k-Nearest Neighbors Regressor, and Decision Tree Regressor, applied to educational tasks for a small dataset. We proposed CodeCarbon as a simple, easy-to-implement tool suitable for estimating the environmental cost of ML run. Our analysis showed that default models produce extremely low emissions (around 10^{-7} to 10^{-6} $kgCO_2eq$), and optimized models even lower (around 10^{-8} $kgCO_2eq$). However, the optimization process itself has higher environmental cost, with emissions rising by a few orders of magnitude (around 10^{-4} to 10^{-3} $kgCO_2eq$). Further, we compared CodeCarbon estimation with those from GoogleColab, a popular cloud-based platform. Emissions reported by Colab are consistently two orders of magnitude higher. This discrepancy can be explained by the resource distribution, idle compute supply, and infrastructure inherent to cloud services, which local estimators like CodeCarbon do not include. These results underline the importance of transparent, and conscious emission tracking. Responsible use of ML implies applications of low-impact computation (employing lightweight ML as it is satisfactory), local resources when it is feasible, minimizing unnecessary optimization cycles, and selection of algorithms that balance accuracy and energy efficiency. As AI becomes increasingly personalized and embedded into global infrastructure, responsible development must prioritize the performance/efficiency trade-off. Although the numerous algorithms (such as those used in this paper) have a minor carbon footprint, their scaling and increasing presence across daily life, science, industry, agriculture, medicine, business, etc., amplify overall energy requirements. Therefore, it is crucial to treat ML emissions not as a separate issue but within the broader context of the expanding digital environment.

Recommendations and Future Directions

The forward path requires intensive action toward the development of green, environmentally responsible AI, to ensure long-term societal and ecological feasibility. AI practitioners should pay attention to using available ML tools thoughtfully, avoiding unnecessary optimization, improving optimization efficiency, considering energy-efficient algorithms and hardware. In addition, they should select local computation over cloud platforms and use renewable energy sources and low-carbon regions when feasible. It would be particularly useful to analyze emissions during the ML run using tools such as CodeCarbon and report results in a research paper along with other results.

Future work should be expanded and based on the analysis of different hardware environments, larger datasets, and a broader range of algorithms, including deep learning models.

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REFERENCES

ALLEA (2022) *Towards Climate Sustainability of the Academic System in Europe and Beyond*. Berlin. ISBN: 978-3-9823967-1-2. DOI 10.26356/climate-sust-acad. https://allea.org/wp-content/uploads/2022/05/ALLEA-Report-Towards-Climate-Sustainability-of-the-Academic-System.pdf (accessed: May 2025)

Altman, N. S. (1992). *An Introduction to Kernel and Nearest-Neighbor Nonparametric Regression*. The American Statistician, 46, pp. 175–185. https://doi.org/10.1080/00031305.1992.10475879

Alpaydın, E. (2010). Introduction to machine learning (2nd ed.). MIT Press. ISBN 978-0-262-01243-0

Alzoubi, Y. (2024). *Green artificial intelligence initiatives: Potentials and challenges*. Journal of Cleaner Production. 468, 143090. https://doi.org/10.1016/j.jclepro.2024.143090

Bannour, N., et al. (2021). *Evaluating the carbon footprint of NLP methods: a survey and analysis of existing tools*. In Proceedings of the Second Workshop on Simple and Efficient Natural Language Processing, pages 11–21. https://aclanthology.org/2021.sustainlp-1.2/

Bergstra, J., et al. (2011). *Algorithms for Hyper-Parameter Optimization*. Advances in Neural Information Processing Systems. 24. Eds J. Shawe-Taylor, R. Zemel and P. Bartlett, F. Pereira, K. Q. Weinberger https://proceedings.neurips.cc/paper_files/paper/2011/file/86e8f7ab32cfd12577bc2619bc635690-Paper.pdf

Bouza, G., et al. (2023). *How to estimate carbon footprint when training deep learning models? A guide and review*. Environmental Research Communications. 5, 115014. https://iopscience.iop.org/article/10.1088/2515-7620/acf81b

CodeCarbon. https://codecarbon.io/ (accessed: March 2025)

https://mlco2.github.io/codecarbon/index.html (accessed: March 2025)

Dayarathna, D., et al. (2015). *Data center energy consumption modeling:A survey*. IEEE Communications Surveys & Tutorials, 18, pp. 732–794. DOI: 10.1109/COMST.2015.2481183.

Dodge, J., et al. (2022). *Measuring the Carbon Intensity of AI in Cloud Instances*. Proceedings FAccT '22: Proceedings of the 2022 ACM Conference on Fairness, Accountability, and Transparency June 21 - 24. https://doi.org/10.1145/3531146.3533234.

Electricity Maps. https://www.electricitymaps.com/

Ember (2025); Energy Institute - Statistical Review of World Energy (2024). https://ember-energy.org/latest-insights/global-electricity-review-2025/(accessed: May 2025)

Freedman, D. (2009). *Statistical Models: Theory and Practice* 2nd. Cambridge University Press. https://doi.org/10.1017/CBO9780511815867.

Google Colab, https://colab.research.google.com/(accessed: March 2025)

Guo, B., et al. (2022). *Energy-efficient database systems: A systematic survey*. ACM Computing Surveys, 55, 1–53. https://dl.acm.org/doi/10.1145/3538225

Henderson, P., et al. (2020). *Towards the Systematic Reporting of the Energy and Carbon Footprints of Machine Learning*. Journal of Machine Learning Research 21 pp. 1-43. https://jmlr.org/papers/v21/20-312.html.

The International Energy Agency (IEA) https://www.iea.org/energy-system/buildings/data-centres-and-data-transmission-networks?mod=livecoverage_web&utm_source=chatgpt.com (accessed: May 2025)

IPCC. (2023). Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, 184 pp., https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_FullVolume.pdf

James, G. et al. (2013). *An introduction to statistical learning* 112. New York: Springer. ISBN 978-1-0716-1417-4 https://doi.org/10.1007/978-1-0716-1418-1

Kaack, L. H., et al. (2022). *Aligning artificial intelligence with climate change mitigation*. Nature Climate Change 12, pp. 518–527. https://doi.org/10.1038/s41558-022-01377-7

Lacoste A, et al. (2019). *Quantifying the carbon emissions of machine learning*. https://arxiv.org/abs/1910.09700

Lannelongue, L., et al. (2021). *Green Algorithms: Quantifying the Carbon Footprint of Computation*. Advanced Science. 8, 2100707. https://doi.org/10.1002/advs.202100707

Lannelongue, L., & Inouye, M. (2023). *The carbon footprint of computational research*. Nature Computational Science 3, 659. https://doi.org/10.1038/s43588-023-00506-2

LEAFframeworkTake part in LEAF | Sustainable UCL - UCL –University College London https://www.ucl.ac.uk/sustainable/case-studies/2020/aug/take-part-leaf (accessed: May 2025)

Luccioni, A., et al. (2023). *Estimating the carbon footprint of BLOOM, a 176B parameter language model*. The Journal of Machine Learning Research. 24 pp. 11990 - 12004 https://dl.acm.org/doi/10.5555/3648699.3648952.

Olawade, D., et al. (2024)a. Artificial intelligence in environmental monitoring: Advancements, challenges, and future directions. Hygiene and Environmental Health Advances, 12, Article 100114. https://doi.org/10.1016/j.heha.2024.100114

Olawade, D., et al. (2024)b. Artificial intelligence potential for net zero sustainability: Current evidence and prospects. Next Sustainability, 4, 100041. https://doi.org/10.1016/j.nxsust.2024.100041.

Patterson, D. et al., (2021). *Carbon Emissions and Large Neural Network Training*. Machine Learning. https://doi.org/10.48550/arXiv.2104.10350.

Rolnick, D., et al., (2019). Tackling climate change with machine learning. ACM Computing Surveys. 55 pp. 1-96. https://doi.org/10.1145/3485128

Schwartz, R. et al., (2020). *Green AI*. Communications of the ACM, 63, pp. 54-63. https://doi.org/10.1145/3381831.

Strubell, E., et al. (2019). *Energy and Policy Considerations for Deep Learning in NLP*. Proceedings of the 57th Annual Meeting of the Association for Computational Linguistics, p. 3645–3650, Florence, Italy. https://aclanthology.org/P19-1355/.

Strubell, E., et al. (2020). *Energy and policy considerations for modern deep learning research*. Proceedings of the AAAI Conference on Artificial Intelligence, 34, pp. 13693-13696. https://doi.org/10.1609/aaai.v34i09.7123.

Thangam, D., et al. (2024). *Impact of Data Centers on Power Consumption, Climate Change, and Sustainability*. In K. Kumar, V. Varadarajan, N. Nasser, & R. Poluru (Eds.), Computational Intelligence for Green Cloud Computing and Digital Waste Management (pp. 60-83). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3693-1552-1.ch004

UC Irvine Machine Learning Repository site https://archive.ics.uci.edu/dataset/320/student+performance

(accessed: March 2025)

Vinuesa, R., et al. (2020). The role of artificial intelligence in achieving the Sustainable Development Goals. *Nature Communications*, 11, p. 233. https://doi.org/10.1038/s41467-019-14108-y

Wang, J., et al. (2022). Sustainable AI: Environmental implications, challenges and opportunities. Machine Learning and Systems, 795–813. https://arxiv.org/abs/2111.00364.

Xing, E. & Monck, A. (2023). *AI emissions are fueling a new doomerism this time it's climate change*.

https://fortune.com/2023/12/12/ai-emissions-doomerism-climate-change-environment-tech/

Wu, C.-J., et al. (2022). *Sustainable AI: Environmental implications, challenges and opportunities*. Machine Learning and Systems. https://arxiv.org/abs/2111.00364

XSEDE Impact – Usage Statistics. (n.d.). Retrieved May 2025, from https://portal.xsede.org/#/gallery

(accessed: May 2025)

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COMPARATIVE ANALYSIS OF DATA SOURCES FOR WILDFIRE MONITORING SYSTEMS

Abstract: *Monitoring wildfire data is essential for risk management and decision-making, given that they seriously threaten ecosystems, economies and human communities. The paper analyzes data on wildfires in the Republic of Serbia obtained from the European Forest Fire Information System (EFFIS), the Global Wildfire Information System (GWIS), and the Statistical Office of the Republic of Serbia. The results show significant differences in the reported number of fires and the burned area, indicating the need for integration of various data sources to obtain a more accurate insight into fire activity. By comparing the methodologies and operational principles of EFFIS and GWIS, this paper provides an overview of their differences, advantages, and limitations. Understanding these differences can contribute to improving wildfire prevention and response both in Serbia and globally. The importance of monitoring different data sources was emphasized to gain a more precise insight into the frequency and spread of fires, as well as to establish a basis for more effective prevention. The monitoring and analysis of this data can contribute to a better understanding of the causes and dynamics of wildfires, with the aim of improving forecasting and timely response.*

Keywords: wildfires, EFFIS, GWIS, number of fires, burned area.

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INTRODUCTION

Monitoring wildfires is of great significance, given that they pose a growing threat to human safety, ecosystem preservation, and the regional economy. In addition, wildfires emit greenhouse gases and affect local air quality. On a global scale, more than 200,000 wildfires occur annually, burning a total area of 3.5 to 4.5 million square kilometers (Hua & Shao, 2017). These effects are exacerbated by climate change, which reduces the moisture content in vegetation, creating favorable conditions for wildfires to ignite. Fire seasons are becoming increasingly longer, wildfires are emerging in areas where they were previously uncommon, and the average fire size is also growing (Artés et al., 2019).

Early and reliable detection and monitoring of wildfires are essential for minimizing potential damage and the costs associated with fire suppression (Hua & Shao, 2017). This process entails not only the identification and characterization of active fire locations, but also the continuous tracking of wildfires throughout their life cycle – including the evaluation of pre-fire fuel conditions and the assessment of post-fire impacts on vegetation, climate, and air quality (Chen et al., 2024).

Historically, wildfire monitoring relied on lookout towers and aerial reconnaissance; however, these methods were limited in their ability to provide continuous observation at continental or global scales. The advent of remote sensing technology, marked by the launch of the first Landsat satellite in the 1970s, enabled early detection and mapping of wildfires (Chen et al., 2024).

Today, systems such as the European Forest Fire Information System (EFFIS), Global Wildfire Information System (GWIS), and Fire Information for Resource Management System (FIRMS) are most commonly used. These platforms enable near real-time active fire data, mapping of affected areas, and the retrieval of various datasets for further analysis.

The European Commission's Joint Research Centre manages both GWIS and EFFIS, platforms that redistribute and visualize hotspot data from Moderate Resolution Imaging Spectroradiometer (MODIS) and Visible Infrared Imaging Radiometer Suite (VIIRS), originally provided by FIRMS, along with other fire-related datasets such as fire weather forecasts and burned area statistics. These systems offer fire-related insights at the global level (GWIS) and for the European Union and neighboring countries (EFFIS). Similar to FIRMS, both GWIS and EFFIS generate updated spatial data products on an hourly basis,

depending on the availability of data from MODIS and VIIRS (Hope et al., 2024).

This paper will focus on the EFFIS and GWIS systems, examining their similarities, differences, and capabilities. For comparison, wildfire data available for the Republic of Serbia from 2019 to 2023 will be used.

EUROPEAN FOREST FIRE INFORMATION SYSTEM (EFFIS)

The European Forest Fire Information System was created by the European Commission (EC) in partnership with national fire administrations to assist those responsible for forest fire protection in the EU and neighbouring countries, and to offer the EC and the European Parliament consistent data on forest fires across Europe. In 2015, EFFIS was integrated as one of the elements of the Emergency Management Services within the EU Copernicus program. Specific applications available through EFFIS include the Current Situation Viewer, Current Statistics Portal, Firenews, Long-term fire weather forecast and Wildfire Risk Viewer (European Forest Fire Information System [EFFIS], n.d.).

The system is structured into modules that cover all phases of the fire cycle: the pre-fire phase, which supports fire prevention and preparedness; the active fire phase; and the post-fire phase, which focuses on evaluating the impact of forest fires – including land cover damage, atmospheric emissions, soil degradation, and erosion. In addition to these modules, the European Forest Fire Database stores data contributed by EFFIS network members, currently encompassing 43 countries across Europe, North Africa, and the Middle East (Monteiro et al., 2013).

The system features several key modules that support this process, starting from the pre-fire phase (EFFIS):

1) Fire Danger Assessment;
2) Rapid Damage Assessment, which involves:
   - Active fire detection;
   - Fire severity assessment;
   - Land cover damage assessment;
3) Emissions Assessment and Smoke Dispersion;
4) Potential Soil Loss Assessment;
5) Vegetation Regeneration.

The first two modules, Fire Danger Assessment and Rapid Damage Assessment, are available in near-real time through the Current Situation Viewer application.

As mentioned, for active fire detection, EFFIS uses satellite sensors MODIS and VIIRS.

The MODIS sensor is located on the TERRA satellite (originally known as EOS AM-1) and the AQUA satellite (originally known as EOS PM-1). The orbit of the TERRA satellite around Earth is timed so that it passes from north to south over the equator in the morning. In contrast, AQUA passes from south to north over the equator in the afternoon. This arrangement ensures that the same area of the Earth is observed both in the morning and in the afternoon, allowing for the monitoring of changes throughout the day. MODIS detects a wide spectrum of electromagnetic energy and performs measurements at three spatial resolutions: 200, 500, and 1000 meters (Modis_brochure, n.d.). The spatial resolution of the active fire detection pixel from MODIS is 1 km (EFFIS).

The VIIRS 375m thermal anomalies/active fire product provides data from the VIIRS sensor aboard the joint NASA/NOAA Suomi National Polar-orbiting Partnership (Suomi NPP) and NOAA-20 satellites. The 375 m data complements MODIS fire detection. Both MODIS and VIIRS products demonstrate strong consistency in detecting hotspots. However, the enhanced spatial resolution of the VIIRS 375 m data product offers better detection of smaller fires and more precise mapping of large fire boundaries. Additionally, this product performs better at night. As a result, it is highly suitable for fire management applications, such as real-time alert systems, and scientific research requiring more accurate fire mapping (NASA Earthdata, n.d.).

EFFIS locates wildfires based on so-called thermal anomalies they produce. Using algorithms, the temperature of the potential fire is compared to the temperature of the surrounding land. If the temperature difference exceeds a predefined threshold, the potential fire is confirmed as an active fire or "hot spot". To reduce false alarms and exclude active fires that are not classified as wildfires (such as agricultural burnings), EFFIS displays only a filtered selection of hotspots detected by FIRMS. This filtering is based on a knowledge-based algorithm that considers factors like nearby land cover types, proximity to urban and artificial areas, and the confidence level of each hotspot. Using the identify feature tool, users can access key information for each active fire, including its geographic coordinates, administrative location (commune and province), and the predominant land cover type affected (EFFIS).

In addition to this information, EFFIS also provides data on the number of fires and the burned area for a given time period. Table 1 presents these data for the Republic of Serbia for the period from 2019 to 2023.

Table 1. *Burned area (ha) and number of fires in Serbia (2019-2025) (EFFIS)*

Year	Burned area (ha)	Number of fires
2019	15763	103
2020	9385	90
2021	7006	61
2022	11508	104
2023	2312	23

The highest number of fires was recorded in 2022 (104), while the largest burned area occurred in 2019, amounting to 15,763 ha. In contrast, the lowest number of fires was reported in 2023 (23), which also had the smallest burned area, amounting to 2,312 ha.

For the monitoring of burned areas, EFFIS utilizes a combination of high spatial resolution data – primarily MODIS at 250 m, along with Sentinel-2 imagery (at 10

– 20 m resolution), enabling more detailed analysis of fire-affected regions. MODIS captures the perimeters of burned areas for fires approximately 30 hectares or larger. Since 2018, the integration of Sentinel-2 imagery has allowed for the mapping of smaller fires (under 30 hectares) and the refinement of final fire perimeters initially delineated using MODIS 250 m imagery (EFFIS, Copernicus Atmosphere Monitoring Service, 2024).

The process of burned area detection in EFFIS involves comparing satellite imagery of the affected region before and after the wildfire. For this purpose, the so-called Normalized Burn Ratio (NBR) is used. NBR is commonly applied and is calculated based on satellite imagery to support the identification of burned areas. Specifically, the difference in NBR values (dNBR) between the two images is used to detect changes on the Earth's surface. The dNBR is calculated by subtracting the post-fire NBR value from the pre-fire NBR value, as shown in Equation 1 (Suárez-Fernández et al., 2024).

$$dNBR = NBR_{prefire} - NBR_{postfire} \quad (1)$$

The purpose of calculating dNBR is to assess fire severity (Arisanty et al., 2022). Positive dNBR values indicate burned areas, with higher values corresponding to more severe vegetation damage (Copernicus Atmosphere Monitoring Service, 2024; Suárez-Fernández et al., 2024).

The dNBR index also provides information on post-fire vegetation dynamics, so negative dNBR values indicate vegetation regeneration following a fire (Llorens et al., 2021).

The process of mapping burned areas within the EFFIS system is based on a semi-automatic procedure. Initial fire mapping is carried out using a combination of spectral band thresholds and auxiliary information, such as data from the CORINE Land Cover database, active fire detection products from MODIS and VIIRS sensors, and fire news applications. After the initial detection, the fire maps are visually verified and corrected using imagery from MODIS and Sentinel-2 satellites (EFFIS).

GLOBAL WILDFIRE INFORMATION SYSTEM (GWIS)

The Global Wildfire Information System (GWIS) is a collaborative initiative under the Group on Earth Observation (GEO) and the Copernicus Work Programs. It aims to provide comprehensive and up-to-date wildfire monitoring, assessment, and forecasting on a global scale. GWIS integrates existing regional and national information sources to offer a comprehensive global assessment of fire regimes and their impacts. GWIS builds on the ongoing activities of the EFFIS, the Global Terrestrial Observing System (GTOS), Global Observation of Forest Cover – Global Observation of Land Dynamics (GOFC-GOLD), Fire Implementation Team (GOFC Fire IT), and the associated Regional Networks. It complements global wildfire information–gathering initiatives by integrating and enhancing existing activities. Currently, GWIS is made of five applications (Global Wildfire Information System [GWIS], n.d.): Current Situation Viewer, Current Statistics Portal, Country Profile, Long-term fire weather forecast and Data & Services.

GWIS operates in a similar manner to EFFIS, with the primary distinction being that EFFIS is focused on Europe, whereas GWIS is a global system. However, although both platforms utilize MODIS and VIIRS data, discrepancies in the number of recorded fires and burned areas may occur. Table 2 presents data on the number of fires and burned areas in the Republic of Serbia, as reported by GWIS, for the same time period from 2019 to 2023.

Table 2. *Burned area (ha) and number of fires in Serbia (2019-2025) (GWIS)*

Year	Burned area (ha)	Number of fires
2019	171753	568
2020	28824	141
2021	34886	155
2022	26587	133
2023	31211	132

A clear discrepancy exists between the data on the number of fires and burned areas in the Republic of Serbia reported by EFFIS and GWIS. These differences can be attributed to the use of different methodologies for fire mapping. The EFFIS methodology for Near-Real-Time (NRT) identification of fire events incorporates MODIS 250 m and Sentinel-2 imagery, which means that the number of fires corresponds to the number of burned areas mapped by EFFIS. In contrast, the GWIS methodology is based on the spatial-temporal clustering of thermal anomalies detected by MODIS and VIIRS. Fires mapped in GWIS may include deliberately ignited fires for vegetation management purposes, which helps explain the discrepancies in the number of fires identified by EFFIS and GWIS (GWIS).

The data available in GWIS are derived according to the GlobFire methodology, which uses the MODIS burned area product (MCD64A1) to define fire events and calculate burned areas for each event. This product integrates satellite imagery from both Terra and Aqua platforms with thermal anomaly data, and delivers pixel-level information on burn extent and data quality. GWIS GlobFire data are not available in real time, as the underlying MCD64A1 product typically requires about two months for processing and release. Additionally, the recorded start and end dates of fire events are subject to a temporal uncertainty of several days (GWIS).

It is also important to note that the definition of a fire event differs between GlobFire and EFFIS. In EFFIS, the same burned area originating from two separate ignition sources is classified as two distinct fire events. In contrast, GlobFire treats it as a single event if two fires remain active within a five-day period and their

burned areas overlap or are contiguous (Artés et al., 2019).

Table 3 summarizes the key methodological differences between EFFIS and GWIS.

Table 3. *Comparison of EFFIS and GWIS Wildfire Monitoring Systems*

Characteristic	EFFIS	GWIS
Geographic scope	Europe, Mediterranean region	Global
Active fire detection	MODIS (1 km), VIIRS (375 m)	MODIS (1 km), VIIRS (375 m)
Burnt Areas	MODIS 250 m + Sentinel-2 Imagery	MODIS MCD64A1
Burnt Area Mapping Method	Semi-automatic classification with visual verification	Fully automatic processing from MCD64A1 burned area product
Update Frequency	Near-real time (daily for active fires, verified weekly)	Seasonal/global updates (not real-time)
Validation Process	Yes – visual inspection and manual correction	No – fully automated
Fire Event Definition	Two ignition points = two fires, even if areas merge	Merged areas within 5 days = one fire
Minimum Fire Size Mapped	~30 ha (due to filtering and validation threshold)	<10 ha possible (high sensitivity, no filtering)

These differences in methodology, approach, and objectives between the two systems contribute significantly to the discrepancies in the reported number of fires and the total estimated burned area. Therefore, data from EFFIS and GWIS should be interpreted in light of their respective frameworks and limitations.

ANALYSIS OF WILDFIRE DATA FROM EFFIS, GWIS, AND THE STATISTICAL OFFICE OF SERBIA

In addition to the data provided by EFFIS and GWIS, official statistics on the number of wildfires and burned areas should also be taken into account.

For the sake of comparison, data from the Statistical Office of the Republic of Serbia on the number of fires and burned areas for the period 2019 to 2023 are also presented.

According to the Statistical Yearbook of the Republic of Serbia (2024), the total forested area in the Republic of Serbia amounts to 2,854,956 hectares. Of this, 42% (1,191,466 ha) is under state ownership, while 58% is privately owned. Furthermore, the Statistical Office of the Republic of Serbia reports that a total of 159 wildfires were recorded in both state-owned and privately owned forests during the period from 2019 to the end of 2023 (Gavrilović, 2024).

In comparison, EFFIS data indicate a total of 381 fires during the same period, while GWIS reports a significantly higher number – 1129 fire events.

The data on the number of wildfires and the burned area, as reported by the Statistical Office of the Republic of Serbia for the specified period, are presented in Table 4.

Table 4. *Burned area (ha) and number of fires in Serbia (2019-2023) (*Statistical Office of the Republic of Serbia*)*

Year	Burned area (ha)	Number of fires
2019	1079	41
2020	196	26
2021	834	34
2022	423	45
2023	192	13

For the purpose of data comparison, Figures 1 and 2 present the number of wildfires and the burned area in Serbia, as reported by EFFIS, GWIS, and the Statistical Office of the Republic of Serbia for the period 2019 – 2023.

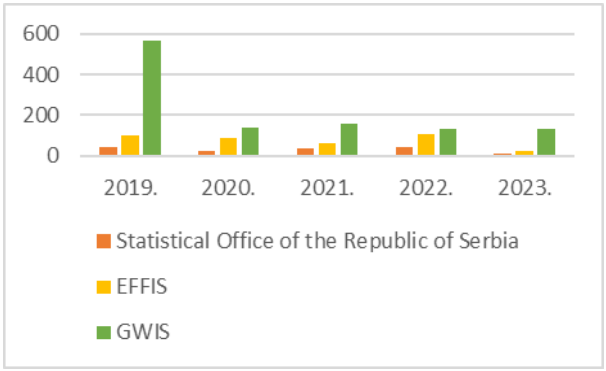


Figure 1. *Number of fires (Statistical Office of the Republic of Serbia, EFFIS, GWIS)*

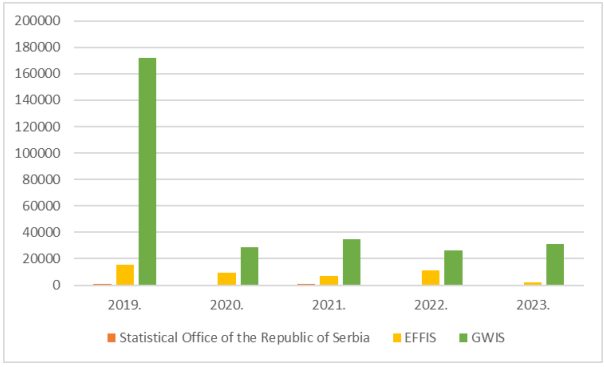


Figure 2. *Burned area (ha) (Statistical Office of the Republic of Serbia, EFFIS, GWIS)*

The discrepancies in the number of wildfires and the burned area during the 2019 – 2023 period can be attributed to the fact that the official data provided by

the Statistical Office of the Republic of Serbia likely include only reported fires or those that required firefighting intervention. On the other hand, EFFIS and GWIS detect wildfires based on thermal anomalies, which may also capture smaller fires such as agricultural burns, waste burning, and similar activities.

Another limitation affecting the reliability of burned area and active fire data is the fact that most currently operational Earth Observation (EO) sensors are not specifically designed for wildfire monitoring. For example, active fires may be falsely detected due to highly reflective surfaces that mimic the thermal signature of fires by reflecting sunlight. Regarding burned areas, rapid vegetation regrowth in certain ecosystems (such as grasslands and croplands) can obscure recent fire evidence. Additionally, it is particularly challenging to develop algorithms that perform well at the global scale due to regional differences in vegetation, climate, and fire behavior (Chen et al., 2024).

CONCLUSION

The comparison of wildfire monitoring systems, EFFIS and GWIS, based on available data on the number of fires and burned areas in the Republic of Serbia for the period 2019–2023, revealed significant discrepancies between the two systems. These differences can be attributed to several factors. First, the systems rely on different satellite data sources. Specifically, for burned area estimation, EFFIS utilizes MODIS 250 m and Sentinel-2 imagery, whereas GWIS relies on the MODIS MCD64A1 product. In addition to differences in sensors, the data processing methodologies also vary. The EFFIS process is semi-automated and includes visual verification, which contributes to higher mapping accuracy but may result in underestimation of the total burned area. In contrast, GWIS employs a fully automated algorithm that can more easily detect very small fires, though it lacks precision in delineating their spatial extent.

These differences are also evident in the detection of active fires. GWIS applies spatial-temporal clustering of thermal anomalies to identify fires, often recording a higher number of events, as each thermal anomaly is treated as a potential fire. In contrast, EFFIS filters detected thermal anomalies and supplements them with additional information, such as news reports and field observations.

The discrepancies between the two systems—including differences in the definition of a “fire” and the criteria for grouping fire events – highlight the importance of careful interpretation of these data. To ensure reliable use of the data for research, decision-making, and risk management, it is essential to understand both the strengths and limitations of each system, as well as the potential for their complementarity.

To improve the accuracy of wildfire detection and analysis, combining data from multiple sources is recommended. Furthermore, integrating satellite-based observations with ground reports and official national statistics can enhance the credibility of analyses. Continued improvement of automatic burned area classification algorithms, along with harmonization of definitions and methodologies between systems, represent key steps toward greater data accuracy and comparability.

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REFERENCES

Arisanty, D., Feindhi Ramadhan, M., Angriani, P., Muhaimin, M., Nur Saputra, A., Puji Hastuti, K., & Rosadi, D. (2022). Utilizing Sentinel-2 Data for Mapping Burned Areas in Banjarbaru Wetlands, South Kalimantan Province. International Journal of Forestry Research, 2022. https://doi.org/10.1155/2022/7936392

Artés, T., Oom, D., de Rigo, D., Durrant, T. H., Maianti, P., Libertà, G., & San-Miguel-Ayanz, J. (2019). A global wildfire dataset for the analysis of fire regimes and fire behaviour. Scientific Data, 6(1). https://doi.org/10.1038/s41597-019-0312-2

Chen, Y., Morton, D. C., & Randerson, J. T. (2024). Remote sensing for wildfire monitoring: Insights into burned area, emissions, and fire dynamics. In One Earth (Vol. 7, Issue 6, pp. 1022–1028). Cell Press. https://doi.org/10.1016/j.oneear.2024.05.014

Copernicus Emergency Management Service. (n.d.). About EFFIS. European Forest Fire Information System (EFFIS). https://forest-fire.emergency.copernicus.eu/about-effis

Copernicus Emergency Management Service. (n.d.). Active fire detection. European Forest Fire Information System (EFFIS). https://forest-fire.emergency.copernicus.eu/about-effis/technical-background/active-fire-detection

Copernicus Emergency Management Service. (n.d.). Rapid damage assessment. European Forest Fire Information System (EFFIS). https://forest-fire.emergency.copernicus.eu/about-effis/technical-background/rapid-damage-assessment

Gavrilović, D. (Ed.). (2024). Statistical Yearbook of the Republic of Serbia, 2024. Statistical Office of the Republic of Serbia. https://www.stat.gov.rs/sr-cyrl/publikacije/publication/?p=15984&tip=2

Hope, E. S., McFayden, C. B., de Jong, M. C., Crowley, M. A., Johnston, J. M., Davies, D. K., Olsina, O., Hewson, J., San-Miguel-Ayanz, J., Ferrari, D., & Sloane, M. (2024). Exploring the use of satellite Earth observation active wildland fire hotspot data via open access web platforms. International Journal of Digital Earth, 17(1). https://doi.org/10.1080/17538947.2024.2420821

Hua, L., & Shao, G. (2017). The progress of operational forest fire monitoring with infrared remote sensing. Journal of Forestry Research, 28(2), 215–229. https://doi.org/10.1007/s11676-016-0361-8

Joint Research Centre. (n.d.). Active fire detection. Global Wildfire Information System (GWIS). https://gwis.jrc.ec.europa.eu/about-gwis/technical-background/active-fire-detection

Joint Research Centre. (n.d.). Burnt areas. Global Wildfire Information System (GWIS).

https://gwis.jrc.ec.europa.eu/about-gwis/technicalackground/burnt-areas

Llorens, R., Sobrino, J. A., Fernández, C., Fernández-Alonso, J. M., & Vega, J. A. (2021). A methodology to estimate forest fires burned areas and burn severity degrees using Sentinel-2 data. Application to the October 2017 fires in the Iberian Peninsula. International Journal of Applied Earth Observation and Geoinformation, 95. https://doi.org/10.1016/j.jag.2020.102243

Modis_brochure. (n.d.). NASA's Earth Observing System.

Monteiro, A., Corti, P., San Miguel-Ayanz, J., Miranda, A. I., & Borrego, C. (2013). The EFFIS forest fire atmospheric emission model: Application to a major fire event in Portugal. Atmospheric Environment, 84, 355–362. https://doi.org/10.1016/j.atmosenv.2013.11.059

NASA Earthdata. (n.d.). VIIRS I-Band 375 m Active Fire Data. NASA. https://www.earthdata.nasa.gov/data/instruments/viirs/viirs-i-band-375-m-active-fire-data

NASA. (n.d.). Active fire data. Fire Information for Resource Management System (FIRMS). https://firms.modaps.eosdis.nasa.gov/active_fire/

Statistical Office of the Republic of Serbia. (2020). Damages to forests, 2019 (Statistical Release SU10, No. 140).

Statistical Office of the Republic of Serbia. (2021). Damages to forests, 2020 (Statistical Release SU10, No. 137).

Statistical Office of the Republic of Serbia. (2022). Damages to forests, 2021 (Statistical Release SU10, No. 138).

Statistical Office of the Republic of Serbia. (2023). Damages to forests, 2022 (Statistical Release SU10, No. 147).

Statitical Office of the Republic of Serbia. (2024). Damages to forests, 2023 (Statistical Release SU10, No. 147).

Suárez-Fernández, G. E., Martínez-Sánchez, J., & Arias, P. (2024). Assessment of vegetation indices for mapping burned areas using a deep learning method and a comprehensive forest fire dataset from Landsat collection. Advances in Space Research. https://doi.org/10.1016/j.asr.2024.12.001

Zhang, P., Hu, X., Ban, Y., Nascetti, A., & Gong, M. (2024). Assessing Sentinel-2, Sentinel-1, and ALOS-2 PALSAR-2 Data for Large-Scale Wildfire-Burned Area Mapping: Insights from the 2017–2019 Canada Wildfires. Remote Sensing, 16(3). https://doi.org/10.3390/rs16030556

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ASSESSING THE PROBABILITY OF CARCINOGENIC RISK CAUSED BY PM_{10} AND $PM_{2.5}$ PARTICLES IN THE CITY OF NIŠ

Abstract: *Analysis of air quality in the city of Niš indicates a presence of increased concentrations of pollutants in outdoor air. In the period from 2019 to 2023 air quality in the area of the city of Niš was in the category of excessively polluted air, because of increased concentrations of PM_{10} and $PM_{2.5}$ particulate matter. Multiple exceedances of the limit and tolerance values of PM_{10} and $PM_{2.5}$ particulate matter are the basis for the emergence of a health risk that manifests itself through various types of pathological conditions. The physicochemical properties and chemical composition of PM_{10} and $PM_{2.5}$ particulate matter are the criteria for classifying these particles as carcinogenic substances. This paper presents the probability of the occurrence of cancerous diseases during exposure to suspended PM_{10} and $PM_{2.5}$ particles. The risk of cancer development (Ri) was determined based on intake dose and unit risk. The calculated probability is in the range of the level of possible and the level of probable carcinogenic risk, depending on the length of exposure. The probability was determined using the methodology provided by US EPA.*

Keywords: PM_{10} and $PM_{2.5}$ particulate matters, health risk, cancer risk, unit risk, exposure

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INTRODUCTION

Air pollution results from a series of complex and interrelated occurrences and processes, connected in terms of content, space, time and developmental origin. In the process of air pollution, one occurrence often leads to the emergence of another (e.g. air pollution – decreased air quality – increased health risks).

The analysis of air quality in the Republic of Serbia indicates the dominant impact of suspended PM_{10} and $PM_{2.5}$ particles on air pollution. Certain global studies indicate that the composition of suspended PM_{10} and $PM_{2.5}$ particles in urban environments most commonly includes: Si, Al, Ca, K, Fe, Zn, Na, Mg, Cu, Ba, Ti, V, Mn, Cr, Ni, As, Pb, NO^{3-}, SO_4^{2-}, NH_4^+, Cl^- and polycyclic aromatic hydrocarbons (Xue, 2021; Roy et al., 2019). Increased concentrations of heavy metals and metalloids (Cr, As, Ni, Pb, Cd) and certain polycyclic aromatic hydrocarbons in outdoor ambient air, which constitute suspended PM_{10} and $PM_{2.5}$ particles, increase the risk of cancer development.

Suspended PM_{10} and $PM_{2.5}$ particles in outdoor ambient air also increase the risk of respiratory and cardiovascular diseases. It was estimated, using the model Alpha–RiskPoll (ARP), that the presence of fine suspended particles in the air in Serbia leads to 4,261 hospitalizations annually due to respiratory issues and 5,144 hospitalizations due to cardiovascular problems, and has resulted in 9,773 premature deaths (Government of the Republic of Serbia, 2022). $PM_{2.5}$ emissions in the Republic of Serbia in 2019 amounted to 45.6 kt $PM_{2.5}$, an increase of 2.3% compared to 2015. Total $PM_{2.5}$ and PM_{10} emissions have been increasing since 2015. According to the Air protection program in the Republic of Serbia for the period 2022–2030 with an Action Plan (Government of the Republic of Serbia, 2022), the prescribed limit values for suspended particles in outdoor ambient air, from a health risk perspective, were exceeded at 15 out of 32 analysed locations in the Republic of Serbia in 2019. Multiple exceedances of the limit values for suspended particles in outdoor ambient air were also recorded in the city of Niš, which is the third largest city in the Republic of Serbia with approximately 250,000 inhabitants. The dominant emissions of suspended particles in the area of Niš are a result of the combustion of fossil fuels used for the operation of heating plants and for heating individual buildings. Suspended particle emissions also originate from traffic and the application of specific technological processes in industry.

METHODS

Concentrations of suspended PM_{10} and $PM_{2.5}$ particles in the area of Niš are recorded above the daily and annual permitted limit values. In the air quality monitoring network of the city of Niš, concentrations of suspended PM_{10} and $PM_{2.5}$ particles are monitored at two measuring locations (Figure 1), the Institute of Public Health Niš and the "Sveti Sava" primary school.

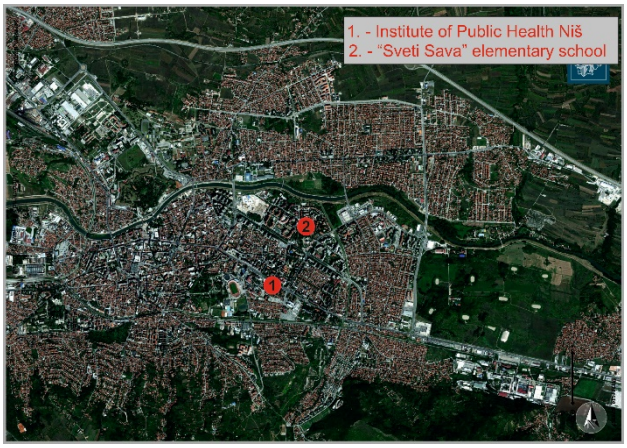


Figure 1. *Location of measuring points where PM_{10} and $PM_{2.5}$ particles are monitored in the city of Niš*

In accordance with the Law on Air Protection of the Republic of Serbia, (National Assembly of the Republic of Serbia, 2009), the air quality in the city of Niš, observed over the period from 2019 to 2023 is classified into the third category (excessively polluted air) due to elevated concentrations of suspended PM_{10} and $PM_{2.5}$ particles (Environmental Protection Agency, 2024).

The causality between the occurrence of air pollution and health risks can be analysed based on the database formed through continuous monitoring of pollutant concentrations. Health risk is defined as the probability of occurrence of adverse health effects in humans, which depend on exposure to a specific concentration of a pollutant and the duration of exposure to that substance in the air. Exposure refers to the relationship between the concentration of a specific pollutant in the air and the time interval of exposure to that pollutant and is defined by the following equation (Đorđević et al., 2013):

$$E = \int_{t_1}^{t_2} C(t)\,dt, \qquad (1)$$

where: E – exposure magnitude [mg/m^3/time], C(t) – pollutant concentration as a function of time [mg/m^3], and t_2-t_1 – duration of exposure [ED]. ED is the continuous time period of exposure (Đorđević et al., 2013).

The assessment of health risk, according to the methodology of the US EPA, is specifically determined for the exposure of a given individual to carcinogenic and non-carcinogenic substances, starting with the calculation of the intake dose (Đorđević et al., 2013; Đorđević & Stevanović, 2020; Greene & Morris, 2006):

$$Intake\ dose = C_{i,x} \cdot \left(\frac{IR_y}{BW_y}\right) \cdot \left(\frac{ED_i \cdot ET_i \cdot EF_i}{AT_x}\right), \qquad (2)$$

where: $C_{i,x}$ – the concentration of the pollutant substance *x* in the environment *i* [mg/m^3], IR_y – the intake rate (breathing rate) at rest per unit of time for a representative individual in subgroup *y* in the environment *i* [m^3/day], ET_i – the exposure time of the representative individual in the environment *i* [hour/day], EF_i – frequency of exposure [day/year], BW_y – the body weight of the representative individual in the corresponding group, represented as *y* [kg], ED_i – the duration of exposure of the representative individual in the environment *i* [years], and AT_x – the average duration of the pollutant's effect *x* [days].

When assessing the health risk conditioned by an individual's exposure to suspended PM_{10} and $PM_{2.5}$ particles, a separate risk assessment is conducted for the development of carcinogenic diseases and non-carcinogenic diseases, such as respiratory and cardiovascular diseases.

The risk of cancer development is represented by the following equation (Đorđević & Stevanović, 2020; Greene & Morris, 2006):

$$R_i = Intake\ dose \cdot UR, \qquad (3)$$

where: R_i – the risk of cancer development for the *i-th* individual and UR – the unit risk for a substance in the exposure to suspended PM_{10} and $PM_{2.5}$ particles.

RESULTS AND DISCUSSION

The Institute of Public Health Niš monitors the concentrations of suspended PM_{10} and $PM_{2.5}$ particles once a week. Table 1 shows the annual average and maximum concentrations of suspended PM_{10} particles monitored at the "Sveti Sava" primary school and the Institute of Public Health Niš, and the number of days with exceedances of the daily limit values (Table 1).

Table 1. *Measured concentrations of suspended PM_{10} particles for the 2019-2023 period in the city of Niš (Institute of Public Health Niš, 2024)*

Monitoring period	Annual average concentrations [μg/m^3]	Maximum concentrations [μg/m^3]	The number of days with exceedances of the limit values
June 2019 – May 2020	42.5	272.3	90
June 2020 – May 2021	46.3	241.8	119
January – December 2022	44.3	186.9	11
January – December 2023	56.6	217.3	16

In the period from 2019 to 2023, the annual average values of suspended PM_{10} particles were exceeded in relation to the allowed annual exposure limit, which is 40 μg/m^3. In the period from January to December 2023, the concentration of suspended PM_{10} particles was the highest and amounted to 56.6 μg/m^3 (Institute of Public Health Niš, 2024). Analysis of the trend of concentrations throughout the year has shown that high concentrations are present during the heating season. The daily exposure limit for concentrations of suspended PM_{10} particles should not be exceeded for more than 35 days during a calendar year (Government of the Republic of Serbia, 2010). In the period from June 2020 to May 2021, the highest number of days with exceedances of the daily exposure limit was recorded, amounting to 119 days (Institute of Public Health Niš, 2024).

The annual average and maximum concentrations of suspended $PM_{2.5}$ particles were monitored at the measuring site of the Institute of Public Health Niš and presented in Table 2.

Table 2. *Measured concentrations of suspended $PM_{2.5}$ particles for the 2019-2023 period in the city of Niš (Government of the Republic of Serbia, 2010)*

Monitoring period	Annual average concentrations [μg/m^3]	Maximum concentrations [μg/m^3]
June 2019 – May 2020	49.5	246.3
June 2020 – May 2021	41.4	244.7
January – December 2022	34	90.4
January – December 2023	30.9	146.1

In the period from 2019 to 2023, the annual average values of suspended $PM_{2.5}$ particles were exceeded in relation to the allowed annual limit value of 25 μg/m^3. The highest recorded value was 49.5 μg/m^3 in the period from June 2019 to May 2020 (Institute of Public Health Niš, 2024). High concentration values are recorded during the heating season. The number of days with exceedances of the limit values for concentrations of suspended $PM_{2.5}$ particles is not available in the presented database of the Institute of Public Health Niš, which is publicly accessible. The inadequate database, because of a lack of records on the number of days with exceedances of the limit values for suspended $PM_{2.5}$ particles, as well as the insufficient number of measurements for PM_{10} and $PM_{2.5}$ concentrations throughout a calendar year (approximately 50 days), does not allow for a precise and representative assessment of the health risk for the exposed population. Considering that for the analysed time period there is a noticeable upward trend in the annual concentrations of suspended PM_{10} particles and that the annual average concentrations of suspended $PM_{2.5}$ particles are above or near the limit values, the risk assessment was performed with regard to the probability of developing carcinogenic diseases, in line with the trend of concentration changes. During the analysed period, the concentrations of suspended PM_{10} particles were 450% above the allowed daily limit values. The probability of cancer development was determined for increased exposure values relative to the limit values, specifically for 50%, 100%, 150%, and 200%. This was based on the assumption that working-age adults, during normal breathing, were exposed to the substances for 4 hours daily (Table 3).

Table 3. *The probability of developing carcinogenic diseases due to exposure to suspended PM_{10} and $PM_{2.5}$ particles*

Increased concentrations above the limit values	The probability of cancer development due to exposure to PM_{10}	The probability of cancer development due to exposure to $PM_{2.5}$
50%	$5.84 \cdot 10^{-6}$	$3.68 \cdot 10^{-6}$
100%	$7.76 \cdot 10^{-6}$	$4.88 \cdot 10^{-6}$
150%	$9.6 \cdot 10^{-6}$	$6.08 \cdot 10^{-6}$
200%	$12 \cdot 10^{-6}$	$7.3 \cdot 10^{-6}$

The risk of cancer development can be classified into specific categories depending on the probability of carcinogenic diseases occurring in the population exposed to suspended particles. The cancer levels are the following:

- *acceptable cancer risk level* (the risk of cancer development lower than $1 \cdot 10^{-6}$);
- *possible cancer risk level* ($1 \cdot 10^{-6} \sim 1 \cdot 10^{-5}$);
- *probable cancer risk level* ($1 \cdot 10^{-5} \sim 1 \cdot 10^{-4}$);
- *definite cancer risk level* ($> 1 \cdot 10^{-4}$) (Xue, 2021; Idolo et al., 2018).

Based on the calculated probability of cancer risk for the exposed adult population in the city of Niš, it can be stated that the risk falls into the 'possible' category (Table 3). With the increase in daily hourly exposure and with exposure values above 200% relative to the daily limit values, the probability of cancer development can be classified into the category of probable cancer risk, with a probability of 10^{-5}.

CONCLUSION

The noted annual average concentrations of suspended PM_{10} and $PM_{2.5}$ particles in the external ambient air of the city of Niš during the 2019-2023 period were above the prescribed allowable limit values or close to the limit values. High concentrations of suspended PM_{10} and $PM_{2.5}$ particles have caused the air quality in the city of Niš to be classified as excessively polluted. Establishing a causal relationship between air pollution and health risks associated with suspended particles

requires continuous monitoring of concentrations in the outdoor ambient air. As the number of days for monitoring the concentrations of suspended particles in Niš during the calendar year is less than 365 and due to the lack of continuity in monitoring concentrations, as well as the absence of an adequately accessible publicly available database of daily concentrations, the assessment of health risks related to the development of cancerous diseases is disrupted. Considering that the recorded daily average concentrations were multiple times above the allowed limit values, with a rising trend at the annual level, it can be expected that the health risk in Niš in the upcoming period will fall into the 'probable' cancer risk. Based on the trend of annual average concentrations of suspended particles monitored during the 2019-2023 period and the lack of measures to reduce air pollution, it can be expected that in the upcoming years, there will be an increase in the annual average concentrations of fine suspended particles. The probability of cancer development in the exposed adult population, with the increase in annual concentrations of fine suspended particles by 50% to 200%, ranges from $3.68 \cdot 10^{-6}$ to $12 \cdot 10^{-6}$.

REFERENCES

Đorđević, A., Milošević L., & Rašić, M. (2013). Analysis of gaseous substance toxicity assessment, *Safety Engineering*, *3*(1), 17–21.

Đorđević, A., & Stevanović, B. (2020). *Ecological risk* (coursebook, in Serbian). Faculty of occupational safety, University of Niš.

Environmental Protection Agency (2024). Reports on air quality status in the Republic of Serbia from 2019 to 2023 (in Serbian). https://sepa.gov.rs/publikacije/

Government of the Republic of Serbia (2010). Regulation on monitoring conditions and air quality requirements (in Serbian). (Official gazette of the Republic of Serbia, no. 11/2010, 75/2010 and 63/2013). https://pravno-informacioni-sistem.rs/eli/rep/sgrs/vlada/uredba/2010/11/9/reg

Government of the Republic of Serbia (2022). Air protection program in the Republic of Serbia for the period 2022-2030 with an Action Plan (in Serbian). (Official Gazette of the Republic of Serbia, no. 140/2022). https://www.ekologija.gov.rs/sites/default/files/2023-03/en_aq_programme_adopted_version.pdf

Greene, N., & Morris, V. (2006). Assessment of public health risks associated with atmospheric exposure to $PM_{2.5}$ in Washington, DC, USA, *International Journal of Environmental Research and Public Health*, *3*(1), 86–97. https://doi.org/10.3390/ijerph2006030010

Idolo, A., De Donno, A., De Giorgi, M., Bagordo, F., Grassi, T., Serio, F., Ceretti, E., Feretti, D., Villarini, M., Moretti, M., Carducci, A., Verani, M., Bonetta, S., Pignata, C., Bonizzoni, S., Bonetti, A., Gelatti, U., & MAPEC_LIFE Study Group (2018). Health risk associated with exposure to PM_{10} and benzene in three Italian towns. *International Journal of Environmental Research and Public Health*, *15*(8), 1672. https://doi.org/10.3390/ijerph15081672

Institute of Public Health Niš (2024). Annual reports on ambient air quality monitoring in the City of Niš (in Serbian), 2019-2024. https://izjz-nis.org.rs/centar-za-higijenu-i-humanu-ekologiju

National Assembly of the Republic of Serbia (2009). Law on Air Protection (in Serbian). (Official Gazette of the Republic of Serbia, no. 36/2009, 10/2013 and 26/2021 – other law). Paragraf. https://www.paragraf.rs/propisi/zakon_o_zastiti_vazduha.html

Roy, D., Chil Seo, Y., Gyu Namgung, H., & Bark Kwon, S. (2019). Inhalation cancer risk from PM_{10} in the metropolitan subway stations in Korea, *Journal of Transport and Health*, *14*(9), 100580. https://doi.org/10.1016/j.jth.2019.100580

Xue, Q. (2021). Potential risks of $PM_{2.5}$ – bound polycyclic aromatic hydrocarbons and heavy metals from inland and marine directions for a marine background site in north China, *Toxics*, *10*(1), 32. https://doi.org/10.3390/toxics10010032

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DIFFERENCES IN SLEEP QUALITY BETWEEN FIXED AND ROTATING SHIFTS AMONG MORNING AND EVENING TYPES

Abstract: *This study examines sleep quality differences among 154 chemical industry workers (103 males, 51 females) categorized by chronotype (morning/evening) using the Morningness–Eveningness Questionnaire (MEQ). Participants worked either fixed or rotating shifts. The results show significant differences in sleep quality based on shift type and chronotype. Morning chronotypes in fixed morning shifts reported better sleep quality, while evening chronotypes surprisingly benefited from fixed morning shifts, experiencing the best sleep quality compared to those in rotating shifts. The findings highlight the importance of considering both chronotype and shift type when evaluating sleep quality. Circadian rhythm plays a crucial role in regulating sleep patterns, and shift work can disrupt this rhythm, leading to poorer sleep quality. The stability and predictability of fixed shifts provide advantages, even for evening chronotypes, by allowing them to establish routines and improve sleep quality.*

Keywords: chronotypes, shift work, sleep quality, circadian rhythm

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INTRODUCTION

The modern workforce is increasingly shaped by non-traditional work schedules, with shift work becoming indispensable in many industries to ensure uninterrupted operations (Costa, 2003; Caruso, 2014). Among these, the chemical industry is particularly reliant on both fixed and rotating shifts to maintain productivity and safety (Folkard & Tucker, 2003). However, such schedules pose significant challenges to workers' health—especially in terms of sleep quality (Åkerstedt, 2003). Sleep is influenced not only by external factors like work timing but also by internal biological predispositions, most notably chronotype, which reflects an individual's natural tendency toward morningness or eveningness (Adan et al., 2012). Chronotype, regulated by the body's circadian rhythm, determines preferred times for sleep and activity and plays a key role in individual adaptation to different work shifts (Roenneberg et al., 2007). Morning types ('larks') tend to function optimally and feel most alert in the early hours of the day, while evening types ('owls') reach their performance peak later (Horne & Östberg, 1976). When work schedules are misaligned with these intrinsic preferences, sleep disturbances and reduced well-being often result (Vetter et al., 2015). Despite the relevance of this interaction, the relationship between chronotype and shift type—particularly within demanding environments such as the chemical industry—remains insufficiently explored (Knutsson, 2003).

The expansion of a 24-hour economy has led to a rise in shift work, especially in sectors such as manufacturing and other critical industries. Although these schedules are essential for maintaining continuous operations, they disrupt the body's circadian rhythms—the internal biological processes that regulate sleep, metabolism, and cognitive functioning (Gradisar & Lack, 2004). When work hours are misaligned with an individual's internal clock, it increases the likelihood of sleep problems, reduced performance, and various health complications (Sephton & Spiegel, 2003; Smith et al., 1999). Night shifts are particularly problematic because they require workers to remain alert during periods typically reserved for biological rest, causing circadian disruption and related health concerns (Arendt, 2010).

An individual's chronotype plays a significant role in how well they adapt to shift work; evening types generally cope better with night shifts than morning types. Additionally, circadian flexibility—the capacity to adjust to changing schedules—contributes to resilience, with those more adaptable experiencing fewer negative effects (Jehan et al., 2017; De Martino et al., 2013). Night shifts pose specific challenges by forcing alertness during natural rest times, often leading to fatigue and diminished cognitive abilities (Smith et al., 1999). Rotating shifts further intensify this misalignment, heightening health risks and impairing job performance (Arendt, 2010).

Circadian Rhythms and Shift Work

Circadian rhythms regulate various physiological functions, including body temperature, heart rate, and hormone secretion, aligning with environmental cues

such as light exposure and sleep patterns (Korf and von Gall, 2022). Shift work disrupts this synchronization, leading to shift lag syndrome—characterized by fatigue, sleep disturbances, and cognitive impairment (Costa, 2003). Rotating shifts complicate adaptation, as workers struggle to adjust their biological clocks between work and rest days (Horowitz et al., 2001; Dumont et al., 2001). Several strategies help mitigate circadian misalignment, including maintaining consistent sleep schedules, using darkened rooms for daytime sleep, and exposure to bright light during night shifts (Baehr, 1999; Burgess et al., 2002). However, melatonin supplementation has shown inconsistent results in improving shift adaptation (Sharkey et al., 2001, 2002). Recent studies highlight the role of circadian rhythm flexibility in determining shift tolerance, with individuals exhibiting greater adaptability experiencing fewer negative effects (Jafari Roodbandi et al., 2015). Effective shift scheduling can ease circadian adaptation. Forward-rotating schedules (morning-afternoon-night) are generally better tolerated, with recommended shifts lasting no more than 10 hours and allowing at least 11 hours of recovery (Potter and Wood, 2020). Timely exposure to short-wavelength light may enhance adaptation, improving sleep and alertness (Scott et al., 2024; Boivin et al., 2022). The prevalence of shift work has increased significantly, with 15-20% of workers in industrialized nations engaged in non-standard schedules (Ker et al., 2010; Hadler et al., 2018).

Circadian Rhythm and Its Role in Sleep Regulation

Circadian rhythms are intrinsic, 24-hour cycles that orchestrate a wide range of physiological, behavioural, and metabolic processes in the human body, most notably the sleep-wake cycle (Alshahrani & BaHammam, 2017; de Bruijn et al., 2025). These rhythms are governed by a biological clock located in the brain's hypothalamus, which responds to environmental cues such as light and darkness to synchronize bodily functions with the external day-night cycle (Alshahrani & BaHammam, 2017). In the morning, exposure to light signals the brain to suppress melatonin production, promoting wakefulness, while darkness at night triggers melatonin release, preparing the body for sleep (Alshahrani & BaHammam, 2017). The stability and amplitude of circadian rhythms are critical for maintaining high-quality sleep. When these rhythms are robust and well-aligned with the external environment, individuals typically experience restorative sleep and optimal alertness during waking hours (de Bruijn et al., 2025). However, shift work—especially night and rotating shifts—can disrupt the natural synchronization between the internal clock and external cues, leading to circadian misalignment (Kılıç, Koran, & Ağargün, 2023; Alshahrani & BaHammam, 2017). This misalignment not only impairs sleep quality but also affects hormone release, metabolism, and cognitive performance, and is associated with increased risks for various health problems (Kılıç et al., 2023; Alshahrani & BaHammam, 2017). Moreover, the ability to adapt to shift work varies among individuals and is influenced by chronotype, or the natural preference for morning or evening activity. Some people possess more flexible circadian rhythms and can better tolerate irregular schedules, while others are more susceptible to sleep disturbances and excessive sleepiness when their circadian system is disrupted (de Bruijn et al., 2025). Understanding the interplay between circadian biology, chronotype, and work schedules is therefore essential for optimizing sleep health and overall well-being in shift-working populations.

Problem

This study aims to address these gaps by investigating how fixed and rotating shift schedules differentially affect sleep quality among morning and evening chronotypes. Understanding these relationships is crucial for developing tailored shift scheduling strategies that mitigate sleep problems, improve worker health, and enhance productivity.

Variables and Instruments

Circadian rhythmicity is operationalized by the Morningness–Eveningness Questionnaire – MEQ (Horne & Östberg, 1976) and registers the individual's functioning on a continuum from morning, through the so-called intermediate, to the evening optimum, depending on sleeping and waking habits. The mentioned questionnaire distinguishes five types: definitely evening type, moderately evening type, mixed type, moderately morning type, and definitely morning type. The types are determined by adding up the scores on all items and the final result (ranging from 16 to 86 points) determines the position to which the respondent dominantly belongs based on arbitrarily determined scores. The reliability of internal consistency on the initial sample is satisfactory (of medium intensity) and expressed through Cronbach's α coefficient is 0.83.

Sleep quality. The Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989) will be used to measure this variable. The questionnaire consists of 19 items, to which the respondent answers on a four-point Likert-type scale. The scale measures seven dimensions of sleep quality: subjective sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disorders, use of hypnotics, and daytime dysfunction. The global score of the PSQI scale ranges from 0 to 21 points, with a higher score indicating poorer sleep quality. A total score of 5 or above indicates poor sleep quality. Psychometric testing of the PSQI has shown that the questionnaire has good internal consistency and differentiation between good and poor sleepers (Buysse et al., 1989).

Shift work was defined as employment outside standard daytime working hours, specifically involving work during evening or night periods. The frequency and duration of shifts varied within the limits prescribed by labour regulations. For analytical

purposes, shift work was categorized into two main types: fixed shift schedules (comprising morning and night shifts) and rotating shift schedules (including all three shifts or rotating day shifts). These categories were used to explore differences in sleep quality, stress perception, and other relevant psychological outcomes across shift types.

Sample

The sample in this research consisted of *154* chemical industry workers (103 males, 51 females). The age of the respondents ranged from 22 to 58 years. The study utilized a purposive sampling method, selecting participants from employed individuals within the industrial sector.

Procedure and Data Analysis

The survey was conducted in June 2023 at a chemical industry company. Prior to participation, respondents received clear instructions on how to complete the questionnaire and were informed about the purpose of the study, the voluntary nature of their involvement, and the assurance of anonymity. Informed consent was obtained from all participants.

Data analysis was performed using SPSS software. To examine differences in sleep quality between employees working fixed and rotating shift schedules, an independent samples t-test was conducted. Additionally, a one-way analysis of variance (ANOVA) was used to determine whether there were statistically significant differences in sleep quality among three different shift types within a subgroup of workers identified as having a morning chronotype.

RESULTS AND DISCUSSION

The present study examined the impact of shift schedules and chronotype on sleep quality among employees working fixed and rotating shifts. The findings provide important insights into how different shift patterns affect sleep, with implications for occupational health and shift work management.

Hypothesis 1 stated that there would be statistically significant differences in sleep quality between employees working exclusively in fixed shift schedules and those working in rotating shift schedules.

Table 1. *Differences in sleep quality among employees working in fixed and rotating shifts*

Shift Schedule	N	Sleep Quality
Fixed	49	.7423
Rotating	97	.8449
t		-3.252
p		.001

As shown in Table 1., the results revealed a statistically significant difference in sleep quality between the two groups, $t(144) = –3.25$, $p = .001$.

Employees working in rotating shifts reported higher sleep quality scores (M=0.84) compared to those working fixed shifts (M=0.74), indicating that rotating shift workers experienced poorer sleep quality. These findings support the hypothesis that shift type is associated with significant differences in sleep quality, with rotating schedules being more detrimental to sleep. This aligns with previous research indicating that rotating shifts disrupt circadian rhythms more severely, leading to increased sleep disturbances and reduced restorative sleep (Costa, 2003; Åkerstedt, 2003). The frequent changes in work hours associated with rotating shifts likely hinder the body's ability to adapt, resulting in cumulative sleep debt and impaired sleep quality.

Hypothesis 2 stated that there are statistically significant differences in sleep quality depending on the type of shift work among workers with a morning circadian chronotype.

Table 2. *Differences in sleep quality based on shift type among workers with a morning chronotype*

Shift Schedule	N	Sleep Quality
Fixed – Morning Shift Only	25	1.0254
Rotating – All Three Shifts	41	1.2307
Rotating – Day Shifts Only	16	1.1160
F		3.516
p		0.032

As shown in Table 2., the results revealed a statistically significant difference in sleep quality scores between the shift groups, $F(3.51) = 4.10$, $p = 0.032$. Workers on rotating shifts covering all three shifts reported the highest mean sleep quality score (M=1.23), indicating poorer sleep quality compared to those working fixed morning shifts only (M=1.02) and those on rotating day shifts only (M=1.11). These results suggest that rotating shifts, especially involving night work, may be associated with diminished sleep quality in morning-type workers. This suggests that morning chronotypes, who naturally prefer early activity and sleep times, are particularly vulnerable to the disruptive effects of night and rotating shifts. The misalignment between their intrinsic circadian preferences and work demands likely exacerbates sleep difficulties. These findings corroborate prior studies showing that morning types struggle more with night shifts and rotating schedules, which can lead to increased fatigue and decreased well-being (Vetter et al., 2015; Juda et al., 2013).

Table 3. *Differences in sleep quality based on shift type among workers with an evening chronotype*

Shift Schedule	N	Sleep Quality
Fixed – Morning Shift Only	24	**0.4938**
Rotating – All Three Shifts	39	0.7152
Rotating – Day Shifts Only	9	0.5166
F		4.098
p		**0.018**

As shown in Table 3., the results revealed a statistically significant difference in sleep quality scores between the shift groups, F (4.09) = 4.10, p = 0.018. Workers engaged in rotating shifts encompassing all three shifts had the highest mean sleep quality score (M=0.72), indicating poorer sleep quality compared to those working fixed morning shifts only (M=0.49) and those working rotating day shifts only (M=0.52). This suggests that rotating shift work negatively affects sleep quality in evening-type workers as well. Although evening chronotypes generally tolerate later schedules better, the inclusion of night shifts and frequent rotation still appears to impair their sleep. This indicates that while evening types may have some resilience to night work, the instability and the irregularity of rotating shifts remain detrimental. These results extend previous research by highlighting that rotating shift work negatively affects sleep quality across chronotypes, though the degree of impact may vary (Adan et al., 2012; De Martino et al., 2013).

CONCLUSION

The results of this study reveal significant differences in sleep quality influenced by both shift type and individual chronotype. Morning chronotypes working fixed morning shifts reported consistently better sleep quality compared to those engaged in rotating shifts. Interestingly, evening chronotypes working fixed morning shifts also exhibited improved sleep quality, while those on rotating shifts experienced the poorest outcomes. Among workers covering all three shifts, morning chronotypes showed the lowest overall sleep quality, highlighting their particular vulnerability to irregular schedules. These findings underscore the critical importance of considering both chronotype and shift type when evaluating sleep quality and designing work schedules. The stability and predictability inherent in fixed morning shifts appear to provide substantial benefits, even for evening chronotypes, by enabling the establishment of consistent routines that enhance overall sleep quality. This suggests that schedule regularity and predictability may have a greater positive impact on sleep health than merely aligning shifts with circadian preferences.

Given the crucial role of the circadian rhythm in regulating sleep and activity patterns, disruptions caused by shift work can lead to poorer sleep quality and associated health risks. Therefore, practical scheduling adjustments are essential. Fixed shifts, particularly those tailored to workers' chronotypes, can help mitigate sleep disturbances and promote better health outcomes. For rotating shifts, reducing the frequency of night shifts and ensuring adequate recovery time between shifts may alleviate negative effects on sleep. Furthermore, incorporating chronotype assessments into shift assignment processes could enhance worker well-being, reduce fatigue, and improve productivity.

Overall, accommodating individual biological rhythms while maintaining schedule stability and predictability emerges as a key strategy to optimize sleep quality and support the health and performance of shift workers.

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REFERENCES

Adan, A., Archer, S. N., Hidalgo, M. P., Di Milia, L., Natale, V., & Randler, C. (2012). Circadian typology: A comprehensive review. *Chronobiology International*, 29(9), 1153–1175. https://doi.org/10.3109/07420528.2012.719971

Åkerstedt, T. (2003). Shift work and disturbed sleep/wakefulness. *Occupational Medicine*, 53(2), 89–94. https://doi.org/10.1093/occmed/kqg046

Alshahrani, S. M., & BaHammam, A. S. (2017). Impact of shift work on sleep and daytime performance among health care professionals. *Annals of Thoracic Medicine*, 12(3), 183–189.

Arendt, J. (2010). Shift work: Coping with the biological clock. *Occupational Medicine*, 60(1), 10–20. https://doi.org/10.1093/occmed/kqp162

Baehr, E. K., Fogg, L. F., & Eastman, C. I. (1999). Intermittent bright light and exercise to entrain human circadian rhythms to night work. *American Journal of Physiology – Regulatory, Integrative and Comparative Physiology*, 277(6), R1598–R1604.

Boivin, D. B., James, F. O., & Wu, A. (2022). Blue-enriched light exposure during night shifts improves alertness and performance: A randomized controlled trial. *Journal of Biological Rhythms*, 37(1), 45–58. https://doi.org/10.1177/07487304211065432

Burgess, H. J., Sharkey, K. M., & Eastman, C. I. (2002). Bright light, dark and melatonin can promote circadian adaptation in night shift workers. *Sleep Medicine Reviews, 6*(5), 407–420.

Buysse, D. J., Reynolds III, C. F., Monk, T. H., Berman, S. R., & Kupfer, D. J. (1989). The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Research*, *28*(2), 193–213.

Caruso, C. C. (2014). Negative impacts of shiftwork and long work hours. *Rehabilitation Nursing*, 39(1), 16–25. https://doi.org/10.1002/rnj.107

Costa, G. (2003). Shift work and occupational medicine: An overview. *Occupational Medicine*, 53(2), 83–88. https://doi.org/10.1093/occmed/kqg045

de Bruijn, L., Berentzen, N. E., Vermeulen, R. C. H., et al. (2025). Chronotype in relation to shift work: A cohort study among 37,731 female nurses. *Journal of Sleep Research*, 34(2), e14308.

De Martino, E., et al. (2013). Chronotype and shift work tolerance: A review. *Chronobiology International*, 30(3), 355–365. https://doi.org/10.3109/07420528.2012.750971

Dumont, M., Paquet, J., & Carrier, J. (2001). *Circadian rhythm adaptation in shift workers: Effects on sleep and performance*. Sleep Medicine Reviews, 5(3), 239–250. https://doi.org/10.1053/smrv.2001.0150

Folkard, S., & Tucker, P. (2003). Shift work, safety and productivity. *Occupational Medicine*, 53(2), 95–101. https://doi.org/10.1093/occmed/kqg047

Gradisar, M., & Lack, L. (2004). Circadian rhythm and sleep disruption in shift work. *Sleep Medicine Reviews*, 8(3), 203–214. https://doi.org/10.1016/j.smrv.2004.02.003

Hadler, P., Neuert, C., & Lenzner, T. (2018). European Working Conditions Survey (EWCS). Cognitive Pretest. European Foundation for the Improvement of Living and Working Conditions

Horne, J. A., & Östberg, O. (1976). A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *International Journal of Chronobiology*, 4(2), 97–110.

Horowitz, T. S., Cade, B. E., Wolfe, J., & Czeisler, C. A. (2001). *Effects of partial circadian adjustments on sleep and vigilance quality during simulated night work*. Journal of Sleep Research, 11(3), 265–274. https://doi.org/10.1046/j.1365-2869.2002.00323.x

Jafari Roodbandi, A., Choobineh, A., & Daneshvar, S. (2015). Relationship between circadian rhythm amplitude and stability with sleep quality and sleepiness among shift nurses and health care workers. *International Journal of Occupational Safety and Ergonomics*, 21(3), 312–317.

Jehan, S., et al. (2017). Circadian rhythm flexibility and shift work adaptation. *Sleep Health*, 3(3), 200–206. https://doi.org/10.1016/j.sleh.2017.02.007

Juda, M., Vetter, C., & Roenneberg, T. (2013). Chronotype modulates sleep duration, sleep quality, and social jet lag in shift-workers. *Journal of Biological Rhythms*, 28(2), 141–151. https://doi.org/10.1177/074873041347855

Ker, K., Edwards, P. J., Felix, L. M., Blackhall, K., & Roberts, I. (2010). Caffeine for the prevention of injuries and errors in shift workers. *The Cochrane database of systematic reviews*, *2010*(5).

Kılıç, A., Koran, S., & Ağargün, M. Y. (2023). Healthcare shift workers' sleep quality, daytime sleepiness, and circadian preference. *Comprehensive Medicine*, 15(2), 156–164.

Knutsson, A. (2003). Health disorders of shift workers. *Occupational Medicine*, 53(2), 103–108. https://doi.org/10.1093/occmed/kqg048

Korf, H. W., & von Gall, C. (2022). Circadian physiology. In *Neuroscience in the 21st century: From basic to clinical* (pp. 2541-2576). Cham: Springer International Publishing.

Potter, G. D. M., & Wood, S. (2020). *Optimizing shift work schedules to improve circadian adaptation and worker health*. *Chronobiology International*, 37(8), 1125–1139. https://doi.org/10.1080/07420528.2020.1759836

Roenneberg, T., Wirz-Justice, A., & Merrow, M. (2007). Life between clocks: Daily temporal patterns of human chronotypes. *Journal of Biological Rhythms*, 18(1), 80–90. https://doi.org/10.1177/0748730402239679

Scott, A. J., Lack, L. C., & Lovato, N. (2024). The effects of short-wavelength light exposure on circadian phase and alertness in shift workers: A systematic review. *Sleep Medicine Reviews*, 68, 101654. https://doi.org/10.1016/j.smrv.2023.101654

Sephton, S. E., & Spiegel, D. (2003). Circadian disruption and health consequences. *The Lancet Oncology*, 4(8), 497–505. https://doi.org/10.1016/S1470-2045(03)01104-7

Sharkey, K. M., & Eastman, C. I. (2002). Melatonin phase shifts human circadian rhythms in a placebo-controlled simulated night-work study. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 282*(2), R454–R463.

Sharkey, K. M., Fogg, L. F., & Eastman, C. I. (2001). Effects of melatonin administration on daytime sleep after simulated night shift work. *Journal of Sleep Research, 10*(3), 181–192.

Smith, L., et al. (1999). Effects of shift work on sleep and performance. *Sleep*, 22(3), 317–326. https://doi.org/10.1093/sleep/22.3.317

Vetter, C., Devore, E. E., Ramin, C. A., Speizer, F. E., Willett, W. C., Schernhammer, E. S. (2015). Association between rotating night shift work and risk of coronary heart disease among women. *JAMA*, 315(16), 1726–1734. https://doi.org/10.1001/jama.2016.4454

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REVIEW PAPER

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OCCUPATIONAL SAFETY ENGINEERS: FROM IDENTITY CRISIS TO RECOGNIZED PROFESSION

Abstract: *This paper, beginning with a historical overview of the evolution of the occupational health and safety engineering profession, examines the characteristics of recognized professions and, based on this discourse, outlines the challenges and offers recommendations for the development of identity and formal recognition of the occupational health and safety engineering profession in contemporary social and economic contexts. These observations collectively suggest that the field of safety is still facing challenges in defining its core purpose and clarifying its professional identity. The article proposes strategies for addressing this identity crisis. In particular, the author explores the potential role of education and certification in facilitating the professional maturity of OSH and achieving the recognition it seeks as a fully acknowledged profession.*

Keywords: profession, engineers, occupational safety and health

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INSTEAD OF INTRODUCTION – A REVIEW OF THE DEVELOPMENT OF THE OCCUPATIONAL HEALTH AND SAFETY ENGINEERING PROFESSION

Since their inception, professions have represented the intellectual elite and the developmental potential of society. The current standing of professions is influenced by the socio-cultural context in which they are viewed. In terms of definition, a profession resists simplistic interpretations and should not be confused with the concept of an occupation. Various sociological analyses (structural, process, causal, and functional) have focused on identifying the characteristics of professions, as well as the processes of professionalization - specifically, the emergence of a profession or the transformation of a particular occupation into a recognized profession. Not all occupations qualify as professions. Occupations tend to rely on routine practices to enhance work quality. Professions, however, do not operate on routine, as it signifies the onset of professional degradation or deprofessionalization. Professions are built on theoretical knowledge; work involves problem-solving through the application of complex scientific and theoretical frameworks. Therefore, it can be concluded that a profession requires a specialized set of knowledge, skills, and competencies gained through formal education courses.

Historically, courses in occupational safety are mentioned in literature dating back to the 19th century. In France, Germany, and the Netherlands[1] safety museums were created with the primary aim of spreading the idea of safety and, later, implementing targeted educational programs (Swuste et al., 2010). In the Netherlands, the government initiated the introduction of educational programs for safety professionals, while the Safety Museum organized and conducted programs for employers, employees, and government officials from labor inspectorates[2]. Prior to World War II, occupational safety and health content was rarely included in university education, mainly at medical faculties, at the postgraduate level for doctors specializing in dermatology or respiratory medicine. In technical schools, only safety aspects related to machine maintenance and operation were covered.[3] The Second World War contributed to the growth of the military industry, along with a rise in workplace injuries and industrial accidents, which triggered the need for education in the field of occupational safety and health[4].

In the second half of the 20th century, higher education and professional training for occupational safety and health specialists expanded in Europe and the United States. In Europe, the first courses in occupational safety and health were introduced at institutions like Delft University of Technology in the Netherlands, The Wuppertal University in Germany, Aston University in Birmingham, and Imperial College London in the UK, as well as in Finland and Stockholm (Hale and Kroes, 1997). Soon after, the network of higher education

[1] In the Netherlands, the Safety Museum was established in 1893.

[2] The first such course was organized in 1951.

[3] ILO Encyclopedia, Geneva, 4th edition, Volume I, Ch.18.

[4] After World War II, the problems were particularly prevalent in countries that gained independence as colonies of European nations and began rapid industrialization.

institutions offering programs in this field spread across various U.S. states and Australia, including Federation Ballarat University (Ibid.).

During this time, the Republic of Serbia and the former SFRY underwent a rapid shift from an agrarian to an industrial economy and urban lifestyle, leading to significant challenges in the working and living environment. The high number of workplace injuries, occupational diseases, disabilities, material losses, and other environmental damages across the Republic of Serbia and the former SFRY led to the implementation of legal regulations. This resulted in the creation of various professional (research institutes) and educational and scientific institutions (universities and colleges) dedicated to training specialists in this field (Nikolic et al. 2018)

A comparative analysis of national and international documents and relevant literature reveals the diversity of approaches to the profession of Occupational Safety Engineering. This situation can be attributed to both national particularities (Verbeek, Kroon, 1995) and differences in legal frameworks, variations in higher education institutions and curriculum designers, as well as distinct cultural perspectives on occupational safety and health (Swuste and Arnoldy, 2003).

METHODOLOGY

Given the vital role of the Occupational Health and Safety Engineering profession in enhancing occupational safety and health systems and, more broadly, in the advancement of the field of occupational safety, it is perplexing that so few studies and papers are available on this subject. Some authors (Verbeek and Kroon, 1995) point to the lack of popularity of this research topic, as well as the relatively low quality of research in this domain. Safety research was predominantly descriptive and lacked in-depth analysis (Gute et al., 1993). This shifted in the 1980s, a decade marked by several catastrophic accidents in high-tech, high-risk sectors. The 1990s saw a continuous production of scientific papers on (post)academic safety education. A review of the literature suggests that most studies in this area focus on worker safety training issues (Elangovan et al., 2005.). When it comes to higher education, research primarily deals with discussions on the inclusion of occupational safety content in university curricula (Hil and Nelson, 2005,); the integration of safety into engineering education (Culvenor and Else, 1997), or the analysis of the content of existing study programs in this field (Toft et al., 2003; Rouhof et al., 2009, etc.).

This research focuses on the profession of Occupational Health and Safety Engineering, aiming to analyze the current status of the profession and to develop strategic directions for its future growth. The study begins by exploring the factors contributing to the identity crisis of Occupational Health and Safety Engineers and continues by examining the characteristics of regulated and recognized professions, ultimately identifying guidelines for establishing a professional identity for Occupational Health and Safety Engineers in the future. The research approach led us to use a descriptive research method, incorporating various data collection techniques. The data collection process involved conducting an internet/desktop study followed by interviews with relevant informants, including representatives of employers, occupational safety associations, and engineering faculties offering accredited study programs in this field. Interviews were carried out either *face-to-face* or via phone. During the data analysis and result interpretation phase, a comparative analysis was applied, comparing insights gathered from the interviews with official documents, curricula, and other published and accessible sources.

RESULTS AND DISCUSSION

The identity crisis of occupational safety engineers

Historical analyses in the introductory section have indicated that for over half a century, both in Europe and the U.S., as well as in Serbia, specialists in occupational health and safety have been trained at the higher education level, with the profession in this field continuously evolving. The establishment of this profession was preceded by the introduction of legislation that legally regulated occupational safety. However, students, their parents, and the broader public remain uncertain about the actual roles and responsibilities of these professionals.

Referring to Maslow's hierarchy of needs, it is evident that the need for safety is a fundamental human need, which, according to Maslow, comes immediately after basic existential needs.

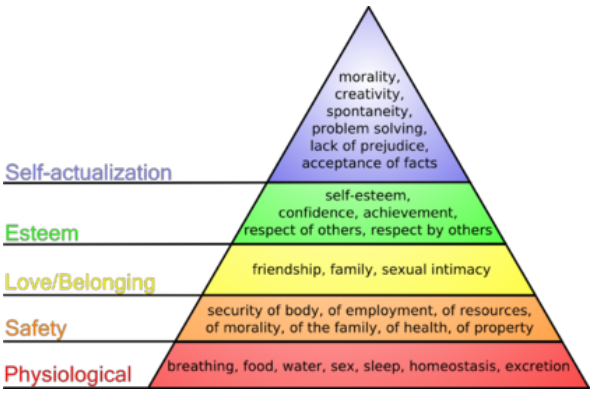


Figure 1. *Maslow's hierarchy of needs*

Although the need for safety, security, and protection has been a defining human need throughout the history of human civilization, the profession of occupational safety and health engineering continues to experience an identity crisis. Unlike doctors, lawyers, and other "recognized" professions, the occupational safety engineering profession is not properly acknowledged or valued. This situation can be attributed to the absence of a universally accepted definition of a "**safety professional**." One might expect clarification from

various safety organizations, but this has not materialized. We believe that the explanation lies in the complex and multidisciplinary nature of the field of safety, which includes various specializations working on diverse tasks across different organizational levels.

Distinction of basic concepts – profession, occupation, qualification

In everyday language, the term *"profession"* has slightly shifted in meaning, enough to no longer represent its original concept. By precisely defining the term "profession" and accurately identifying the concept it refers to, we not only clarify the terminology but also address the significant social implications of its use in daily life.

In everyday language, the terms *"profession" (lat.professio*[5]) and *"occupation"* are frequently used interchangeably, often conveying the same or similar meaning. It is uncommon for "occupation" to denote a current job, whereas "profession" typically refers to a job for which an individual has received education and certification. The scientific literature contains numerous studies examining the distinctions between these concepts. According to Huntington (2004:10), three interrelated and essential attributes of a profession should be highlighted: expertise, responsibility, and group membership.

According to the Australian professional organization (Professions Australia, 2010), a profession is defined as a disciplined group of individuals who adhere to ethical standards and are recognized by the public for their specialized knowledge and skills, which are acquired from a recognized educational institution. These competencies are grounded in research, education, and training at the higher education level, and professionals are committed to applying their expertise for the benefit of others. This definition underscores the importance of ethical conduct, specialized knowledge and skills, a scientific basis, and a commitment to societal welfare.

Every profession undergoes its own "*life cycle*." The development of existing professions or the emergence of new ones is influenced by new research, the expansion of the scientific knowledge base, technological innovations, patents, solutions, and new procedures. A profession is established, grows, evolves, and matures. When a profession grows and matures, it is acknowledged as a distinguished profession by its practitioners. Thus, it can be inferred that the development of a profession necessitates specialized knowledge and skills that fundamentally define it. Additionally, the enhancement of professionals' knowledge base requires education and continuous professional development.

Unlike qualifications, which are earned through formal education, an **occupation** is gained through work experience. An occupation encompasses a set of jobs[6] and tasks (positions) that are so similar and interconnected in their content and type, both organizationally and technologically, that they are performed by an individual with the appropriate knowledge, abilities, and skills. According to the Law on the National Qualifications Framework of the Republic of Serbia, **an occupational standard** is a document that outlines the duties and tasks, as well as the competencies required for an individual to efficiently perform jobs in a specific occupation, established in accordance with employment regulations.

Considering the focus of our research, we must ask: What is the primary distinction between an occupation and a profession? Is a safety engineer considered a profession or an occupation? An occupation can be seen as a collection of activities and tasks performed to earn a living. In contrast, **a profession** requires specialized knowledge and skills that are applicable in its practice and provide the professional with an advantage in decision-making (Star, 1984). To be regarded as a professional, one must work in a recognized profession, possess the necessary knowledge, skills, and abilities, or competencies, and hold the appropriate qualifications.

According to the Law on the National Qualifications Framework (NOKS)[7], **a qualification** is the formal acknowledgment of acquired competencies[8]. An individual attains a qualification when the relevant authority verifies that they have met the learning outcomes[9] at a specific level and in accordance with the established qualification standard, which is validated by an official document (diploma or certificate). The same law defines **a qualification standard** as a document that outlines the objectives and learning outcomes, along with information about the qualification, which is used to determine its level, classification, and evaluation (Ibid).

[5] The term "profession" originates from the Latin word professio and denotes an occupation, vocation, or activity. Along with "profession," the following terms are commonly associated: "professional," "specialist," and "expert."

[6] A job (position) is defined as a set of work tasks performed by one person. Data on organizationally and technologically related jobs or positions are grouped into occupations.

[7] *Competence* – An integrated set of knowledge, skills, abilities, and attitudes that enable an individual to act effectively in accordance with the qualification standard.
Key competences for lifelong learning – The ability to use acquired knowledge, skills, and attitudes necessary for personal, social, and professional development and further learning. These competences are embedded in the objectives and standards at all levels of education as new areas relevant for the continuous acquisition of competences, managing private and social life, professions, and navigating real-world problems and demanding situations.

[9] *Learning outcomes* – Clear statements about what an individual is expected to know, understand, and be able to demonstrate or perform after completing a learning process. They enable the verification of the level of competence development, as well as the achievement of knowledge, skills, attitudes, and abilities.

Characteristics of recognized professions

Historically, the evolution of professions in their modern form is associated with the establishment of universities and the secularization of knowledge. The earliest professions, such as medicine and law, emerged in the 16th century from occupations requiring university education. Given the limited access to higher education at that time, it can be inferred that membership in a profession was a privilege determined by birth (social status) rather than by knowledge and skills. This historical context explains the exclusivity of professional membership and the efforts to establish various conditions to maintain its power and privileges.

The professionalization of contemporary societies involves the transformation of occupations, existing professions, and inter-professional dynamics into new professions. An occupation evolves into a profession when it sufficiently develops and systematizes a body of theoretical knowledge and techniques to deliver a specific professional service. The institutional basis for the formation of a profession is the establishment of higher education institutions that cultivate and disseminate knowledge. Professions subsequently form professional associations and establish ethical codes to govern their practices. This process culminates in the legitimization and often legal endorsement of a monopoly over the provision of professional services. The extent to which these aspects are developed contributes to the degree of societal recognition of a profession.[10]

Broadly speaking, **the recognition of professions and professional qualifications** enables the employment and mobility of the workforce within the EU[11], and globally. According to the Professional Qualifications Directive 2005/36/EC, seven professions are recognized as regulated[12] across all EU member states: doctors, nurses, dentists, veterinarians, midwives, pharmacists, and architects. The updated 2013 version of this directive introduced principles of reciprocity and mutual recognition, along with a framework for mutual evaluation based on training. These documents govern access to labor markets in EU countries. Each country retains the right to create its own list of regulated professions, while the directives standardize the regulation of the aforementioned professions across the EU.

The Republic of Serbia has enacted the Law on Regulated Professions and Professional Qualifications ("Official Gazette of RS", No. 66/2019), which will take effect upon the country's accession to the European Union. This law establishes the general system for the recognition and automatic recognition of qualifications. The adoption of this law completes the transposition of Directive 2005/36/EC, its amended version from 2013, and Regulation 1024/2012 on administrative cooperation through the Internal Market Information System.

The referenced documents primarily outline a framework for recognizing regulated professions within the EU, with provisions for extending this recognition under specific conditions to other countries, including the EEA and Switzerland. Achieving the status of a regulated profession, or even gaining broader social recognition for a profession, is a complex process. Credible sources highlight the attributes that are typically associated with regulated and well-established professions (*Dean,* 1995.):

- **Service Orientation & Code of Ethics -** The majority of regulated or recognized professions deliver essential services to society, prioritizing the public good over ersonal interests and operating in alignment with their professional code of ethics[13].
- **Specialized Body of Knowledge** - A profession is founded on specialized expertise and competencies. Professionals acquire and refine these skills and knowledge through dedicated education and training to provide effective service to their clients.
- **Academic Education/Qualification** as a condition sine qua non of recognized professions

[10] Professions can be divided into three groups:
- *Classical professions* (doctors, lawyers, professors), characterized by high authority based on knowledge and autonomy in decision-making.
- *Professions that emerged later as a result of industrialization* (engineers).
- *Paraprofessions* (teachers, nurses, social workers), which typically require shorter education, have less clearly defined fields of activity, are tied to bureaucratic hierarchies, and have limited autonomy in decision-making.

[11] The Treaty on the Functioning of the EU guarantees the free movement of workers and services, as well as the freedom of establishment within the EU's single market. These rights allow all EU citizens, whether employed by someone else ("workers") or self-employed, to move freely between member states for professional purposes. These rights are part of the four fundamental freedoms in the EU (free movement of goods, services, capital, and labor).

[12] According to the Law on Regulated Professions and Professional Qualifications (Official Gazette of the Republic of Serbia, No. 66/2019), a regulated profession is a professional activity or a set of professional activities where access to and performance of the activity, or the way the activity is carried out, is directly or indirectly conditioned by possessing certain professional qualifications, based on legal, sublegal, or other acts adopted under legal authority. It also refers to professional activities or a set of professional activities carried out by members of professional organizations with a professional title. As a rule, a profession is considered regulated if the prerequisite for working in that profession is the possession of a specific diploma, the passing of a special exam such as a state exam, and/or registration with a professional body. A professional qualification includes completed formal education and additional professional training and development carried out during or after the completion of formal education, and is evidenced by a diploma or other official document issued by the relevant educational institution.

[13] It defines socially acceptable and desirable behavior when performing a professional activity.

- The prestige and status of a profession, along with its knowledge base, are elevated through rigorous educational standards. A particularly significant feature of academic education in recognized professions (e.g., medicine, law) is the inclusion of extensive internships, clinical training, or other culminating off-campus experiences. These opportunities enable students to apply their specialized knowledge and skills in real-world settings under the guidance of more experienced professionals.

- **Continuous Learning and Professional Development -** Following the completion of higher education programs, professionals pursue ongoing development of their knowledge and skills through various informal and non-formal educational avenues, such as seminars, symposiums, and conferences. At the same time, the exchange and dissemination of professional knowledge enhance the intellectual capital of the profession. This, in turn, strengthens the scientific foundation of the field, enabling timely responses to new professional challenges. Such continuous development is particularly crucial for Occupational Health and Safety Engineers, as it fosters their broader recognition and appreciation.

- **Socialization/Collegiality**
  Professional socialization refers to the process of forming a group identity or collegial consciousness. Professionals gain membership in the group through alignment with the values, practices, and personal identity of the profession. Moreover, a profession may implement licensing, certification, or other means of affirming professional identity. **By doing so, governments formally acknowledge the validity of entering the profession by certifying membership and legally** preventing non-professionals from practicing. (Dean, 1995)

Barriers to the development of the occupational health and safety engineering profession identity

There are several limitations and obstacles in the process of recognizing and developing the identity of Occupational Health and Safety Engineers, which contribute to the fact that occupational safety and health is not yet widely acknowledged as a profession.

One of the primary issues is that the field of occupational safety and health has not established the necessary requirements for recognizing appropriate academic qualifications and certifications, meaning that Occupational Health and Safety Engineers still lack priority and exclusivity in practicing their profession. This has resulted in a blurred distinction between qualified professionals and those without the necessary qualifications, who have found opportunities in this field. Consequently, a significant number of outsiders, amateurs, and unqualified individuals have been employed in occupational safety and health roles. To draw a parallel with the medical profession, one might ask: can a person be a doctor without completing medical school (an accredited medical education program) or a lawyer without graduating from law school?

Furthermore, it is not uncommon for employers to designate, or rather "transform," an existing employee into the person responsible for occupational safety and health without the requisite academic qualifications or necessary certifications. Can such an individual be trusted to assess risks and determine what is safe or unsafe in the workplace? Would society accept someone without medical education and the proper specialization performing surgeries on people? Therefore, it is crucial to create barriers that prevent "outsiders" and amateurs from entering this profession permanently.

External sources highlight that academic programs are frequently not accredited, or employers may not require specific accreditation or certification to perform these duties. Additionally, in many countries, there are no defined or adopted qualification standards as fundamental components for developing academic programs in this field. From these considerations, it can be concluded that the professionalization of occupational safety engineering, and the recognition and development of the professional identity of Occupational Health and Safety Engineers as they progress toward becoming a regulated profession, involves the following:

Defined and Established Qualification Standard for Occupational Health and Safety Engineers with Clearly Defined Competencies Achieved Through Accredited Higher Education Programs;

For the profession of Occupational Health and Safety Engineer to be recognized and regulated, it is crucial to clearly define the qualification standard for Occupational Health and Safety Engineers. In line with the qualification framework outlined in the Law on NOKS, the qualification of an Occupational Health and Safety Engineer represents formal recognition of competencies gained through academic or vocational higher education in the field of Occupational Safety Engineering. The profession's status and its knowledge base are advanced through the qualification standard, which serves as the primary input for designing academic programs. An individual is awarded the qualification when the relevant authority confirms that they have met the learning outcomes[14] for a particular level and in accordance with the qualification standard, as evidenced by an official document (such as a diploma or certificate). According to the same law, the qualification standard is a document that describes the

[14] Learning outcomes – Clear statements about what an individual is expected to know, understand, and be able to demonstrate or perform after completing a learning process. They enable the verification of the level of competence development, as well as the achievement of knowledge, skills, attitudes, and abilities.

objectives and learning outcomes, as well as details about the qualification, which are used to establish its level, classification, and evaluation.

Establishing Clear Criteria to Differentiate Between Qualified and Unqualified Individuals *(determining barriers to ''entry'' into the Profession);*

Establishing Professional Associations *(facilitating professional socialization and fostering collegiality);*

Establishing a System for Informal Education *(continuous improvement of knowledge and skills for their members;*

Continuous Professional Development *of Members Outside of University through Informal Education Formats (in Compliance with Regulations)*

A review of relevant literature and practical experience indicates that Occupational Health and Safety Engineers have well-established and active associations. Many of these associations organize conferences, seminars, and other informal professional development opportunities for their members, or serve as publishers of professional journals and other technical literature in the field (for example, The European Society of Safety Engineers, ESSE).

Guidelines and recommendations for the recognition of the OSH profession

On the path to becoming a recognized OSH profession, several areas should be considered in order to be regarded as a profession.

The Role of Education – Formal education equips individuals with specialized knowledge and valuable learning experiences necessary for obtaining an academic qualification. As previously stated, the profession must clearly outline the fundamental knowledge, specific professional skills, competencies, and outcomes that graduates of an accredited Occupational Health and Safety program are expected to attain.[15]

The specific program outcomes identified by ASSE (2004) include the ability of graduates to:

- Anticipate, recognize, assess, evaluate, and develop control strategies for hazardous conditions and work practices;
- Demonstrate the application of business and risk management concepts;
- Understand fundamental aspects of safety, industrial hygiene, environmental science, fire science, hazardous materials, emergency management, ergonomics, and/or human factors;
- Design and evaluate SH&E (Safety, Health, and Environment) training programs;
- Apply adult learning theory to safety training methodology;
- Identify and apply applicable standards, regulations, and codes;
- Conduct accident investigations and analyses;
- Apply principles of safety and health in a non-academic setting through an internship, cooperative, or supervised experience.

Certainly, this is not an exhaustive list of the topics and issues present in occupational safety and health practice. Today, in the era of digitalization, occupational safety and health converges with various challenges in the workplace environment. However, these outcomes provide a framework for the fundamental knowledge and skills that graduates of a bachelor's program should be expected to possess.

Professional Degree Integrity - As formal higher education is a vital means of acquiring a specialized set of professional knowledge and skills, how can we differentiate quality programs from subpar ones? With limited regulatory bodies overseeing continuous education in occupational safety and health, there is a risk that questionable academic courses could be offered. The notion that anyone can create and offer a Safety program undermines the profession's credibility. The Council for Higher Education Accreditation (CHEA, 2009) addresses such questionable program providers. Thus, maintaining the integrity of professional degrees is crucial for a profession's ability to ensure occupational exclusivity. It is essential to safeguard the integrity of degrees earned through accredited educational programs that are designed based on established qualification standards. Accreditation and quality assessment are the best mechanisms for ensuring the relevance and high standard of study programs in this field. Furthermore, these processes help foster confidence among employers. As some employers still hire individuals without the proper qualifications, the profession must develop mechanisms to regulate itself and separate qualified professionals from unqualified ones. Drawing a parallel to the medical profession, could hospitals hire individuals without the proper medical education?

The Role of Professional Certification - Similar to how a degree obtained through an accredited academic program serves as proof of advanced knowledge, an accredited professional certification (license) is recognized by the public as credible evidence of expertise and competencies within a profession (Adams, et. al., 2004). Certification programs typically establish benchmarks to assess an individual's competencies and professional skills. These benchmarks often include minimum education/training requirements, experience, and

[15] This has been done in part by ASSE's Educational Standards Committee, which has identified specific outcomes for safety curriculum. These outcomes have been adopted by the Accreditation Board of Engineering and Technology (ABET) as part of the Applied Science Accreditation Commission (ASAC) for use in accreditation evaluations of safety programs.

proven knowledge and abilities demonstrated through exams.

Certification brings advantages at different levels. Individuals benefit from personal satisfaction, as they are recognized as qualified professionals by their peers and the wider community. Certification can also lead to incentives such as rewards, bonuses, increased responsibilities, career advancements, improved position, status, and higher salaries. Various salary surveys conducted by both ASSE and BCSP have shown that certified safety professionals receive significantly higher compensation than their non-certified counterparts (Brauer, 2008). For employers, certification can enhance a company's reputation and competitiveness (Adams, et al., 2004). Employers view certified candidates as possessing the necessary competencies, reinforcing the value and importance of hiring those with the proper certifications.[16] The creation of a certification exam is a time-consuming process. Currently, there is an increase in both the number of certifications in the OSH field and the number of certified individuals (BCSP, 2010c). Nevertheless, similar to the ongoing assessment of academic program quality, it is crucial to consistently evaluate and review the quality of certifications.

Evaluating Professional Certifications - Achieving high-quality certification is a costly and lengthy process. Therefore, it is crucial to evaluate the value and quality of certification. Generally, the more stringent the certification requirements, the greater the authority and recognition that certificate holders receive from the public, including external accrediting bodies, government agencies, employers, courts, and peers. Job advertisement analysis (Adams et al., 2004) indicates that employers often require certified professionals, such as those needed for expert testimony in court, among other roles.

CONCLUSION: MOVING OSH FROM OCCUPATION TO PROFESSION

Professions that are recognized and established possess several defining characteristics that set them apart from those still in the early stages of development. One of these key characteristics is the existence of a governing body responsible for overseeing the work and conduct of professionals in the field. For the occupational safety engineer to complete their journey toward becoming a recognized profession, the following actions must be taken:

- First and foremost, the practice of employing individuals with insufficient qualifications for OSH positions (such as safety and health advisors or consultants) must be stopped.
- The field of OSH should primarily be made available to individuals with appropriate academic qualifications or relevant credentials, creating clear barriers for others and ensuring a distinction between qualified and unqualified professionals.
- It is necessary to initiate the development of a qualification standard for Occupational Safety Engineers, which would serve as the basis for accrediting academic programs in this area.
- Professional licensure or regulation can be a powerful tool in the process of establishing a recognized profession. Licensing, in accordance with established regulations and laws, provides strong support for professional practice. It effectively closes the profession to those who have not, or cannot, demonstrate the necessary education, training, or certification required for professional practice (The Knapp Report, 2003).

Evaluating these criteria clearly highlights that occupational safety and health is a profession that warrants regulation, recognition, and licensing. Achieving recognition as a profession is unlikely unless it changes the current hiring practices (employing individuals with inadequate qualifications), establishes barriers[17] to unqualified outsiders, and reaches a level of professional regulation, such as licensure. Furthermore, employers and professional associations in OSH must collaborate more closely with university programs to advance program-level accreditation. It is particularly important that employers prioritize Occupational Safety Engineers when hiring for occupational safety and health roles.

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REFERENCES

Adams, P.S., et al. (2004.). *Professional certification: Its value to SH&E practitioners and the profession*, Professional Safety, 49(12), 26-31.

ASSE (2010). *ASSE college and university directory*, from http://www .asse.org/professionalaffairs_ new/directory

[16] In many certifications, there is a need to provide a developmental path through paraprofessional certifications, so practitioners can progress toward a professional certification. Examples of paraprofessional (technician)-level certifications in OSH are construction health and safety technician (CHST), certified loss control specialist (CLCS) and occupational health and safety technologist (OHST). All of these certifications are offered by BCSP through the 28 professional safety (www.asse.org CCHEST). The OHST certification covers general safety and health practice at the technician level, CLCS covers loss control responsibilities common to the insurance industry, and CHST is designed for safety and health specialists in the construction industry (BCSP, 2010a).

[17] This may result in a short-term decrease in the number of "professionals for occupational safety and health," but in the long run, it affects the reputation and status of this profession.

ASSE (2004). *Safety curriculum guidelines*. Des Plaines, IL: Educational Standards Committee.

Brauer, R. (2008). *Career success: Lessons learned from a new CSP salary and demographic survey*. Savoy, IL: BCSP.

BCSP. (2008.). *Content delineation and analysis for the safety fundamentals examination*, Savoy, IL. from http://www.bcsp.org

BCSP. (2010a). *BCSP certifications at a glance*. Savoy, IL. from http://www.bcsp.org/ataglance

BCSP.(2010b).*GSP.Savoy*, IL.from http://www.bcsp.org/GSP

BCSP. (2010c). *Choosing the right certification for you*. . Savoy, IL: from http://www.bcsp.org/ certifcationshopping

Culvenor, G.J. Else, D. (1997). Finding occupational injury solutions: the impact of training in creative thinking, Safety Science, Vol 25 (1-2), 1997, pp. 187-205.

CHEA (Council for Higher Education Accreditation, 2009). Toward effective practice: Discouraging degree mills in higher education. Joint publication between CHEA and UN, DC, Washington.

Dean, J.C. (1995.). *What makes a profession*. Fund Raising Management.

Gute, D., et al. (1993). Factors affecting the permanence of occupational safety and health topics in engineering courses, J. Eng. Educ, 1993, Vol 82 (2), 163-168.

Elangovan, R., et al. (2005.). Effectiveness of the designed safety education program modules by their implementation in selected industries, Journal of Loss Prevention in the Process Industries, Vol 18, 2005, pp. 553-557.

Hill,R.,Nelson,D.(2005.).Strengthen safety education of chemistry undergraduates, Chemical Health and Safety, pp.19-23.

Huntington, S. P. (2004). Who Are We? The Challenges to America's National Identity. Simon & Schuster, Inc

Hale, A., Kroes J. (1997). System in safety, Safety Science, Vol 26 (1/2), 1997, pp. 3-19.

Knapp &Associates International Inc. (2003.). *Safety as a profession: Framework and recommendations*, Princeton, NJ.

Law on Regulated Professions and Professional Qualifications, "Official Gazette of RS", No. 66/2019.

Law about NOKS Official Gazette of RS", No27/2018, 6/2020, 129/2021 - dr. zakon i 76/2023.

National Council of State Boards of Nursing (NCSBN). (2010). *Uniform core licensure requirements*. Chicago: from http://www.ncsbn.org/667.htm

Professions Australia (2010). Definition of a Profession. http://www.professions.com.au/Homepage.html.,pristupljeno: 02.01.2011.

Nikolic, V. et al. (2018). Higher education in the field of OSH in national and international context, Proceedings of

18th International Conference "Man and Working Environment'', Faculty of Occupational Safety, Niš.

Rouhof, P. et al. (2009.). Ensuring minimum SHE competences: a case study for manufacturing employees in a multinational, Journal of Applied.

Swuste ,P., Arnoldy, F. (2003.). The safety adviser/manager as agent of organisational change: a new challenge to expert training, Safety Science, Vol 41, 2003, 15-27.

Swuste, C.et al (2010). Safety metaphors and theories, Safety Science, Vol 48, pp. 1000-1018.

Starr, P. (1984). *The social transformation of American medicine*. NewYork: Basic Books

Toft, Y et al.(2003.).Changing paradigms for professional engineering practice towards safety design – an Australian perspective", Safety Science, Vol 41, 2003, 263-276.

Verbeek, J., Kroon,P. (1995). Editorial special issue on education and training on occupational health and safety, Safety Science, Vol 20 (3-4), 1995.

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LIMITING FACTORS FOR THE USE OF VR TECHNOLOGY IN OCCUPATIONAL SAFETY AND HEALTH TRAINING

Abstract: *This paper presents the current limiting factors in the application of virtual reality (VR) in the training process for safety and health at work. Although VR offers significant advantages in occupational safety and health training, such as the simulation of hazardous situations and the enhancement of interactive learning, several factors may limit its widespread implementation. The main limiting factors include technical barriers and high implementation costs. Additionally, the need for specialized equipment, as well as the psychological effects on workers during training, can pose constraints on its application. Furthermore, various organizational factors, along with the lack of qualified personnel for VR content development, represent additional limitations to its implementation. The paper analyzes these limitations and proposes possible solutions to overcome them, aiming to enable a broader use of VR technology in occupational safety and health training.*

Keywords: virtual reality (VR) technology, limiting factors, training for safety and health work

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INTRODUCTION

The process of training employees for safe and healthy work represents a fundamental step within the occupational health and safety system in every workplace. During this process, workers must become thoroughly familiar with all identified hazards and harmful factors present in the work environment, as well as with the established risk levels and safety rules that have been implemented to manage the recognized risks (Nikolić et al., 2017). In addition to providing information about hazards, the training process also includes education on ergonomic principles, proper use of work equipment and tools, safe movement within the workspace, and correct methods of load handling. The goal of the training process is to equip workers with the necessary knowledge and skills that enable the safe performance of work tasks, while minimizing the risk of injuries and damage (Nikolić et al., 2018). Although complete elimination of errors in the work process is impossible, the likelihood of their occurrence can be significantly reduced through adequate and effective training, that is, by systematically educating workers. Research has shown that effective safety training not only increases employees' ability to recognize hazards but also reduces the frequency of unsafe behaviour, while simultaneously improving the safe handling of work tools and equipment. Therefore, training programs must be specifically tailored to the conditions of each individual workplace, taking into account the specific characteristics of work processes, tools, equipment, and the working environment. Effective training programs for safe and healthy work represent one of the most direct methods for reducing the frequency of human errors, thereby achieving not only an increased level of safety but also significant financial savings through the prevention of accidents and the reduction of treatment costs, compensation claims, and work stoppages (Neville, 1998). A systematic approach to training and the continuous development of employees, combined with the evaluation of acquired knowledge and skills, are key factors in building a lasting culture of occupational safety. The traditional approach to training for safe and healthy work includes both theoretical and practical components. The effectiveness of knowledge acquisition in the theoretical segment largely depends on the expertise, skills, and pedagogical competencies of the instructors. The practical component of training is carried out directly in the workplace, often as an integral part of the preparation for specific work tasks. Hands-on training and demonstrations in real-world conditions have proven to be particularly effective in conveying key safety principles, enhancing hazard awareness, and developing safe work practices. In addition to the traditional approach to training, it is now also possible to incorporate modern technologies into this process. The technology that stands out and demonstrates the best results in training for safe and healthy work is virtual reality (VR). The use of virtual reality technology in occupational safety training offers numerous advantages, such as the simulation of

hazardous situations without real risk and increased participant engagement. However, the application of VR also has certain limitations, such as constraints related to the effectiveness of virtual simulations in accurately reproducing all aspects of the real work environment, including complex sensory information such as touch, smell, and the weight of loads. The absence of these elements may reduce the effectiveness of transferring practical skills necessary for the safe performance of work tasks. Additionally, access to VR technology can be limited by the high costs of acquisition, maintenance, and equipment updates, which poses a significant barrier, especially for small and medium-sized enterprises. The technical complexity of using VR systems requires additional resources for training instructors and users, further complicating implementation. Furthermore, some users may experience physiological reactions, such as nausea or fatigue due to prolonged use of virtual devices (a phenomenon known as "cybersickness"), which can negatively impact the quality of learning. According to research, although VR can enhance theoretical knowledge and hazard recognition, there are limitations in transferring acquired skills to the real work environment, especially concerning motor skills and responses in unexpected situations.

This paper aims to provide a detailed overview of the current limitations in the use of VR technology for training in safe and healthy work practices.

APPLICATION OF VR IN OCCUPATIONAL SAFETY AND HEALTH TRAINING

In today's context of widespread use of information technologies, these tools are increasingly being applied across various forms of training, including occupational safety and health. Virtual reality (VR) is being utilized in training processes for safe and healthy work, particularly in high-risk industries such as construction, mining, and energy (Grassini & Laumann, 2020). The application of VR technology enables training participants (Figure 1) to gain practical experience in simulated, yet controlled conditions, without being exposed to real hazards.



Figure 1. *Trainee undergoing occupational safety and health training using VR technology (source: author's own)*

In this way, hazard awareness is enhanced, safe behaviour skills are developed, and preparedness for emergency response is improved (Hendrix & Johannsen, 2008). The most common models of VR application in training include desktop simulations, game-based training, and integration with Building Information Modelling (BIM) software. Desktop solutions enable the visualization of work environments (Pedro et al., 2020), while VR-based games help simplify complex tasks and strengthen user interactivity (Wang et al., 2018). BIM-integrated systems offer additional capabilities for simulating construction processes and improving decision-making with the aim of reducing risks on construction sites (Chen et al., 2022; Park et al., 2013). VR has also proven to be extremely useful in the mining industry, where training based on virtual simulations improves miners' preparedness for various scenarios and emergency situations (Grabowski & Jankowski, 2015; Duarte et al., 2019). In addition to enhancing safety, VR contributes to better visualization of complex information and ergonomic challenges, as well as to the optimization of equipment design (Foster & Burton, 2004). Flexibility, repeatability of training, mobility, and relatively lower operational costs make VR technology an attractive option for enhancing occupational safety and health training systems.

LIMITATIONS IN THE APPLICATION OF VR TECHNOLOGY IN OCCUPATIONAL SAFETY AND HEALTH TRAINING

Despite its numerous advantages, challenges remain – particularly regarding the high costs of content development and the need for continuous software updates. Although hardware advancements in VR technology are progressing, software development aimed at safety training still lags behind, which poses a limitation to the broader application of this technology. Creating high-quality and relevant training content requires significant resources and the involvement of competent educators. Technical difficulties, physical discomforts such as fatigue, nausea, and disorientation, psychosocial factors such as anxiety or feelings of isolation, as well as legal ambiguities regarding liability and regulation, represent key barriers that can limit the effective use of this technology. Additionally, there is a risk that inadequately designed VR scenarios may generate new forms of hazards for users, which necessitates careful planning, standardization, and continuous improvement of VR training programs. Upon analysis of previous research on the limitations of virtual technology usage, all limitations can be classified into two groups (Figure 2): limitations arising from the direct impact of virtual technology on humans and technical-administrative limitations in the application of VR technology.

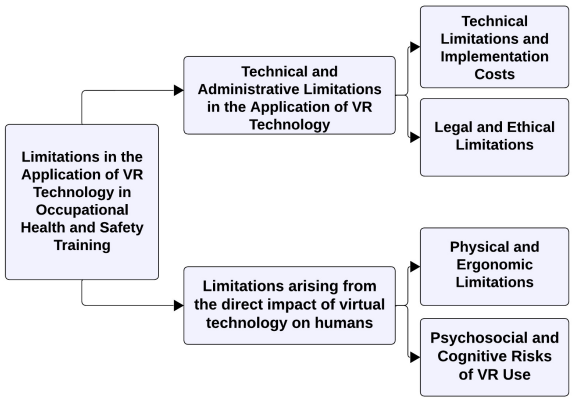


Figure 2. *Limitations in the application of VR technology in occupational health and safety training*

Technical Limitations and Implementation Costs

The application of virtual reality (VR) technology in training processes requires significant initial investments in both hardware and software infrastructure. High-quality head-mounted display (HMD) devices demand high-performance graphics processors, precise motion-tracking sensors, as well as adequate network infrastructure capable of supporting real-time processing and transmission of large volumes of data (Bérastégui, 2024). The costs of acquiring high-end equipment, along with additional expenses for regular maintenance and software updates, often exceed the financial capabilities of small and medium-sized organizations. In addition to the high cost of basic equipment, issues of technical compatibility between different VR platforms and devices also arise, making it difficult to standardize and scale VR training programs. Software packages developed for specific industrial applications typically require expensive licenses, while the need for content localization and customization generates additional costs. Technical characteristics, such as image transmission latency, limited display resolution, and the need for physical space sufficient for safe user movement, further complicate implementation – especially in facilities not designed for the use of such technologies, which require additional adaptation. Additionally, technical maintenance of VR systems poses an ongoing challenge, as hardware failures can directly cause interruptions in training and reduce its overall quality. Due to all these factors, VR solutions are currently significantly more accessible to organizations with substantial investment capacity, while remaining less accessible to a broader range of users.

Within the scope of technical limitations, the quality of VR presentation content must also be mentioned. This necessitates the involvement of qualified educators who will be engaged in creating appropriate content. VR presentation materials should comprehensively familiarize trainees with all aspects of the workplace required for safe work performance. This primarily refers to familiarizing trainees with all existing hazards and harmful factors, the prescribed measures for their avoidance and mitigation, as well as the procedures for responding to the occurrence of risky situations.

Physical and Ergonomic Limitations

Prolonged use of virtual reality devices, especially head-mounted display (HMD) systems, is associated with various physical and ergonomic risks. The weight of the device itself, combined with often inadequately designed ergonomics, can cause pain in the neck, shoulders, and upper back, as well as contribute to the development of musculoskeletal disorders in users (Souchet et al., 2023). Additionally, due to the close proximity of the screen to the eyes, users often experience visual fatigue, difficulty focusing, blurred vision, and, according to some studies, a potential increased risk of developing myopia (Turnbull & Phillips, 2017; Németh et al., 2021). One of the most serious challenges related to the physical health of users is the occurrence of the so-called cybersickness, a phenomenon that includes symptoms such as nausea, dizziness, disorientation, headaches, and general discomfort (Stanney et al., 2020; Bérastégui, 2024). Research (Vajkić et al., 2025) shows that older people are more prone to the effects of cybernetic illness when using VR technology. Cybersickness occurs due to a mismatch between the visual information received through the VR system and the proprioceptive and vestibular information coming from the body's internal sensors, leading to confusion in sensory perception processing. According to available research, it is estimated that between 30% and even 90% of users may experience some form of cybersickness, depending on the characteristics of the VR simulation, the duration of exposure, and the technical specifications of the equipment used (Caserman et al., 2021; Kim et al., 2021). Prolonged exposure to VR environments can lead not only to immediate symptoms but also to longer-lasting effects, such as disturbances in spatial perception, reduced stability, and a sense of insecurity, which may persist for several days after using the VR system (Bérastégui, 2024).

Psychosocial and Cognitive Risks Associated with the Use of VR

The application of virtual reality (VR) technology in the work environment and training processes may generate significant psychosocial and cognitive risks that can negatively impact workers' well-being and overall performance. One of the frequently reported issues is the sensation of isolation experienced by users during or following VR sessions. The limited opportunity for physical interaction with colleagues and the reduction in direct social communication may contribute to elevated stress levels, feelings of loneliness, emotional exhaustion, and a decline in motivation (Biener et al., 2022). In addition to psychosocial challenges, VR environments often require users to process a large volume of visual and auditory information within a short period of time. This increased cognitive load can result in reduced attention,

accelerated mental fatigue, and a heightened risk of errors or accidents occurring in real-world environments following the completion of training (Filho et al., 2018; Zielasko et al., 2019). A particular challenge is the phenomenon of technostress, which arises as a result of rapid technological development and the need for constant adaptation to new systems and software. Technostress is increasingly being identified among workers exposed to VR technologies and may manifest through symptoms such as anxiety, frustration, a sense of insecurity regarding one's own abilities, and resistance to technological innovations (Bondanini et al., 2020). Another significant risk is the potential development of addiction to VR technology. Excessive use of VR environments, particularly in contexts characterized by a high level of immersion and user engagement, may lead to compulsive behaviour and difficulties in controlling usage. According to available studies, between 2% and 20% of users have shown signs of addiction to VR content, which further underscores the need for responsible planning and monitoring of VR technology usage (Barreda-Ángeles & Hartmann, 2022).

Legal and Ethical Challenges

One of the key challenges to the wider adoption of virtual reality (VR) technology is the lack of clear and comprehensive legal regulation that would address issues of privacy, data security, and liability in case of incidents. Although existing regulations, such as the General Data Protection Regulation (GDPR) in the European Union, provide a certain framework for the protection of personal information, they largely fail to cover the specificities arising from the use of VR technology, particularly with regard to the processing of biometric data collected through HMD devices (EU-OSHA, 2023). During the use of VR systems, sensitive information is collected, including users' kinematic fingerprints such as eye, head, and body movement patterns. Although technical in nature, these data can enable highly precise individual identification, thereby increasing the risk of privacy breaches and compromising workers' security (Spiegel, 2017). In addition to data protection concerns, VR environments raise new ethical challenges, including risks of cyberbullying, identity theft, and digital harassment. Virtual interactions through avatars, which are often inadequately regulated, may become venues for various forms of abuse and violations of users' dignity (Porta et al., 2024). Additionally, the issue of legal liability for injuries that may occur during VR sessions remains undefined. Traditional occupational health and safety laws are not fully adapted to the specificities of virtual work environments. It is often unclear who bears responsibility in cases of injuries caused by technical malfunctions, design flaws in VR programs, or inadequate simulation settings, highlighting the need for the development of new legal standards and guidelines to keep pace with the expansion of this technology.

RECOMMENDATIONS FOR OVERCOMING THE LIMITATIONS OF VR TECHNOLOGY APPLICATION IN OCCUPATIONAL SAFETY AND HEALTH TRAINING

Although the identified limitations in the application of virtual reality (VR) in occupational safety and health training present significant challenges, they are not insurmountable. Contemporary technological advancements, combined with appropriate strategic planning and institutional support, create opportunities for their substantial mitigation. Effective implementation of VR technology requires a multidisciplinary approach that involves coordinated activities at technical, organizational, educational, and regulatory levels. Based on the previously analyzed limitations, it is possible to identify a range of specific measures and recommendations that can contribute to reducing their impact and, in some cases, even completely eliminating them.

Recommendations for Overcoming Technical and Economic Limitations

To mitigate the high initial costs of implementing VR technology, the establishment of public-private partnerships is recommended, along with the adoption of shared ownership models for equipment among multiple organizations. The development of open-source software and modular VR systems can significantly reduce dependence on expensive, closed platforms. Furthermore, improving technical interoperability between different devices and systems would reduce integration costs and facilitate content standardization. Recommendations for enhancing the quality of VR content include additional training for educators responsible for developing VR training materials, as well as the involvement of multidisciplinary teams. The creation of such content should involve multidisciplinary experts, including specialists in occupational safety and health, as well as experts in andragogy. Occupational safety experts should be engaged in the analysis of the specific work environment to identify all hazards and harmful factors associated with the particular workplace, while andragogues should provide appropriate models for the presentation and transfer of information to the targeted users.

Measures to Reduce Physical and Ergonomic Risks

To mitigate physical discomfort such as fatigue and cybersickness, it is recommended to limit the duration of VR sessions and introduce regular breaks. The use of lighter and ergonomically designed HMD devices, as well as adaptation of simulations to the physical capabilities of users, can contribute to greater comfort and safety. Additionally, improving software algorithms to reduce latency and optimize display performance may alleviate symptoms of discomfort and disorientation.

Psychosocial Support and Cognitive Adaptation

To reduce psychosocial and cognitive risks, it is recommended to develop VR programs with a moderate intensity of information and the possibility of personalizing content complexity. Incorporating elements of social interaction and team collaboration within the VR environment can help alleviate feelings of isolation. Furthermore, it is important to provide psychological support to employees during the adaptation to VR technologies and to offer training for the development of digital competencies, thereby preventing technostress.

Guidelines for Overcoming Legal and Ethical Limitations

It is essential to develop specific legal frameworks and ethical guidelines concerning the use of VR in the workplace. This includes regulating the collection and processing of biometric data, defining liability in cases of injuries during VR training, and ensuring mechanisms for protecting users from digital harassment. Institutions and employers should collaborate with regulatory bodies and ethics experts to establish standards that safeguard the rights and safety of users.

CONCLUSION

The foundation for overcoming and mitigating the limitations of applying VR technology in occupational safety and health training lies in continuous monitoring and evaluation. This process enables the timely identification and resolution of potential issues, ensuring not only the improvement of the technical and functional aspects of VR systems but also the optimization of the training programs themselves. Through ongoing analysis of feedback from users, as well as experts in safety, ergonomics, and adult education, it is possible to detect and correct deficiencies in simulations, reduce the risk of physical discomfort or psychosocial issues, and enhance the overall training experience. Continuous monitoring allows for the detection of even the smallest technical errors or irregularities that could affect the quality of training, enabling their prompt and efficient correction, thereby ensuring optimal outcomes. Moreover, this approach contributes to the ongoing alignment of VR training programs with new standards, technologies, and labour market demands, making VR training increasingly relevant and beneficial for all stakeholders involved. Following the pace of technological advancement and the continuous need to improve occupational health and safety training, the potential offered by new technologies such as virtual reality (VR) should not be overlooked. The overarching goal of any occupational safety training is to reduce the likelihood of risk realization in the workplace, thereby decreasing the number of injuries and enhancing workers' well-being.

To achieve this in occupational safety, it is essential to provide adequate training to all workers within the workplace. In any case, the possibility of improving training through the application of new technologies should not be disregarded, especially in work environments where employees face elevated levels of risk. Moreover, during the training process itself, it is crucial to avoid exposing workers to risks unless absolutely necessary. Furthermore, other advantages of VR-based training, such as flexibility, mobility, and easy reproducibility and repeatability, should also be utilized. The general conclusion is that the occupational safety specialist is the person responsible for selecting the appropriate training model, carefully considering both the advantages and disadvantages of traditional occupational safety training methods, as well as the benefits and limitations of new technologies.

REFERENCES

Barreda-Ángeles, M., & Hartmann, T. (2022). Hooked on the metaverse? Exploring the prevalence of addiction to virtual reality applications. Frontiers in Virtual Reality, 3, Article 1031697.

Bérastégui, P. (2024). Working in the metaverse: What are the risks? ETUI, The European Trade Union Institute. https://www.etui.org/publications/working-metaverse-what-are-risks

Biener, V., et al. (2022). Quantifying the effects of working in VR for one week. arXiv. https://doi.org/10.48550/arXiv.2206.03189

Bondanini, G., et al. (2020). Technostress dark side of technology in the workplace: A scientometric analysis. International Journal of Environmental Research and Public Health, 17(21), Article 8013.

Caserman, P., et al. (2021). Cybersickness in current generation virtual reality head-mounted displays: Systematic review and outlook. Virtual Reality, 25(4), 1153–1170.

Duarte, J., et al. (2019). Virtual reality applications in the extractive industry—A short review. In Studies in Systems, Decision and Control (pp. 53–60). Springer International Publishing.

Filho, J., et al. (2018). VirtualDesk: A comfortable and efficient immersive information visualization approach. Computer Graphics Forum, 37(3), 415–426.

Foster, P., & Burton, A. (2004). [Title missing]. Journal of the Southern African Institute of Mining and Metallurgy, 104(2), 129–133.

Grabowski, A., & Jankowski, J. (2015). Virtual reality-based pilot training for underground coal miners. Safety Science, 72, 310–314. https://doi.org/10.1016/j.ssci.2014.09.017

Grassini, S., & Laumann, K. (2020). Evaluating the use of virtual reality in work safety: A literature review. In P. Baraldi, F. Di Maio, & E. Zio (Eds.), Proceedings of the 30th European Safety and Reliability Conference and the 15th Probabilistic Safety Assessment and Management Conference (pp. 4964–4971). Research Publishing, Singapore.

Hendrix, D., & Johannsen, G. (2008). A knowledge sharing and collaboration platform. Knowledge Magazine, 11.

Kim, H., et al. Clinical predictors of cybersickness in virtual reality (VR) among highly stressed people. Scientific Reports, 11(1), Article 12139.

Neville, H. (1998). Workplace accidents: They cost more than you might think. Industrial Management, 40(1), 7–9.

Németh, J., et al. (2021). Update and guidance on management of myopia. European Society of Ophthalmology in cooperation with International Myopia Institute. European Journal of Ophthalmology, 31, 853–883.

Nikolić, V., & Anđelković, B. (2018). Sistem bezbednosti i zaštite & Razvoj ljudskih resursa i upravljanje znanjem. Fakultet zaštite na radu u Nišu.

Nikolić, V., & Živković, N. (2017). Bezbednost radne i životne sredine, vanredne situacije i obrazovanje. Fakultet zaštite na radu u Nišu.

Park, C. S., & Kim, H. J. A. (2013). A framework for construction safety management and visualization system. Automation in Construction, 33, 95–103. https://doi.org/10.1016/j.autcon.2012.09.012

Pedro, A., et al. (2020). Development and evaluation of context-based assessment system for visualization-enhanced construction safety education. International Journal of Occupational Safety and Ergonomics, 26(4), 811–823. https://doi.org/10.1080/10803548.2018.1553377

Porta, C. M., et al. (2024). Sexual violence in virtual reality: A scoping review. Journal of Forensic Nursing, 20(1), 66–77.

Souchet, A. D., et al. (2023). A narrative review of immersive virtual reality's ergonomics and risks at the workplace: Cybersickness, visual fatigue, muscular fatigue, acute stress, and mental overload. Virtual Reality, 27(1), 19–50.

Spiegel, J. S. (2017). The ethics of virtual reality technology: Social hazards and public policy recommendations. Science and Engineering Ethics, 24, 1537–1550.

Stanney, K. M., et al. (2020). Identifying causes of and solutions for cybersickness in immersive technology: Reformulation of a research and development agenda. International Journal of Human–Computer Interaction, 36(19), 1783–1803.

Turnbull, P. R., & Phillips, J. R. (2017). Ocular effects of virtual reality headset wear in young adults. Scientific Reports, 7(1), Article 16172.

Vajkic, M., et al., (2025). Improvement of Occupational Safety and Health Training Process for CNC Operator using Virtual Reality Technology, INTERNATIONAL JOURNAL OF ENGINEERING EDUCATION, Vol. 41, No. 1, pp. 113 - 124, Jan, 2025

Wang, P., Wu, P., Wang, J., Chi, H. L., & Wang, X. (2018). A critical review of the use of virtual reality in construction engineering education and training. International Journal of Environmental Research and Public Health, 15(6), 1204.

https://doi.org/10.3390/ijerph15061204

Zielasko, D., & Riecke, B. E. (2020). Sitting vs. standing in VR: Towards a systematic classification of challenges and (dis) advantages. In 2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops. https://doi.org/10.1109/VRW50115.2020.00067

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AWARENESS OF YOUNG PEOPLE IN SERBIA OF THE EFFECTS OF CLIMATE CHANGE – A CASE STUDY

Abstract: *Despite the growing public interest and public debates on the topic of climate change, caused primarily by human production and consumption activities, there is a noticeable lack of research on the attitudes and behaviour of young people regarding climate change in the Serbian social context. Although young people are the future of every society and the bearers of development, their awareness and attitudes about climate change and pro-environmental behaviour in the form of reducing negative human impact on the environment have not been sufficiently researched. In this paper, we focused on examining the relationship between young people's awareness of climate change and behaviour in the form of reducing negative impact on the environment in Serbia. The study is based on a survey conducted as part of the project entitled "Youth and Climate Change." We surveyed students of the Faculty of Occupational Safety in Niš with the aim of finding out what they think and feel about climate change and what activities they are ready to do to contribute to reducing the impact of climate change on Serbian society.*

Keywords: youth, climate change, youth awareness of climate change, pro-environmental behaviour

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INTRODUCTION

The main actors in both the existing and future challenges related to climate change, one of the key challenges of humanity, are young people (Steffen et al., 2015). Humanity is already facing the negative consequences of climate change, which is why scientists point to the need for urgent action (e.g. Ripple et al., 2021). Therefore, it is precisely today's generations of young people, as witnesses of the increasing dangers but also as future decision-makers and bearers of agreed-upon changes, who are in the best position to define a long-term collective response to climate change.

On the other hand, young people are also the most sensitive to the inherited decisions and approaches of older generations. Recently, there has been a collective action of young people in Serbia, who have engaged in the fight for environmental preservation through various associations. Despite growing public interest and public debates on the topic of ecology and human-caused climate change, a review of the available literature reveals a lack of research on the environmental attitudes and behaviour of young people, especially in the Serbian context.

There is no significant amount of research on the attitudes of young people in Serbia regarding the impact of climate change. Therefore, in this study, we started from the results of the research conducted in the region. According to the obtained results (Šimac et al., 2021), the biggest increase in support for environmental protection was recorded among the Central European countries considered (Czech Republic, Hungary, Poland, Slovakia, and Slovenia) over a ten-year period (2008 vs. 2018). Previous research shows that sociodemographic characteristics (except for the level of education in some cases) are generally not relevant sources of differences in environmental attitudes and behaviour (Ančić et al., 2016; Landau et al., 2008; Šimac et al., 2021). Thus, Ančić et al. (2016), based on data from the International Social Survey Programme (ISSP) from 2011 and 2013, confirmed that a higher level of concern and willingness to act in the form of environmental protection, as well as recognition that the increase in temperature is caused by climate change, are important determinants of citizens' willingness to make material sacrifices for the sake of environmental protection. The findings indicate the importance of awareness and information about the negative consequences of climate change as potentially important determinants of pro-environmental behaviour. Of course, it should be noted that attitudes and behaviour regarding climate change and environmental care are intertwined with many other attitudes and dispositions, i.e. contextual characteristics such as values or worldviews at the individual or

societal level, which is confirmed by previous results (Brajdić Vuković, 2014; Brajdić Vuković, Ančić & Domazet, 2020; Kufrin, 2014).

The few studies to date on the environmental and climate attitudes and/or behaviour of young people have mostly been conducted on small convenience samples (Dolenec and Pejnović, 2014; Hadžiselimović, 2015; Lukšić et al., 2019) or as part of bachelor's theses (Cvetković, 2017; Toljan, 2020). Overall, the results show that young people are more or less informed and relatively aware of environmental problems and generally express a willingness to preserve the environment and natural resources (Gvozdanović et al., 2019; Lukšić et al., 2019; Stanić and Buzov, 2009). At the same time, they express a greater preference for simpler and more concrete activities for environmental protection (Hadžiselimović, 2015; Toljan, 2020).

Surveys show that young Europeans are equally or more interested and concerned about climate change than older people. Data from surveys of young people in countries such as Australia, Germany, and the United States (Borgstedt, Christ, and Reusswig, 2010; Thielking et al., 2002; Stevenson et al., 2014), show that women are more concerned about climate change than men. Thus, in some countries, female students self-assess themselves as more aware, while in others, male students do. According to individual research findings in the region, among secondary school students, female students express a more positive attitude towards environmental topics compared to male students (Dolenec and Pejnović, 2014), and female students are somewhat more environmentally aware and inclined to environmentally friendly behaviour than male students (Cvetković, 2017). Similarly, Henn, Sloam, and Nunes (2022), in a more comprehensive analysis of data from the 2017 European Values Study (EVS), found that among young people (aged 18-25) from ten countries, women are more likely to be environmentally active than men. Their findings also confirm the level of education of young people as an important source of differences in environmental activism, pointing to the importance of education for empowering and more intensively involving young people in environmental policies. We can assume that school, as an instrument of socialization, teaching, and upbringing, as in many other spheres of life, plays an important role in encouraging young people to act towards contributing to the fight against climate change.

In Serbian educational programs, climate education does not exist as a separate subject. Also, knowledge about environmental protection in primary school is studied as part of the content of other specialized subjects (e.g. The World Around Us; Nature and Society; Biology). Unlike research on the representation of environmental topics, no research has been conducted in Serbia that would examine in more detail the role of school in the formation of environmental attitudes and behaviour of young people. Thus far, the individual findings indicate that young people believe that they do not have enough opportunities to learn about environmental protection issues in educational institutions (Gvozdanović et al., 2019).

Research goal and methodology

The research was designed to survey 90 young people aged 15 to 29. All respondents were students of the Faculty of Occupational Safety in Niš. The majority of respondents were from urban areas (77%) (Figure 4). The research was conducted on a unique random sample in a way that ensured reliable data analysis and objective conclusions. More precisely, all students of the Faculty of Occupational Safety had an online survey available, but only some completed it. The survey was conducted via Google Survey. Data was collected in May 2024. A questionnaire with open and closed questions was created for the respondents. The respondents included in the research were guaranteed anonymity, which contributed to obtaining more honest and accurate data. Data entry and data processing were done using SPSS (Statistical Package for Social Sciences) software, which is used for data processing and analysis, with the necessary logical controls.

About the research sample

The aim of the quantitative research is to assess how familiar young people in Serbia are with the topic of *climate change*, emissions of harmful gases, their impact on human health and the environment, and risk factors associated with climate change in the local environment and the country. The results of this research will serve as a basis for determining priorities in this area, i.e. including the opinions of young people in future development and policy-making in the field of climate change. The research was conducted on a sample of 90 students, who can generally be classified as young people up to 29 years of age.

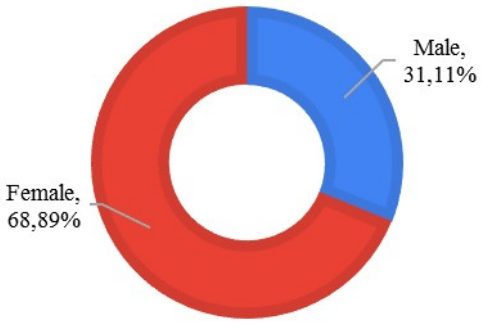


Figure 1. *Gender structure (%)*

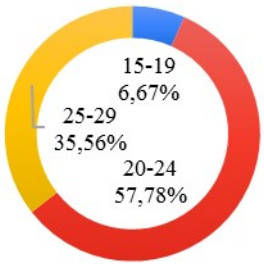


Figure 2. *Age structure (%)*

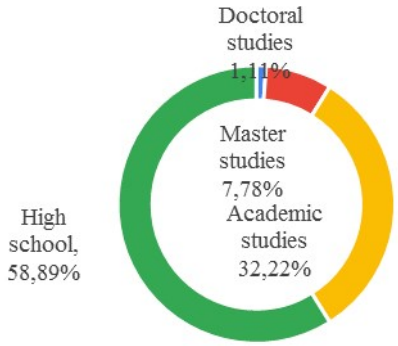


Figure 3. *Educational structure (%)*

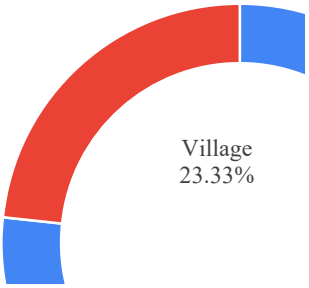


Figure 4. *Place of residence of the respondents (%)*

In terms of the demographic characteristics of the research sample, specifically its gender structure, slightly more than two-thirds of the respondents are female. More precisely, the sample consists of 68.99% women and 31.11% men. This indicates that there is a higher representation of female students compared to male students in the surveyed sample (Figure 1). The most represented age category is from 20 to 24 years of age (57.78%) (Figure 2). The largest percentage of respondents has completed secondary school (58.89%) (Figure 3), while 76.67% of respondents are city residents (Figure 4).

Presentation and analysis of research results

The research entitled *Attitudes of Youth in Serbia on the Impact of Climate Change* was carried out by a team of researchers from the Faculty of Occupational Safety in Niš, based on the research conducted globally and in southeastern Europe by the United Nations Development Program (UNDP). The aim of the research was to assess the extent to which the topic of climate change is present among young people in Serbia. In addition, a preliminary assessment was made of key perceptions and awareness of young people of the topic of climate change, emissions of harmful gases, their impact on human health and the environment, the recognition of risk factors associated with climate change in the local environment and the country, the future development of Serbia regarding climate change, etc. Young people in Serbia believe that the impact of climate change is a major problem, which is especially pronounced at the global level (87%). The research showed that young people from urban areas aged 25 to 29 are more aware of the impact of climate change at the national and global level.

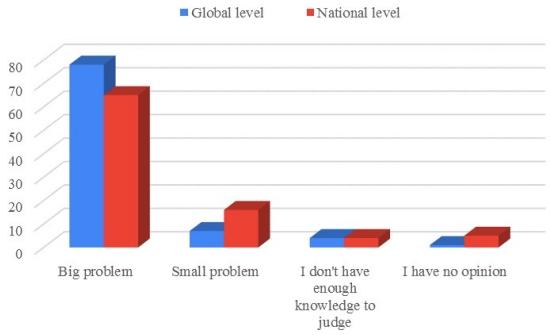


Figure 5. *Evaluation of the effects of climate change on the national and global level (%)*

The level of awareness of young people of all the consequences of climate change can be assessed as high (more than 70%). They are most familiar with the negative consequences of climate change on plants and animals (97.77%) and the impact on the frequency of extreme weather events (96.66%), while they are least familiar with the negative consequences of erosion (76.66%). Women are more familiar with the consequences of climate change than men, and greater awareness is developed among young people aged 25 to 29 compared to young people aged 15 to 19, or 20 to 24. Observed by type of settlement, young people from urban areas are more familiar with the consequences of climate change than those from rural areas (Figure 6).

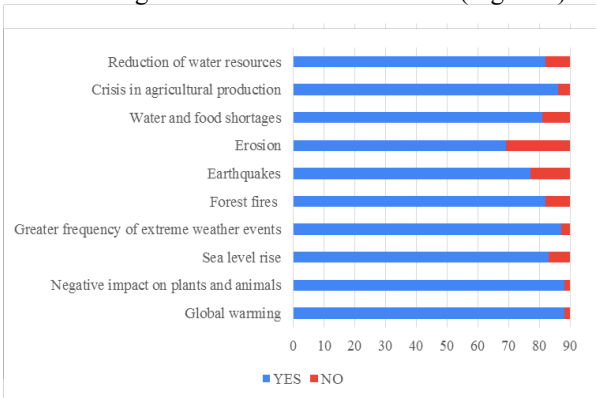


Figure 6. *Knowledge about the consequences of climate change (%)*

A third of young people feel concerned about climate change (32.22%). Responsibility for environmental protection was shown by 18.99% of young people. Ten percent of young people feel scared and 12.22% feel powerless to change anything (Figure 7).

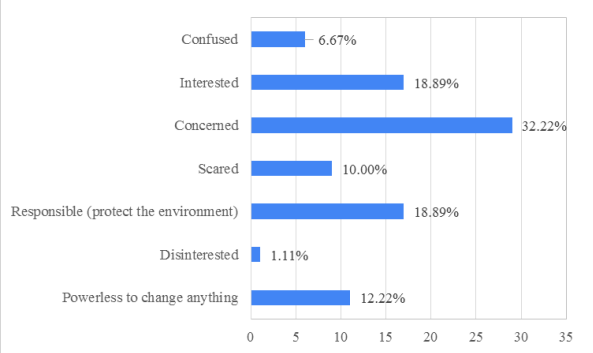


Figure 7. *How do you feel about climate change? (%)*

Two-thirds of young people identified industry/ factories (87.77%) and traffic and air pollution (81.11%) as the main causes of climate change, but uncontrolled waste generation and disposal (48.88%) is not far behind. A small percentage of young people stated that climate change is a natural process (3.33%). Unlike young people from urban areas who recognized uncontrolled waste generation and disposal as the biggest cause of climate change, young people from rural areas believe that industry and factories are some of the main activities contributing to the occurrence of climate change (Figure 8).

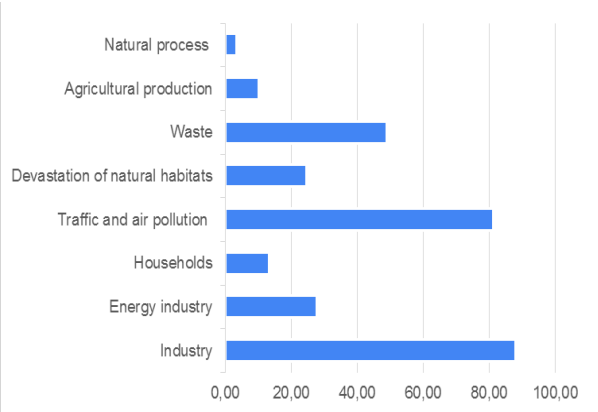


Figure 8. *What contributes most to climate change? (%)*

More than half of the respondents (68.89%) believe that most young people are unaware that their behaviour can affect climate change, while 11.11% of the respondents believe that young people are not aware of this at all (Figure 9).

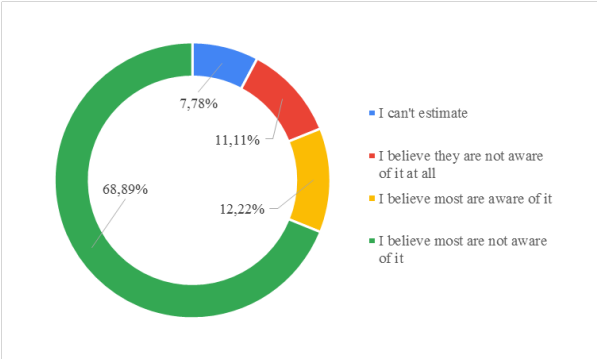


Figure 9. *Are young people in Serbia aware that they can influence climate change through their behaviour? (%)*

Slightly more than half of the respondents indicated that they were familiar with the UN Framework Convention on Climate Change (UNFCCC) and the Paris Agreement, as well as with Serbia's commitments to reduce greenhouse gas emissions (58.69%). In terms of the respondents' age, older respondents (25 to 29) are more familiar with the UN Convention and the Paris Agreement than younger ones. On the other hand, young people from rural areas are less familiar with the UN Convention and the Paris Agreement, as well as Serbia's commitments, than young people from urban areas (Figures 10 and 11).

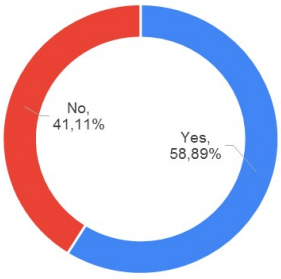


Figure 10. *Are you familiar with the UN Framework Convention on Climate Change (UNFCCC) and the Paris Agreement (%)?*

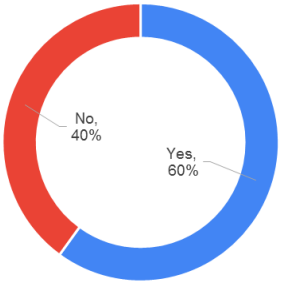


Figure 11. *Are you aware of the commitments that Serbia has made (as well as other countries that are signatories to the Paris Agreement) to reduce greenhouse gas emissions (%)?*

Of the total number of respondents, as many as 26.67% cannot assess how informed they are about climate change. On the other hand, 58.89% of the respondents believe that they are well informed, while 13.33% believe that they are poorly informed about climate change. More women believe that they are well informed about climate change compared to men, while a greater number of men cannot assess their level of informedness (Figure 12).

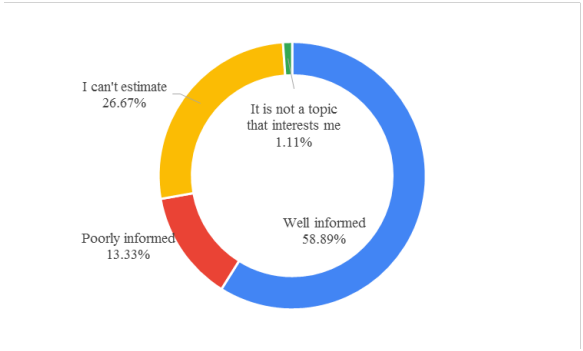


Figure 12. *Level of informedness about climate change (%)*

Around half of the respondents (51.11%) learned about climate change at university; considering that we surveyed the student population, such results are expected. In addition, 50% of the respondents learned about it through internet portals and websites, while 42.22% of the respondents learned about it through social networks. It was noted that young people listen to the radio or read the daily press very little, so they receive very little information in this way, and there is also a small percentage of those who attend lectures, round tables, and panels on this topic (Figure 13).

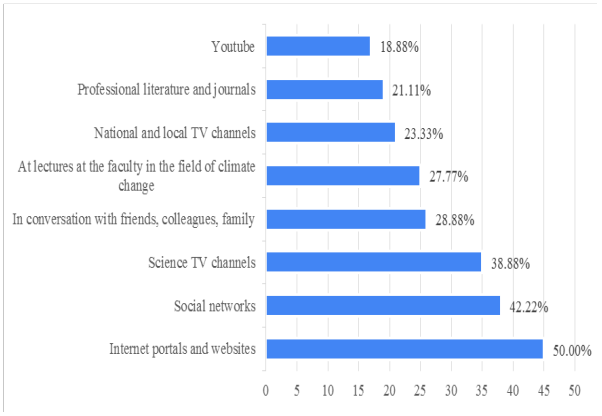


Figure 13. *How do you get information about climate change? (%)*

Interest in the topic of climate change was expressed by 33.33% of the respondents, as it is very important for them to learn more about this topic. Almost half of the sample (46.67%) stated that they would learn more if they knew that they could contribute to reducing harmful impacts. Interest in this topic is equally represented among young people in both urban and rural areas, while young people aged 15 to 19 showed less interest in receiving more information about climate change compared to older respondents (Figure 14).

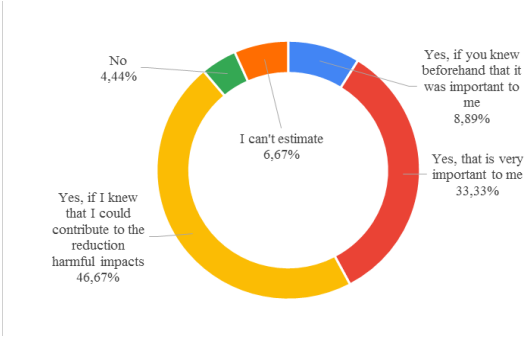


Figure 14. *Do you want to learn more about climate change? (%)*

Almost one in two respondents rates their awareness of the impacts of climate change as "sufficient" at all levels. Around 20% of the respondents state that they do not have enough knowledge about the impacts of climate change at all levels (Figure 15).

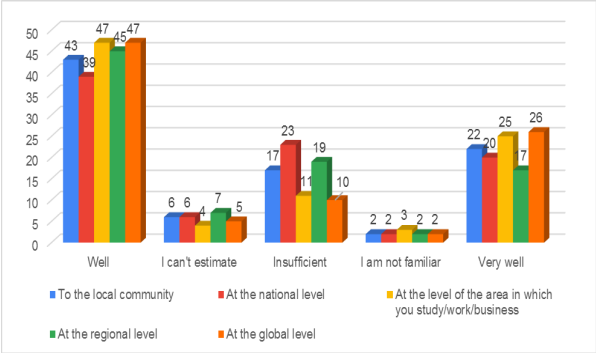


Figure 15. *Are you aware of the impact of climate change (%)*

Young people are generally equally pessimistic about climate change in the near and distant future, but they are more concerned about the far future (Figure 16).

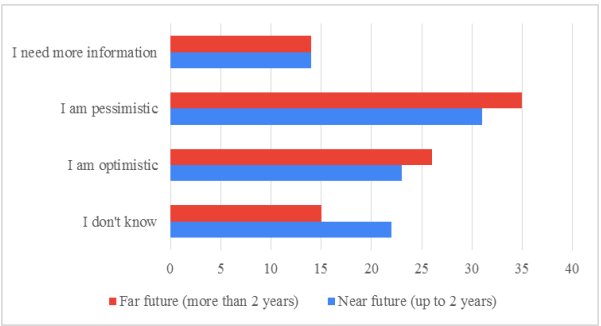


Figure 16. *In the context of climate change, how do you view the near and far future? (%)*

Young people in Serbia believe that climate change has a significant impact on the health and lives of people in general (over 75%) (Figure 17). The largest number of respondents, more precisely 80 out of 90 respondents, said that climate change has a significant impact on the health and lives of older people.

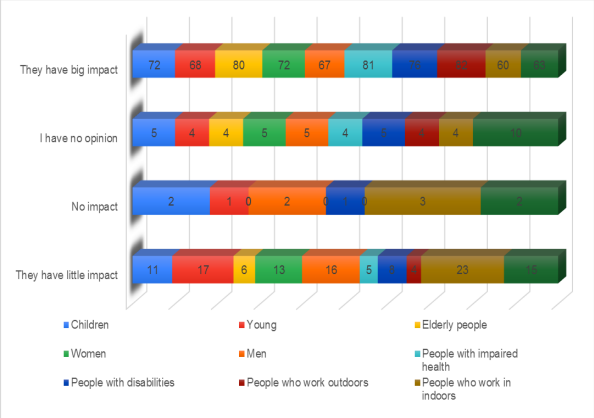


Figure 17. *Impact of climate change on health and life (%)*

The largest percentage of respondents (88.66%) believe that the state is responsible for the problems arising as a result of climate change, followed by the local community (68.88%) (Figure 18).

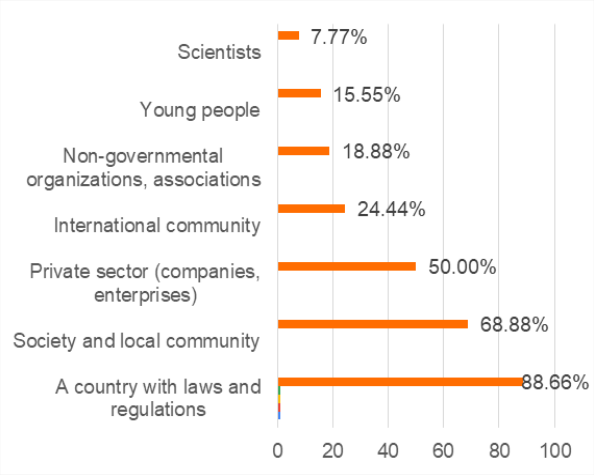


Figure 18. *Who is responsible for the problems caused by climate change? (%)*

The survey showed that young people are insufficiently familiar with climate change mitigation activities at all levels (35%) (Figure 19).

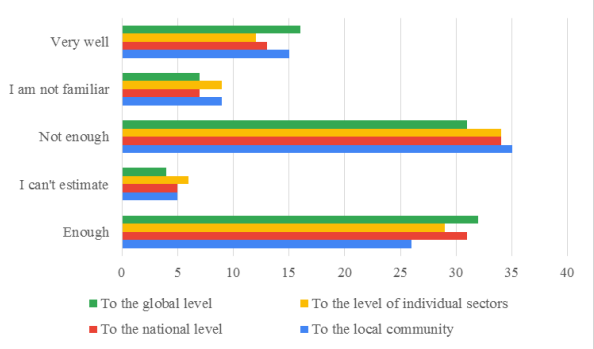


Figure 19. *Awareness of activities in the field of climate change mitigation (%)*

Among the respondents of all ages, there is a great willingness to change their lifestyle habits in order to protect the environment or reduce human impact on climate change.

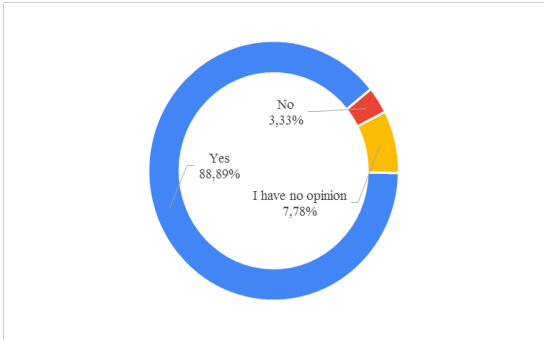


Figure 20. *Are you willing to change your lifestyle to reduce the negative impact of humans on the environment? (%)*

The largest number of respondents, more precisely 57 out of a total of 90 respondents, stated that they walk every day, 21 respondents use public transportation, while 19 respondents stated that they buy environmentally friendly products every day (Figure 21).

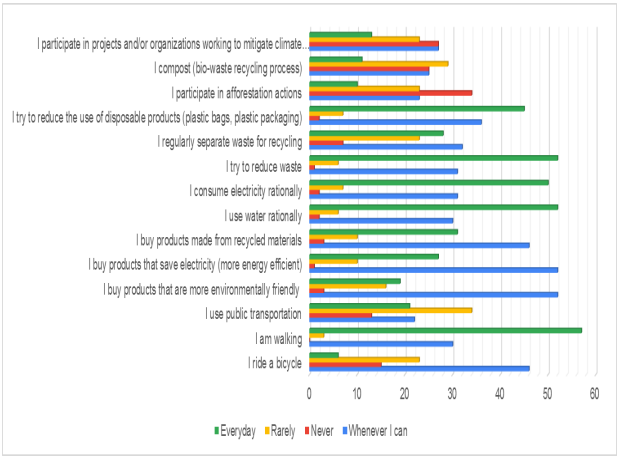


Figure 21. *What do you do every day to mitigate the negative impact of humans on the environment? (%)*

Concerning the priorities that Serbia should adopt in order to better adapt to climate change, the respondents believe that they should include the following: protecting nature and integrating climate change issues into all sectoral policies, investing in renewable energy sources, improving energy efficiency, and better managing biodiversity (Figure 22).

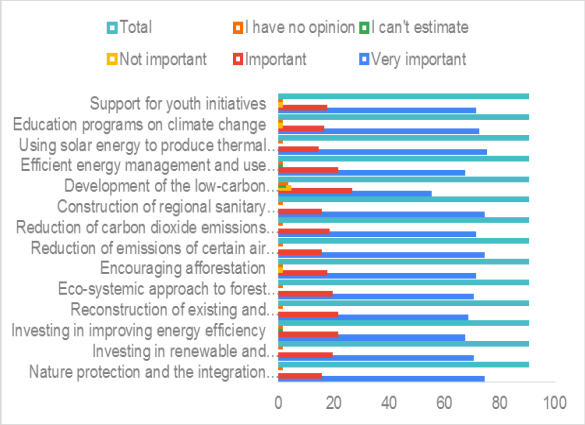


Figure 22. *What priorities should Serbia adopt to better adapt to climate change? (%)*

CONCLUSION

Based on the results of the research *Attitudes of Youth in Serbia on the Impact of Climate Change*, it can be concluded that young people have some knowledge about climate change and its impacts. Based on the research conducted and the analysis of the results obtained, several relevant conclusions can be drawn. The prevailing opinion among young people is that climate change is a very serious problem on a global level. Likewise, in Serbia, more than two-thirds of the respondents believe that climate change is a problem. Young people's awareness of the consequences of climate change is at a high level. They most often cited negative impacts on plants and animals, frequent weather-induced disasters, rising sea levels, and forest fires as possible effects or consequences of climate change. Young people of all age categories share the opinion that industries/factories, traffic, and uncontrolled waste generation and disposal are the main causes of climate change. More than half of young people are unaware that their behaviour can affect climate change. Young people in Serbia are familiar with the UN Framework Convention on Climate Change (UNFCCC) and the Paris Agreement, as well as with Serbia's obligations to reduce greenhouse gas emissions. More than half of young people believe that they are informed about climate change. The most suitable way to acquire new knowledge and information about climate change is the Internet, social networks, and scientific TV channels, as well as educational institutions. Women are more interested in learning about climate change than men, especially if they know in advance that they can contribute to reducing its harmful effects. The dominant view is that climate change has a significant impact on people's health and lives, which is especially pronounced among older people. Young people believe that the state is most responsible for solving problems arising as a result of climate change. The contribution of young people to environmental protection is reflected in daily walking instead of using motor vehicle transport, reducing waste, and using environmentally friendly products. Young people believe that it is very important for Serbia to choose its priorities regarding climate change, the most prominent of which are the following: nature protection and integration of climate change issues into all sectoral policies, investment in renewable energy sources, improvement of energy efficiency, and better management of biodiversity.

The results of this research should be taken with caution, given the type and size of the sample. However, despite these methodological shortcomings, the research provided a wealth of information about the attitudes and values of young people in determining their attitude towards the most significant problem of the 21st century – climate change.

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REFERENCES

Ančić, B., Puđak, J., and Domazet, M. (2016). Vidimo li klimatske promjene u Hrvatskoj? Istraživanje stavova o nekim od aspekata klimatskih promjena u hrvatskom društvu. *Hrvatski meteorološki časopis*, *51*(51): 27-45.

Beauducel, A., and Herzberg, P. Y. (2006). On the performance of maximum likelihood versus means and variance adjusted weighted least squares estimation in CFA. *Structural Equation Modeling*, *13*(2): 186-203.

Borgstedt, S., Christ, T., and Reusswig, F. (2010). *Environmental awareness in Germany 2010. Results of a representative population survey* [Umweltbewusstsein in Deutschland 2010. Ergebnisse einer repraesentativen Bevoelkerungsumfrage]. Berlin: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU).

Brajdić Vuković, M. (2014). The Sustainability Potential of the Knowledge Society: Empirical Study, in: Domazet, M. and Marinović Jerolimov, D. (Eds.). *Sustainability Perspectives from the European Semi-Periphery.* Zagreb: Institut za društvena istraživanja u Zagrebu and Heinrich Böll Stiftung, 195-222.

Cvetković, K. (2017). *Ponašanje studenata Sveučilišta u Rijeci spram održivog razvoja* (diplomski rad). Rijeka: Filozofski fakultet.

Dolenec, Z. and Pejnović, J. (2014). Čovjek i okoliš – stavovi srednjoškolskih učenika. *Educatio biologiae: časopis edukacije biologije*, *1*: 63-68.

Gvozdanović, A., Ilišin, V., Adamović, M., Potočnik, D., Baketa, N., and Kovačić, M. (2019). *Istraživanje mladih u Hrvatskoj 2018/2019*. Zagreb: Friedrich Ebert Stiftung.

Hadžiselimović, Dž. (2015). *Klima se mijenja, a mi...:prilozi psihologiji klimatskih promjena*. Pula: Društvo psihologa Istre.

Henn, M., Sloam, J., and Nunes, A. (2022). Young cosmopolitans and environmental politics: How postmaterialist values inform and shape youth engagement in environmental politics. *Journal of Youth Studies, 25*(6): 709-729.

Kufrin, K. (2014). Structure and Action Potential of Environmental Attitudes and Knowledge of Environmental

Problems in Croatia, in: Domazet, M. and Marinović Jerolimov, D. (Eds.). *Sustainability Perspectives from the European Semi-Periphery.* Zagreb: Institut za društvena istraživanja u Zagrebu and Heinrich Bőll Stiftung, 243-276.

Landau, S., Legro, S. and Vlašić, S. (Eds.) (2008). *Dobra klima za promjene. Klimatske promjene i njihove posljedice na društvo i gospodarstvo u Hrvatskoj.* Zagreb: Program Ujedinjenih naroda za razvoj (UNDP) u Hrvatskoj, Zagreb.

Lukšić, B., Bošnjak, K., Čačić, I., and Vranić, M. (2019). Očuvanje okoliša i praksa zbrinjavanja otpada prema mišljenju učenika mlađe školske dobi Grada Zagreba. *Agronomski glasnik: Glasilo Hrvatskog agronomskog društva, 81*(1): 45-58.

Ripple, W. J., Wolf, C., Newsome, T. M., Gregg, J. W., Lenton, T. M., Palomo, I., Eikelboom, J. A. J., Law, B. E., Huq, S., Duffy; P.B., and Rockström, J. (2021). World scientists' warning of a climate emergency 2021. *BioScience*, *71*(9): 894898. https://doi.org/10.1093/biosci/biab079

Stanić, S., and Buzov, I. (2009). Recikliranje i zbrinjavanje otpada – stavovi i aktivnosti studenata. *Godišnjak Titius: godišnjak za interdisciplinarna istraživanja porječja Krke, 2*(2): 275-296.

Steffen, W., Richardson, K., Rockstrom, J., Cornell, S. E., Fetzer, I., Bennett, E. M., and Sorlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science, 347* (6223): 1259855. https://doi.org/10.1126/ science.1259855

Stevenson, K. T., Peterson, M. N., Bondell, H. D., Moore, S. E., and Carrier, S. J. (2014). Overcoming scepticism with education: interacting influences of worldview and climate change knowledge on perceived climate change risk among adolescents. *Climatic change, 126*(3): 293-304.

Šimac, B., Poljak, T. T., and Ivanović, V. (2021). Schwartz's Human Values and the Care for Nature in Croatia and Five Other Central European Countries Based on ESS Data from Round 4 (2008) and Round 9 (2018). *Revija za sociologiju, 51*(3): 431-459.

Thielking, M., and Moore, S. (2001). Young people and the environment: Predicting ecological behaviour. *Australian Journal of Environmental Education, 17*: 63-70.

Toljan, S. (2020). *Znanja, stavovi i spremnost na poučavanje o klimatskim promjenama* (diplomski rad). Rijeka: Filozofski fakultet.

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GENDER EQUALITY – POLICIES AND LEGISLATION OF THE INTERNATIONAL LABOUR ORGANIZATION

Abstract: *Although we have witnessed significant progress in achieving gender equality in the workplace over the past century, and especially in recent decades, the need to eliminate gender disparities in the world of work undoubtedly still exists. This paper examines gender equality from the perspective of the International Labour Organization (ILO). It analyzes gender equality policy measures in the field of labour and international labour standards in this area. The research shows that the ILO implements an active policy aimed at achieving gender equality at work, equal treatment, and equal opportunities for all. Some of the policy measures focus on promoting gender equality and decent work, reducing the gender pay gap, decreasing workplace violence and harassment, etc. This policy is supported by legislation in the form of international labour standards aimed at preventing harassment and violence at work, protecting maternity, safeguarding employees with family obligations, and similar protections.*

Keywords: gender equality, International Labour Organization, policy, legislation

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INTRODUCTION

Gender equality constitutes a fundamental human right, entailing that individuals of all genders possess equal rights, responsibilities, and freedoms. This principle mandates that the interests and needs of all genders are equally acknowledged and valued. As articulated by the United Nations, gender equality signifies that women and men, as well as girls and boys, enjoy the same rights, resources, opportunities, and protections. Gender discrimination encompasses any distinction, exclusion, or restriction based on sex that impairs or nullifies the recognition, enjoyment, or exercise of human rights and fundamental freedoms in political, economic, social, cultural, or civil spheres. To dismantle entrenched power hierarchies within society, it is imperative that all individuals are treated with respect and afforded equal participation across all facets of social life (Mikkola & Miles, 2007).

Gender equality in the workplace and employee protection represent a crucial multidisciplinary concern. Over the past few decades, the status of women in the labour market has improved significantly, yet gender disparities persist (Kübler et al., 2018). This raises critical questions regarding the underlying factors that sustain discriminatory differences between men and women during hiring processes. Women continue to encounter unstable forms of employment, such as part-time or precarious contracts (Messing & Östlin, 2006). Empirical evidence reveals that non-standard employment – characterized by low compensation, limited benefits, and job insecurity – is disproportionately gendered, with women overrepresented in these precarious roles (Heilman et al., 2024). Vertical segregation or intrinsic occupational hierarchy remains pronounced: women are overrepresented in roles with restricted promotion opportunities, whereas men predominate in occupations conferring greater organizational power (Kamenov, Galić, 2011). Consistent with this, women are often entrusted with fewer responsibilities compared to men, thus hindering their potential for career progression (Hoyt, 2010). The aforementioned gender disparities in the labour sector, among many others, adversely affect the safety and health of employees – primarily women – in the workplace.

Women play an indispensable role in the global economy. Currently, approximately 50 percent of women of working age worldwide are gainfully employed (Hassard, 2023). Although this figure remained largely unchanged from 2000 to 2020, the participation of women in the labour force continues to rise across Europe. This trend benefits families by boosting household incomes and enhancing employer productivity. Nevertheless, this expansion is accompanied by considerable challenges for both women and organizations. In Europe, projections indicate that if the female employment rate remains constant, the region will confront a shortfall of 24 million workers by 2040. Conversely, should women's employment rate align with that of men, this deficit could be reduced by some 3 million.

These statistics underscore the imperative of recognizing and supporting women as a vital resource

within the workforce – efforts that must be reinforced through policy interventions and organizational strategies.

This study employs a methodology based on the analysis of relevant academic literature and the prevailing legal framework to examine gender equality from the perspective of the International Labour Organization. It investigates the ILO's policy measures on gender equality in the workplace, along with the corresponding international labour standards.

GENDER EQUALITY AS A HUMAN RIGHT

Gender equality is a basic human right. It can be asserted that gender equality constitutes a fundamental human right, as it is promoted by the United Nations in the Universal Declaration of Human Rights from 1948. This Declaration states that "all human beings are born free and equal in dignity and rights" and that "everyone is entitled to all the rights and freedoms set forth in this Declaration, without distinction of any kind, such as race, colour, sex, language, religion, birth or other status" (UN, Universal declaration, 1948). Thirty-one years later, the Convention on the Elimination of All Forms of Discrimination against Women (1979) was adopted by the UN. This was followed 16 years later by the Beijing Declaration and Platform for Action (1995), adopted at the Fourth World Conference on Women in Beijing as a visionary agenda for the empowerment of women (UN-Women, 2025). These documents clearly demonstrate that gender equality is a fundamental human right and that it was formally established in the second half of the twentieth century.

In addition to adopting foundational documents, gender equality is actively promoted and supported by the United Nations through various mechanisms (UN-Women, 2025). For example, the UN organizes a series of global conferences dedicated to this topic. The First World Conference on Women took place in Mexico City in 1975, as part of the International Women's Year. The Second was held in Copenhagen in 1980, serving as the mid-decade review under the UN Decade for Women. The Third convened in Nairobi in 1985, where the Nairobi Forward-Looking Strategies for the Advancement of Women were adopted.

Furthermore, the United Nations has established specialized bodies and organizations dedicated to the advancement of gender equality. One such entity is the Commission on the Status of Women, which serves as the principal global intergovernmental body exclusively tasked with promoting gender equality and the empowerment of women (UN, 2025a).

Additionally, the United Nations established UN Women, the United Nations Entity for Gender Equality and the Empowerment of Women. UN Women is the UN organization responsible for implementing programs, policies, and standards that uphold women's human rights and ensure that every woman and girl can realize her full potential (UN, 2025b).

ILO POLICY ON GENDER EQUALITY

The International Labour Organization, as a specialized agency of the United Nations dedicated to the protection of workers' rights, addresses gender equality within the scope of its mandate. Like the United Nations, the ILO has established its own policy on gender equality in the world of work and undertakes various initiatives aimed at the implementation of this policy.

In this context, the ILO publishes various types of documents – such as manuals, guidelines, and handbooks – that predominantly address specific issues related to gender equality, often focusing on particular countries. An example of a publication providing guidance to states in implementing gender equality policies is Gender-responsive National Employment Policies: A Path for Gender Equality (ILO, 2025), which offers countries practical advice on how to develop and implement gender-responsive national employment policies.

The ILO actively promotes gender equality in the world of work at the national level. For instance, the factsheet Fostering Women's Entrepreneurship Development and Gender Equality for a Just Transition in Egypt underscores the importance of empowering women entrepreneurs in Egypt as key contributors to a just transition toward environmentally sustainable economies (ILO, 2024).

Moreover, the ILO conducts research and publishes reports on the status of gender equality in the workplaces of its member states. For example, the report Women and the World of Work in Uzbekistan: Towards Gender Equality and Decent Work for All (2023) addresses the need for a comprehensive analysis of women's position in Uzbekistan's labour market. It aims to inform policies, legislation, and initiatives that promote decent work opportunities for all women and men. Similarly, the report titled Building Back Better with Environmental Sustainability and Gender Equality: Viet Nam Country Summary (ILO, 2022) highlights country-specific findings from the study, including priorities and recommendations identified by stakeholders to enhance environmental sustainability and gender equality within Vietnam's labour sector.

In addition to these activities, the most significant contribution of the ILO to gender equality policy in the world of work is the adoption of international instruments – conventions and recommendations. Through these mechanisms, international labour standards on gender equality are established, creating a foundation for harmonizing the status of men and women in the workplace.

INTERNATIONAL LABOUR STANDARDS ON GENDER EQUALITY

At present, international labour standards on gender equality comprise five conventions. The fact that these documents are legally binding for ratifying states underscores the significant attention the ILO dedicates

to this issue, recognizing it as a crucial component of the occupational safety and health system.

The Violence and Harassment Convention No. 190 (ILO, 2019) acknowledges that gender-based violence and harassment disproportionately affect women and girls, and that an inclusive, integrated, and gender-responsive approach – addressing underlying causes and risk factors, including gender stereotypes, multiple and intersecting forms of discrimination, and unequal gender-based power relations – is essential to ending violence and harassment in the world of work. Each ratifying state commits to enacting legislation and policies that guarantee the right to equality and non-discrimination in employment and occupation, including for women workers.

The Maternity Protection Convention No. 183 (ILO, 2000) takes into account the specific circumstances of women workers and the necessity of providing protection during pregnancy, which is a shared responsibility of governments and society. Each Member shall, after consulting representative organizations of employers and workers, adopt appropriate measures to ensure that pregnant or breastfeeding women are not required to perform work deemed by the competent authority to be harmful to the health of the mother or child, or where an assessment has identified significant health risks to either.

The Workers with Family Responsibilities Convention No. 156 (ILO, 1981) stipulates that, with a view to creating effective equality of opportunity and treatment for men and women workers, each Member shall make it a national policy objective to enable persons with family responsibilities who are engaged or wish to engage in employment to exercise that right without facing discrimination and, as far as possible, without conflict between their employment and family responsibilities.

The Discrimination (Employment and Occupation) Convention No. 111 (ILO, 1958) requires each Member for which the Convention is in force to declare and pursue a national policy designed to promote, by methods appropriate to national conditions and practices, equality of opportunity and treatment in employment and occupation, with the aim of eliminating any discrimination in these areas.

The Equal Remuneration Convention No. 100 (ILO, 1951) establishes that each Member shall, through methods appropriate to the systems in place for determining remuneration rates, promote and, to the extent consistent with those methods, ensure the application of the principle of equal remuneration for men and women workers for work of equal value.

CONCLUSION

Men and women differ not only in their biological characteristics (sex differences) but also in the types of occupations they engage in, the working conditions they encounter, and the societal roles they experience (gender differences). These factors influence both the types and levels of risks they encounter in the workplace, and consequently, the methods by which those risks should be assessed and managed.

Men and women differ in both biological and societal aspects, and these differences have a significant impact on the types of occupational risks they face, as well as on how these risks should be identified, evaluated, and managed. In particular, women: tend to be employed in certain sectors and are concentrated in specific roles that differ from those typically held by men; commonly manage dual responsibilities, balancing paid employment with unpaid domestic and caregiving duties; are underrepresented in leadership positions, including supervisory and managerial roles; and possess physiological differences from men, although it is important to note that variation among women themselves can often exceed the average differences between men and women, for example, in areas such as physical strength, etc. Despite their relevance, these factors are often insufficiently considered in occupational safety and health policies and practices. As a result, the unique risks and workloads experienced by women may be underestimated or inadequately addressed in workplace health and safety strategies. That is why the ILO aims to highlight these differences and help improve OSH in areas that affect women most.

Gender equality, as a fundamental human right, constitutes a necessary foundation for a peaceful, prosperous, and sustainable world. Although it remains one of the most pressing challenges of our time, it simultaneously presents an unparalleled opportunity to transform societies. Discrimination, understood as unequal treatment of individuals based on personal characteristics, persists across various segments of society, including the world of work.

The ILO is engaged in protecting workers from discrimination based on sex as a personal attribute of employees or job seekers. With regard to ILO regulations, international labour standards on gender equality currently comprise five conventions. Given their legally binding nature, it can be inferred that the ILO regards gender equality as fundamental to the protection of workers. These conventions obligate ratifying states to enact national legislation and define their own policies on gender equality in employment.

Beyond adopting binding and non-binding instruments, the ILO actively pursues gender equality policies through various other means. It publishes a range of documents on the subject, provides guidance to member states on the practical implementation of these policies, conducts research, and issues reports on the state of gender equality within member countries.

All of the above leads to the conclusion that the ILO maintains a highly active and comprehensive gender equality policy in the world of work, thereby encouraging and obligating member states to formulate their own policies and practices. Progress in gender equality in the workplace, in turn, will contribute to the overall enhancement of occupational safety and health for all workers.

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REFERENCES

Hassard, J. (2014). *Women at Work: An Introduction*. OSHwiki. https://test-oshwiki.osha.europa.eu/en/themes/women-work-introduction#Historicalbackgroundtowomenatworkandthechangingworldofwork

Heilman, M. E., et al. (2024). Women at Work: Pathways from Gender Stereotypes to Gender Bias and Discrimination. *Annual Review of Organizational Psychology and Organizational Behavior, 11*(1), 165–192.

Hoyt, C. L. (2010). Women, Men, and Leadership: Exploring the Gender Gap at the Top. *Social and Personality Psychology Compass, 4*(7), 484–498.

ILO (1951). *Equal Remuneration Convention No. 100.* https://normlex.ilo.org/dyn/nrmlx_en/f?p=NORMLEXPUB%3A12100%3A0%3A%3ANO%3A%3AP12100_INSTRUMENT_ID%3A312245

ILO (1958). *Discrimination (Employment and Occupation) Convention No. 111.* https://normlex.ilo.org/dyn/nrmlx_en/f?p=NORMLEXPUB%3A12100%3A0%3A%3ANO%3A%3AP12100_ILO_CODE%3AC111

ILO (1981). *Workers with Family Responsibilities Convention No. 156.* https://normlex.ilo.org/dyn/nrmlx_en/f?p=NORMLEXPUB%3A12100%3A0%3A%3ANO%3A%3AP12100_ILO_CODE%3AC156

ILO (2000). *Maternity Protection Convention No. 183.* https://normlex.ilo.org/dyn/nrmlx_en/f?p=NORMLEXPUB%3A12100%3A0%3A%3ANO%3A%3AP12100_ILO_CODE%3AC183

ILO (2019). *Violence and Harassment Convention No. 190.* https://normlex.ilo.org/dyn/nrmlx_en/f?p=NORMLEXPUB%3A12100%3A0%3A%3ANO%3A%3AP12100_ILO_CODE%3AC190

ILO (2022). *Building back better with environmental sustainability and gender equality: Viet Nam country summary.* ILO. https://www.ilo.org/sites/default/files/wcmsp5/groups/public/%40asia/%40ro-bangkok/documents/publication/wcms_872129.pdf

ILO (2023). *Women and the world of work in Uzbekistan. Towards gender equality and decent work for all.* ILO. https://www.ilo.org/sites/default/files/wcmsp5/groups/public/%40europe/%40ro-geneva/%40sro-moscow/documents/publication/wcms_907344.pdf

ILO (2024). *Fostering women's entrepreneurship development and gender equality for a just transition in Egypt.* ILO. https://www.ilo.org/sites/default/files/2025-01/Fostering%20Women%27s%20Entrepreneurship.pdf

ILO (2025). *Gender-responsive National Employment Policies: A path for gender equality.* ILO. https://www.ilo.org/sites/default/files/2025-03/Technical%20Guidance%20Note%20Gender-Responsive%20NEPs%20-%2003.2025.pdf

Kamenov, Z., & Galić, B. (2011). *Gender Equality and Discrimination in Croatia: A Study on Perceptions, Experiences and Attitudes Toward Gender Discrimination in the Republic of Croatia.* Office for Gender Equality of the Government of the Republic of Croatia.

Kübler, D., et al. (2018). Gender Discrimination in Hiring Across Occupations: A Nationally-representative Vignette Study. *Labour Economics, 55*, 215–229.

Messing, K., & Östlin, P. (2006). *Gender Equality, Work and Health: A Review of the Evidence.* World Health Organization.

Mikkola, A., & Miles, C. A. (2007). *Development and Gender Equality: Consequences, Causes, Challenges and Cures.* HECER.

UN (1948). *Universal Declaration of Human Rights.* https://www.un.org/en/about-us/universal-declaration-of-human-rights

UN (1979). *Convention on the Elimination of All Forms of Discrimination against Women.* https://www.ohchr.org/en/instruments-mechanisms/instruments/convention-elimination-all-forms-discrimination-against-women

UN (1995). *The Beijing Declaration and Platform for Action.* https://archive.unescwa.org/sites/www.unescwa.org/files/u1281/bdpfa_e.pdf

UN (2025a). *Conferences: Women and Gender Equality.* https://www.un.org/en/conferences/women

UN (2025b). *UN Women.* https://www.unwomen.org/en

UN-Women. (2025). *Women's rights in review 30 years after Beijing.* UN-Women. https://www.unwomen.org/sites/default/files/2025-03/womens-rights-in-review-30-years-after-beijing-en.pdf

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REVIEW PAPER

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CLIMATE CHANGE EDUCATION FOR MITIGATION AND ADAPTATION IN ENGINEERING

Abstract: *Climate change mitigation and adaptation represent two basic strategies in the fight against climate change and two basic directions of modern education for climate change. Engineers, as creators of new technologies and solutions in various fields, have an inevitable impact on climate change, but at the same time, they can contribute to solving this significant problem. For this reason, climate change education of engineers is an imperative of modern times. The work is aimed at elaborating the need for climate change education of engineers, identifying ways of integrating climate change into the curriculum, as well as understanding the challenges and problems accompanying the integration and implementation of climate change education in engineering. In addition, the paper aims to map courses on climate change in the current higher education engineering curricula in Serbia.*

Keywords: climate change education, climate change mitigation, climate change adaptation, engineering

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INTRODUCTION ON CLIMATE CHANGE EDUCATION

Increasingly extreme weather events, rising temperatures, melting glaciers and rising sea levels, increasing droughts, as well as heavy rainfall and floods, etc., are clear indicators of climate disruption on Earth, with accompanying negative effects. This is why climate change is often described as a "super-wicked"[1] problem in the literature. Life in a changed climate has caused the need for adaptation to the newly created conditions, but also the necessity of mitigating the consequences of climate change in the future. This led to the need for education in this area. As an important element in the fight against climate change, climate change education is becoming a basic tool for addressing it. This is also confirmed by the UNICEF survey (2023), according to which, on average, 85% of young people from 55 countries, aged 15-24, pointed out that they have heard about climate change, but only half of them know what climate change actually is.

Climate change education can be described as education that helps people understand and address the impacts of the climate crisis, empowering them with the knowledge, values and attitudes needed to act as agents of change[2]. These efforts can be accomplished through: enriching the fund of knowledge on causes and effects of climate change; facilitating the understanding of consequences of climate change; developing skills to consider complex issues and think critically; cultivating skills necessary to take action; as well as changing behavior and attitudes towards more sustainable lifestyles[3]. Universities, which are becoming the so-called "climate change agents" have shown support in implementing the previous actions. On the one hand, they are striving to become "carbon neutral" institutions when it comes to their operational practices, while on the other hand, they are developing their curricula and pedagogical approaches to educate students (and society) about the imperatives of carbon neutrality and climate change mitigation and adaptation. Therefore, the role of universities becomes crucial when it comes to educating future

[1] The term "wicked" was created in 1973 based on the idea of researchers Rittel and Webber, who used it to denote problems that persist because they are difficult to solve (Hald-Mortensen, 2023) due to reasons such as: time to find a solution is running out; there is no central authority to manage the problem; those causing the problem are those who can contribute to its resolution; the problem is long-term and large-scale, so any short-term improvement can be considered inadequate. As climate change consists of numerous sustainability-related wicked problems, such as biodiversity crisis, climate migration, etc., it becomes a super-wicked problem (Cambridge & Cambridge ZERO, 2024).

[2] Climate Change Education, https://www.unesco.org/en/climate-change/education

[3] What is climate change education?, https://cambridge-community.org.uk/professional-development/gswcce/

environmental auditors, community organizers, corporate managers, engineers, practitioners, technical professionals, policy makers, and the entire community about actions that can be taken in the field of climate change mitigation and adaptation (Leal Filho et al., 2021).

Here, engineering professions stand out as particularly important. Namely, the engineers of the future "play an urgent and pivotal role in sustainable growth, technological development, and environmental regeneration, with all sectors of engineering working inclusively and across fields. Engineers are demonstrating leadership, creativity and technical excellence by implementing solutions that shape the future and enable society to navigate immediate challenges" (NEPC & Royal Academy of Engineering, 2024b), as that of climate change. The role of engineers in this field and the need for climate change education for mitigation and adaptation in engineering are presented below.

ENGINEERS AND CLIMATE CHANGE: THE NEED FOR EDUCATION

The connection between engineering and climate change can be described as two-sided: engineering is both the cause of the problem and its solution. Namely, numerous aspects related to engineering, e.g., traffic, factories (machinery and tools), households (devices, appliances, etc.) are also the main emitters of carbon dioxide, contributing greatly to the problem of global warming and, consequently, to climate change. On the other hand, innovative engineering solutions[4] help our vehicles, production processes, homes, etc. become more carbon neutral, that is, more sustainable, thereby contributing to solving the problem of climate change. More precisely, the role of engineers in addressing climate change involves two aspects: mitigation and adaptation. Their difference is highlighted by McCowan (2021), stating that mitigation refers to the reduction or prevention of the causes of climate change, primarily the emission of greenhouse gases, while adaptation implies necessary changes in relation to climate change impacts, i.e. ensuring the survival and well-being despite the challenges. As engineers are "immediate inventors and implementers of new technologies, harnessing raw materials, and using energy both at the construction stage and throughout their operational life" (Axelithioti et al., 2023, p. 3), their role in mitigating the causes of climate change is obvious. When it comes to climate change adaptation, their role can be observed through the practices of responding to increasingly severe weather events and sea level rise. For example, engineers are expected to reinstate critical infrastructure[5] through disaster recovery and risk management (Axelithioti et al., 2023).

As pointed out by Molthan-Hill et al. (2019), implementation of adaptation and mitigation strategies requires capable policymakers and an informed public. Educated people are more aware of the climate change risks and are better equipped to make informed decisions when it comes to responding to climate change at the local, national and international level. Therefore, the answers to the aforementioned challenges in engineering can be sought and found in engineers' climate change education for mitigation and adaptation, or, more precisely, in the reshaping of engineering education, and the need to react in this field can be labeled as "urgent". This urgency stems from the fact that the consequences of climate change are becoming more and more obvious and massive, and the temperature rise is constant. Also, there is a fact pointed out by Martin et al. (2022), that "engineers beginning their education in 2022 will practice into the 2060s or beyond, and the impact of their decisions will be seen well into the 22nd century" (p. 744). Unless sustainability and resilience become part of engineering designs today, engineering will continue to have a negative impact on the climate for decades, requiring expensive modifications to achieve resiliency. To sum up, the climate crisis is happening right now, and we cannot wait for a new generation of engineers to be trained (Martin et al., 2022) in the field of "education made to measure" climate change. It is necessary to integrate climate change in all possible aspects of the formal education system, while also applying the rule of continuous learning and improvement (lifelong learning) for engineers who are outside the formal system - in practice. Also, as Amarquaye (2024) points out, upskilling[6] becomes particularly important in encouraging talent mobility, allowing engineers to easily move across sectors, such as academia, industry and government.

[4] For example, environmental protection engineers are focused on designing products and systems for air and water purification; civil and mechanical engineers can contribute to reducing our impact on the environment by changing and designing new materials used in modern technologies; engineers also create and use alternative sources of energy such as geothermal, solar or biomass energy, which slows down greenhouse gas emissions (Climate Change, https://www.teachengineering.org/populartopics/view/climatechange).

[5] The existing infrastructures are based on historical climate data that support the assumption of a stable climate. However, due to rising sea levels and increasingly frequent extreme weather events which have been happening in recent history, this assumption has been called into question (Higgs & Patil, 2024).

[6] The term upskilling refers to the acquisition of additional/new skills, i.e. improvement of existing ones. According to Gillis (2024), upskilling is a workplace trend that provides training programs and development opportunities to expand an employee's abilities and minimize skill gaps.

CLIMATE CHANGE AND ENGINEERING CURRICULUM: INTEGRATION, IMPLEMENTATION, CHALLENGES

Integrating climate change education for mitigation and adaptation into engineering curricula is not a simple task at all. Namely, climate change education cannot be reduced only to acquisition of a series of facts, but also requires the development of practical skills, adherence to values relating to humanity and nature, changes in lifestyles and collective modes of organizing, which can be particularly challenging. Also, students must be trained to critically and autonomously examine the evolving debates and evidence about climate, rather than passively adopting "neatly packaged" knowledge and beliefs. In addition, each student comes to the classroom with a set of existing knowledge, capacities and attitudes about climate, and already faces the challenges of climate change in their daily lives (McCowan, 2021). It is important to note that students' current attitudes on climate can be very extreme, based on wrong assumptions, and even on distrust in human-caused climate change (Higgs, 2024, according to Milovanovic et al., 2022; Shealy et al., 2017). Also, very often students cannot see the connection between their future profession and climate change and environmental problems (Axelithioti et al., 2023). The integration and implementation of climate change education are also accompanied by problems related to uncertainty regarding the best way to integrate climate change issues into the curriculum, resistance to the introduction of such content, on account of the contested values involved and the lack of expertise of the teaching staff (McCowan, 2021). Furthermore, if climate change were to become a part of the curriculum as a course/module, other issues regarding their status would ensue - should such courses be compulsory for all students, to ensure that every student is introduced to this key issue? It is also necessary to mention the principle of such courses' electability. There are constraints on universities as institutions in compelling students to engage in particular activities, given that the learners in question are normally adults who have freely chosen to study there. Also, if courses are compulsory, but not directly connected with disciplinary content, they might not be taken seriously and even cause resistance among students. In addition, questions of "space" in the curriculum are raised, because climate change, in a way, competes with other important topics such as peace, global health, human rights and citizenship (Ibid).

When it comes to the ways of integrating climate change into the curriculum, as in the case of any topic, climate change can become a part of already existing courses, with an effort to connect the contents of those courses with climate change, but it can also be studied as a separate course whose contents would fully cover the issues and problems of climate change. Also, entire faculty programs can be devoted to climate change. Molthan-Hill et al. analyzed the ways of integrating climate change into university curricula (2019), and singled out the following approaches:

(1) *Piggybacking* – adding climate change to existing courses or modules;

(2) *Specializing* – creation of separate modules, courses or programs;

(3) *Mainstreaming* – integration of climate change throughout the curriculum;

(4) *Connecting (transdisciplinary)* – designing new cross-disciplinary offers, such as a course on climate change that would be common to all students of one university/faculty, and within which teaching materials from different disciplines would be integrated.

Regardless of the mentioned challenges and the ways of integrating climate change in the curriculum, it is required that it must contribute to the development of certain skills of engineers in the field of climate change, with adequate didactic and methodical practices[7]. More precisely, the education of engineers for climate change should be implemented by engaging students with real-world problems, e.g. through case studies and open access digital tools, in order to develop skills such as multidisciplinary and systems thinking, as well as through hands-on experiential learning, which provides a space for creativity and the ability to connect theory with practice (Casciato, 2024). In addition, engineers must be equipped with skills such as critical thinking that will help them develop problem solving and design thinking capabilities (Ibid); technical competencies such as data analysis, project management; as well as soft skills like creativity, adaptability, collaboration, and effective communication to facilitate the transfer of information about the societal and economic impacts of climate change to industry leaders, policy makers and the public (Amarquaye, 2024). Furthermore, engineers are required to be "socially aware and ethically minded, resilient and innovative" (Cambridge & Cambridge ZERO, 2024, p. 2).

An interesting set of engineering skills is provided by Martin et al. (2022), who state that the following four

[7] According to graduate engineering students (NEPC & Royal Academy of Engineering, 2024a), a greater and more consistent integration of real-life professional experience into the curriculum and development of professional skills can be achieved through: collaboration with industry and community partners (e.g. visits, guest lectures, mentorships, etc.); active learning (real-life projects, collaborative learning, case studies); exposure to interdisciplinary practices (integrated coursework, group projects, cross-departmental collaboration); shifting towards more flexible and student-centered degrees (emphasis should be on motivating students to be more active through various projects, reduction of teaching-centred content delivery, possibility of choosing courses in accordance with future professional interests or narrower specialization); emphasizing lifelong learning and continuous professional development.

skills are most readily identifiable as necessary in engineering:

(1) *An understanding of climate, sustainability, and resilience linked to engineering design* – understanding the essence of climate and climate impacts; taking climate adaptation into account when considering the impact of climate change on the performance of their systems and designing for resiliency in response to increasingly frequent climate events; consideration of long-term climate change mitigation; understanding how the functionality and performance of technology and infrastructure change in the conditions of a changing climate, etc.;

(2) *An ability to incorporate knowledge from a range of scientific disciplines into engineering solutions* – the need for engineers to cooperate with ecologists, biochemists, biologists, epidemiologists, experts in the field of public health, etc. conditions change in how they are educated in biological, ecological and life sciences, as well as how they develop skills needed for successful communication and cooperation with different scientific communities;

(3) *Understanding the ethics and justice dimensions of engineering* – without an ethical framework, engineers can create solutions whose costs and benefits are unequally and even unethically distributed, causing harm to certain communities[8]; it is especially important to understand the concepts of environmental justice and energy equality (in order to incorporate these concepts during the development and deployment phase in a way that addresses the entire life cycle of systems);

(4) *Listen to and collaborate with diverse communities* – the ability of engineers of all backgrounds to work with underrepresented communities (such as non-white), respecting embedded community knowledge, connecting their solutions with the experiences and knowledge of local communities, etc.

METHODS

The aim of the research is to map study programs and courses dedicated to climate change at the universities and faculties of the Republic of Serbia. For that purpose, a desktop analysis of available data on the official websites of engineering faculties in Serbia, including both state and private institutions, was used. The following universities/faculties were included in the analysis: University of Kragujevac (Faculty of Engineering, Faculty of Mechanical and Civil Engineering, Faculty of Agronomy in Čačak, Faculty of Technical Sciences in Čačak); University of Novi Sad (Faculty of Technical Sciences, Faculty of Agriculture, Faculty of Technology, Mihajlo Pupin Technical Faculty); University of Belgrade (Faculty of Architecture, Faculty of Civil Engineering, Faculty of Mining and Geology, Faculty of Agriculture, Faculty of Forestry, Faculty of Mechanical Engineering, Faculty of Transport and Traffic Engineering, Faculty of Technology and Metallurgy, School of Electrical Engineering, Technical Faculty in Bor); University of Niš (Faculty of Occupational Safety, Faculty of Agriculture in Kruševac, Faculty of Civil Engineering and Architecture, Faculty of Electronic Engineering, Faculty of Mechanical Engineering, Faculty of Technology in Leskovac); University of Prishtina (Faculty of Technical Sciences Kosovska Mitrovica, Faculty of Agriculture and Veterinary Medicine); Megatrend University (Faculty of Biofarming Bačka Topola); Alfa BK University (Faculty of Information Technologies); University Business Academy in Novi Sad (European Faculty "Kallos" Belgrade, Faculty of Economics and Engineering Management in Novi Sad; Faculty of Applied Sciences in Niš); University Metropolitan (Faculty of Information Technology, Faculty of Management); Singidunum University (Faculty of Informatics and Computing); Union University Belgrade (School of Computing); State University of Novi Pazar (engineering study programs such as Architecture, Agronomy, etc.); University of Criminal Investigation and Police Studies (study program Forensic Engineering); Educons University (Study program of Information Technology and Faculty of Ecological Agriculture); University "Union Nikola Tesla" (Faculty of Construction Management); MB University (Faculty of Business and Law).

The analysis was based on the key term "climate change", i.e. the intention was to identify only those study programs and courses that contain the term "climate change" in their title. Therefore, courses whose title contains terms "climate", "climatology", etc., and whose contents include broader topics that may be, but are not necessarily related to climate change, were excluded from the analysis. One study program, i.e. module, and 24 courses were identified.

RESULTS

Study programs on climate change

The analysis of study programs at engineering faculties in the Republic of Serbia showed that no study program contains the term "climate change" in its title. However, the master's academic study program of the Faculty of Agriculture in Novi Sad "Soil, plant and genetics"[9] contains an elective area, i.e. module entitled "Climate smart agriculture". This study program was accredited in 2021, and in addition to the

[8] For example, while nuclear power plants reduce greenhouse gas emissions, three quarters of total uranium production comes from mines in or near Indigenous communities. After the production process is completed, mines are often left unremediated, which leads to land and people poisoning, while impacting traditional ways of life (Martin et al., 2022, according to Verma & Djokic, 2021).

[9] http://polj.uns.ac.rs/sr/node/3163

aforementioned, it contains eight more modules dedicated to soil, plant cultivation and nutrition, irrigation, genetics, etc. The module "Climate smart agriculture" aims to "educate and train students for a better understanding and mitigation of the harmful effects of extreme weather conditions and climate change in agriculture" [10]. The Module equips students with competencies for designing original solutions in order to mitigate/eliminate the negative consequences of climate change, planning the production and protection of plants according to the expected effects of climate change, using publicly available results of weather and climate simulations, etc. [11]

In the first semester, the Module contains three compulsory courses: Principles of experimental work, Climate change and extreme weather events, and Physiological responses of plants to changes in environmental factors. In addition, students choose two of the six elective courses offered: Climate change and insects, Modeling in plant production and plant protection, New technologies, Climate change adaptation measures in crop production, Soil and management measures for climate change adapted agriculture, Irrigation and climate change. The second semester is devoted to writing a master's thesis. Module courses that contain the term "climate change" in the title are also given in Table 1.

Courses on climate change

Courses that contain the term "climate change" in their title are presented in Table 1. Course traits – status (compulsory or elective), level of studies and year of studies (in the case of undergraduate academic studies) are also given in Table 1.

Table 1. *Courses on climate change at engineering faculties in Serbia*

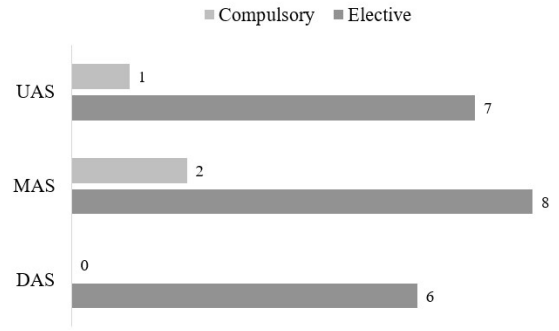
University	Course name	Course traits
University of Kragujevac		
Faculty of Engineering[12]	Engineering and cc	E/UAS, IV
University of Novi Sad		
Faculty of Technical Sciences[13]	Energy efficiency of buildings and cc	E/DAS
Faculty of Agriculture[14]	Cc and extreme weather events	C/MAS
	Cc and insects	E/MAS
	Cc adaptation measures in crop production	E/MAS
	Soil and management measures for cc adapted agriculture	E/MAS
	Irrigation and cc	E/MAS
	Forest ecosystems and cc	E/DAS
	Modeling of forest ecosystems and cc	E/DAS
University of Belgrade		
Faculty of Agriculture[15]	Agriculture and global cc	E/UAS, IV
	Cc and adaptation	E/MAS
	Cc and fruit tree adaptation	E/MAS
	Cc and food	E/DAS
Faculty of Forestry[16]	Climate disaster risk management and cc	E/UAS, III
	Cc and forest ecosystems	E/UAS, II
	Cc and forest ecosystems	E/DAS
	Vegetation and cc	E/MAS
University of Niš		
Faculty of Occupational Safety[17]	Adaptation to the effects of cc	E/MAS
Faculty of Agriculture in Kruševac [18]	Adaptation measures to cc in agricultural production	C/MAS
Faculty of Civil Engineering and Architecture [19]	Construction and cc	C/UAS, I
	Adaptation to cc	E/UAS, II
University of Prishtina		
Faculty of Technical Sciences Kosovska Mitrovica [20]	Adaptation to the effects of cc	E/UAS, III
Educons University		
Faculty of Ecological Agriculture[21]	The impact of cc on agricultural production	E/DAS
State University of Novi Pazar		
Agronomy[22]	Crop production and cc	E/UAS, III

Notes: cc – climate change; E – elective course; C – compulsory course; UAS – undergraduate academic studies; MAS – master academic studies; DAS – doctoral academic studies; I-IV – year of studies (for UAS courses)

As shown in Table 1, courses on climate change are represented at all state universities, as well as at two

[10] http://efaidnbmnnnibpcajpcglclefindmkaj/http://polj.uns.ac.rs/sites/default/files/upload/ЗЕМЉИШТЕ%2С%20БИЉКА%20И%20ГЕНЕТИКА%20НОВО.pdf
[11] Ibid.
[12] www.fink.rs
[13] www.ftn.uns.ac.rs
[14] http://polj.uns.ac.rs
[15] http://www.agrif.bg.ac.rs/
[16] www.sfb.bg.ac.rs
[17] www.znrfak.ni.ac.rs
[18] https://poljfak.ni.ac.rs
[19] www.gaf.ni.ac.rs
[20] https://ftn.pr.ac.rs/
[21] https://educons.edu.rs/
[22] https://www.dunp.np.ac.rs/

private universities. However, the resulting number of faculties is very small in relation to the total number of faculties, i.e. programs related to engineering sciences. Most courses belong to the field of agriculture, followed by forestry. The representation of courses by their status and level of studies is given in Figure 1.



Notes. UAS – undergraduate academic studies; MAS – master academic studies; DAS – doctoral academic studies

Figure 1. *The representation of courses on climate change by their status and level of studies*

Almost all courses are elective, except for three: Climate change and extreme weather events (Faculty of Agriculture, University of Novi Sad); Adaptation measures to climate change in agricultural production (Faculty of Agriculture, University of Niš); Construction and climate change (Faculty of Civil Engineering and Architecture, University of Niš). The first two courses are a part of the master's academic studies, while the third is the only compulsory course at undergraduate academic studies, as well as the only course on climate change that is taken in the first year of studies. Apart from this course, there are seven other courses at bachelor academic studies, namely: two in the second year of studies; three in the third year of studies; and two in the fourth year of studies. All of them are elective. The largest number of courses belongs to master's academic studies - 10 of them, while 6 subjects are a part of doctoral academic studies.

CONCLUSION

Raising the awareness of the impact of engineering on climate change and successful action in the field of its mitigation, as well as creating innovative solutions for climate change adaptation, requires adequate education, because one thing is certain: "If education is a preparation for life, then inescapably it must address the challenges of climate change" (McCowan, 2021, p. 3).

Universities, recognized as climate change agents, are incorporating it into their curricula in different ways - as part of existing courses or by creating special courses, as well as study programs in this field. Although this integration is accompanied by many challenges, such as difficulties in finding the connection between certain contents and climate change, insufficient training of teachers for the successful delivery of such contents, lack of "space" in the already overcrowded curricula, etc., the conclusion is clear - the challenges must be overcome, because engineers facing climate change already need skills such as systemic and critical thinking, creativity, collaboration, project management, data analysis, etc.

The analysis of the curriculum at engineering faculties in the Republic of Serbia showed the following:

- Only one study program, i.e. module, entirely dedicated to climate change was identified, at the Faculty of Agriculture of the University of Novi Sad;
- There are courses on climate change at all state universities, as well as at two private universities; however, it is a very small number of faculties, that is study programs, that offer such courses;
- Most courses belong to the field of agriculture, followed by forestry;
- Almost all courses are elective;
- The largest number of courses are a part of master's academic studies.

Finally, it is important to point out two "critical points", i.e. challenges, that require special attention:

- Most of the existing courses on climate change belong to the fields of agriculture and forestry, which further leads to the conclusion that the programs of many engineering fields, such as traffic, environmental protection, mechanical engineering, construction, etc., do not have courses fully dedicated to climate change. Consequently, this can lead to the inability to see the connection of one's profession with climate change clearly, and to the complete neglect of climate change in practice.
- Also, when it comes to existing courses, a big problem is that they are mostly elective, which means that students who do not choose a course on climate change are once again deprived of the possibility of a deeper connection of their profession with the climate change issues.

However, this does not mean that climate change content at other engineering faculties has been completely neglected. For future research, it is recommended to analyze all courses (except those that contain the term "climate change" in their title) of all engineering programs, in order to determine the representation of climate change as part of the teaching content.

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REFERENCES

Amarquaye, L. (2024). *Education and skills for climate adaptation in engineering.* https://www.imeche.org/news/news-article/education-and-skills-for-climate-adaptation-in-engineering

Axelithioti, P., Fisher, R. S., Ferranti, E. J. S., Foss, H. J., & Quinn, A. D. (2023). What are we teaching engineers about climate change? *Education Sciences*, 13(153), 1-21. https://doi.org/10.3390/educsci13020153

Cambridge & Cambridge ZERO (2024). *Ready for the world: Empowering engineers of the future through climate change education.* Cambridge University Press & Assessment, Shaftesbury Road, Cambridge, https://www.calameo.com/cupeducation/read/0064339975f0da2bd7d3c

Casciato, P. (2024). *Future engineers need climate education in school - Cambridge report*. https://www.zero.cam.ac.uk/who-we-are/blog/news/future-engineers-need-climate-education-school-cambridge-report

Climate Change Education. https://www.unesco.org/en/climate-change/education

Climate Change. https://www.teachengineering.org/populartopics/view/climatechange

Dokumentacija za akreditaciju studijskog programa master akademskih studija, Poljoprivredni fakutlet, Univerzitet u Novom Sadu. http://efaidnbmnnnibpcajpcglclefindmkaj/http://polj.uns.ac.rs/sites/default/files/upload/3ЕМЉИШТЕ%2C%20БИЉКА%20И%20ГЕНЕТИКА%20НОВО.pdf

Državni univerzitet u Novom Pazaru. https://www.dunp.np.ac.rs/

Fakultet ekološke poljoprivrede, Educons Univerzitet. https://educons.edu.rs

Fakultet inženjerskih nauka, Univerzitet u Kragujevcu. www.fink.rs

Fakultet tehničkih nauka, Univerzitet u Novom Sadu. www.ftn.uns.ac.rs

Fakultet tehničkih nauka, Univerzitet u Prištini. https://ftn.pr.ac.rs/

Fakultet zaštite na radu, Univerzitet u Nišu. www.znrfak.ni.ac.rs

Gillis, A. (2024). *What is upskilling and why is it important for your career?* https://www.techtarget.com/whatis/definition/upskilling

Građevinsko-arhitektonski fakultet, Univerzitet u Nišu. www.gaf.ni.ac.rs

Hald-Mortensen, C. (2023). *8 reasons why climate change is a 'super wicked' problem.* https://medium.com/@christianhaldmortensen/8-reasons-why-climate-change-is-a-super-wicked-problem-41ffc6758753

Higgs, B. J., & Patil, U. D. (2024). Integrating climate change into engineering education. *Fall ASEE Mid-Atlantic Section Conference*, Farmingdale State College, NY, New York. https://doi.org/10.18260/1-2—49448

Leal Filho, W., Sima, M., Sharifi, A., Luetz, J. M., Salvia, A. L., Mifsud, M., Olooto, F. M., Djekic, I., Anholon, R., Rampasso, I., Kwabena Donkor, F., Dinis, M. A. P., Klavins, M., Finnveden, G., Chari, M. M., Molthan-Hill, P., Mifsud, A., Sen, S. K., & Lokupitiya, E. (2021). Handling climate change education at universities: An overview. *Environmental sciences Europe*, 33(1), 109. https://doi.org/10.1186/s12302-021-00552-5

Martin, M. J., Diem, S. J., Karwat, D. M. A., Krieger, E. M., Rittschof, C. C., Aghazadeh, B. B. M., Asensio, O., Zeilkova, T. J., Garcia-Cazarin, M., & Maurosa, G. A. (2024). The climate is changing. Engineering education needs to change as well. *Journal of Engineering Education*, 111(4), 740-746. https://doi.org/10.1002/jee.20485

McCowan, T. (2021). *Climate change in higher education: A curriculum topography approach.* Transforming Universities for a Changing Climate, Working Paper Series No. 6. https://www.researchgate.net/publication/356086887_Climate_change_in_higher_education_a_curriculum_topography_approach

Milovanovic, J., Shealy, T., & Godwin, A. (2022). Senior engineering students in the USA carry misconceptions about climate change: Implications for engineering education. *Journal of Cleaner Production*, 345, 131-129.

Molthan-Hill, P., Worsfold, N., Nagy, G. J., & Leal Filho, W. (2019). Climate change education for universities: A conceptual framework from an international study. *Journal of Cleaner Production*, 226, 1092-1101.

National Engineering Policy Centre (NEPC) & Royal Academy of Engineering (2024a). *Calibrating future curricula*. https://nepc.raeng.org.uk/engineers-2030

National Engineering Policy Centre (NEPC) & Royal Academy of Engineering (2024b). *Engineers 2030: Vision and Principles.* https://nepc.raeng.org.uk/engineers-2030

Poljoprivredni fakultet u Kragujevcu, Univerzitet u Nišu. https://poljfak.ni.ac.rs

Poljoprivredni fakultet, Univerzitet u Beogradu. http://www.agrif.bg.ac.rs/

Poljoprivredni fakultet, Univerzitet u Novom Sadu. http://polj.uns.ac.rs

Shealy, T., Valdes-Vasquez, R., Klotz, L., Potvin, G., Godwin, A., Cribbs, J., & Hazari, Z. (2017). Half of students interested in civil engineering do not believe in anthropogenic climate change. *Journal of Professional Issues in Engineering Education and Practice*, 143(3). https://doi.org/10.1061/(ASCE)EI.1943-5541.0000323

Studijski program Zemljište, biljka i genetika, Poljoprivredni fakutlet, Univerzitet u Novom Sadu. http://polj.uns.ac.rs/sr/node/3163

Šumarski fakultet, Univerzitet u Beogradu. www.sfb.bg.ac.rs

UNICEF (2023). Only half of young people able to identify correct definition of climate change – UNICEF, Gallup. https://www.unicef.org/press-releases/only-half-young-people-able-identify-correct-definition-climate-change-unicef-gallup

Verma, A., & Djokic, D. (2021). Reimaging nuclear engineering. *Issues in Science and Technology*, 32(3), 64-69. https://issues.org/reimagining-nuclear-engineering-verma-djokic/

What is climate change education? https://cambridge-community.org.uk/professional-development/gswcce/

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CERTIFICATES FOR OCCUPATIONAL SAFETY AND HEALTH PROFESSIONALS

Abstract: *Professional certification in Occupational Safety and Health (OSH) serves as a critical mechanism for ensuring that practitioners possess the necessary competencies, knowledge, and skills to manage workplace safety and health risks effectively. While certification frameworks are typically regulated at the national level, global efforts have been made to harmonize standards and promote cross-border recognition of professional credentials. This paper reviews the contributions of key international organizations such as INSHPO and ENSHPO, in standardizing certification criteria and provides an analysis of OSH certification in the United States, the United Kingdom, the European Union, Canada, Australia, and Serbia.*

Keywords: occupational safety and health; professional certificates; continual professional development.

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INTRODUCTION

Professional certification constitutes a structured and standardized process by which individuals are formally recognized as possessing the requisite competencies, knowledge, and practical skills to perform duties within a specific professional domain. This validation is conducted by an independent certifying body, ensuring objectivity and adherence to predefined competency frameworks. Certification is widely utilized across numerous professional sectors, including medicine, architecture, engineering, finance, and notably, occupational safety and health (OSH).

Within the OSH field, professional certification plays a critical role in safeguarding the integrity and effectiveness of safety management systems. It serves as a key mechanism for ensuring that practitioners meet uniform standards of practice, which is crucial for preventing occupational injuries, illnesses, and fatalities.

Terminological variations exist globally concerning both the designation of the field itself and the professional titles assigned to individuals working within it. As such, we may encounter slight variations, for example, "occupational safety and health," "occupational health and safety," just "safety," or "safety and health at work," etc. Job titles in this field also vary significantly and may include terms such as "engineer", "professional", "technician", "practitioner", "officer", "adviser", or "manager" (Hale, Hudson, & Pryor, 2020).

In the context of the Republic of Serbia, legislative and institutional advancements related to OSH professional certification have been observed in recent years. However, systemic gaps and inconsistencies persist, indicating a need for further harmonization with international best practices. This paper aims to analyze the current framework governing the certification of OSH professionals in Serbia and compare it with established models in other countries.

PROFESSIONAL CERTIFICATION IN OCCUPATIONAL SAFETY AND HEALTH

Professional certification in the OSH field is regulated at the national level, with each country establishing specific criteria that candidates must fulfill to obtain certification. These criteria typically encompass formal education, relevant professional experience, continuous professional development, and exams for assessing knowledge of national OSH legislation and regulatory frameworks.

In pursuit of harmonizing certification processes globally, international organizations have been established with the primary objective of addressing this challenge and promoting standardization in the field. The two most prominent organizations focused on developing unified frameworks for safety and health at work professionals' certification are the International Network of Safety and Health Professional Organisations - INSHPO and the European Network of Safety and Health Professional Organizations - ENSHPO. INSHPO undertook the task of establishing a global framework for the occupational health and safety OHS profession, titled *Occupational Health and Safety Professional Capability Framework: A Global Framework for Practice* (Pryor, Hale, & Hudson, 2019). *OHS Professional Capability Framework: A Global Framework for Practice* was published with the main goal of clearly defining the role, functions, and

competencies of OHS professionals (INSHPO, 2017). On the other side, ENSHPO is more focused on a regional level, specifically the EU market (Hale, 2019).

Both INSHPO and ENSHPO have a substantial number of members, with some organisations belonging to both networks. Members of INSHPO are the following professional associations: American Society of Safety Professionals - ASSP and Board of Certified Safety Professionals - BCSP from United States of America USA, Health and Safety Professionals Canada - HSPC and Board of Canadian Registered Safety Professionals - BCRSP from Canada, Australian Institute of Health and Safety - AIHS from Australia, New Zealand Institute of Safety Management - NZISM and New Zealand Safety Council - NZSC from New Zealand, Association of Occupational Health and Safety Specialists - AEPSAL from Spain, Korea Occupational Safety and Health Agency - KOSHA from South Korea, Singapore Institution of Safety Officers - SISO from Singapore, National Examination Board in Occupational Safety and Health - NEBOSH and Institution of Occupational Safety and Health - IOSH from United Kingdome UK, Institution of Occupational Safety and Health Management - IOSHM from Mauritius, while the following are associated member: Board of Global EHS Credentialing from USA, Health & Safety Association of New Zealand - HASANZ, and Royal Society for the Prevention of Accidents - ROSPA from UK.

Full members of ENSHPO are: Association of Occupational Health and Safety Specialists - AEPSAL from Spain, Italian Environment and Safety Association - AIAS from Italy, Umbrella Organization for Occupational Health and Safety Professionals - AM-PRO from Denmark, Safety Professionals Association - DPALV from Latvia, Cyprus Safety And Health Association - CYSHA from Cyprus, , Society of Safety Engineers - DVJ Ljubljana from Slovenia, European Society of Occupational Safety and Health - ESOSH from Ukraine, Institute for Risk Management, Occupational Health and Safety - IMRSS from Romania, Institution of Occupational Safety and Health - IOSH from UK and Ireland, Hungarian Occupational Safety and Health Academy - Association for Safety Culture Development - MMA from Hungary, Malta Occupational Safety & Health Practitioners Association - MOSHPA from Malta, National Irish Safety Organisation – NISO from Ireland, National Association of Occupational Health and Safety Service Workers - OSPSBHP from Poland, Portuguese Society of Occupational Safety and Hygiene - SPOSHO from Portugal, Royal Flemish Association for Prevention and Protection – PREBES from Belgium, Association for Safety, Health and Environmental Protection at Work - VDSI from Germany, and The Centre for Occupational Safety from Finland, as a professional member.

Serbia

Under the Occupational Safety Law that was in force in the Republic of Serbia until 2005, occupational safety duties could be performed by a worker with at least a higher education degree in occupational safety or another relevant higher education qualification, depending on the company's industry (Occupational Safety Law, 1998).

When the old Occupational Safety Law was replaced in 2005 by a new law, the name of the field was changed to "Safety and Health at Work". The Safety and Health at Work introduced the requirement to pass a professional exam in practical competence for performing safety and health at work duties, which represented small progress forward in certifying these professionals in Serbia. This law states that individuals designated by the employer as Safety and Health at Work Officers are required to have successfully passed the corresponding professional examination.

A few years later, the Decree on Occupational Safety and Health at Temporary or Mobile Construction Sites introduced two additional types of professional certification: the Safety and Health Coordinator during the execution phase, and the Safety and Health Coordinator during the design phase. For both roles, passing specialized professional exams was required. Interestingly, for the coordinators' professional exams, mandatory preparation was also introduced, although in a limited scope of only 40 classroom hours (Rulebook, 2015).

The most recent Safety and Health at Work Law, adopted in 2023, introduced further changes for professionals in this field. This law introduced new roles in the field of OSH in Serbia in the form of advisors and associates for safety and health at work, which essentially replaced the function of previous safety and health at work officers. For these two roles, there is a process of acquiring professional certificates. Individuals who want to work as either Safety and Health at Work Advisor or Associate must meet specific qualification criteria set by the Safety and Health at Work Law. To qualify for the Health and Safety at Work Advisor certificate in Serbia, candidates must (Safety and Health at Work Law, 2023):

- Hold a degree (at least 240 ECTS credits) in academic or applied studies in the educational-scientific field of technical-technological sciences and natural-mathematical sciences in the following areas: biological sciences, environmental protection sciences, physical sciences, physic-chemical and chemical sciences, and
- Pass Health and Safety at Work Advisor exam.

To qualify for the Health and Safety at Work Associate certificate in Serbia (Safety and Health at Work Law, 2023), candidates must:

- Hold a degree (at least 180 ECTS credits) within the educational-scientific field of technical-technological sciences, natural-mathematical sciences, medical sciences, or social and humanistic sciences, and
- Pass Health and Safety at Work Associate exam.

For certificate renewal, Health and Safety at Work Law requires continuous professional development (Safety and Health at Work Law, 2023). However, this issue still needs to be further elaborated through secondary legislation.

The fundamental difference between an advisor and an associate lies in the specific branches of industry in which they are permitted to work. For example, employers in industries like construction, agriculture, forestry and fishing, mining, manufacturing, electricity, gas, steam and air conditioning supply (trade in electricity and gas via the gas pipeline network are excluded), water supply, wastewater management, waste disposal process control, wholesale trade, transport and storage and similar activities, and health and social care services must hire a Health and Safety at Work Advisor, while employers in other industries can hire either Advisor or Associate (Safety and Health at Work Law, 2023). Employers in health and social care services are granted a specific exception, allowing them to appoint an advisor with at least 240 ECTS credits from academic or applied studies in the field of medical sciences (Safety and Health at Work Law, 2023).

The following section will examine similar certificates in the OSH field from the USA, the UK, the EU, Canada, and Australia. Some certification programs, although originally designed as national qualifications, are recognized and accepted beyond their countries of origin, reflecting their broader relevance and credibility in the international context.

USA

The Certified Safety Professional - CSP is one of the most widely recognized and respected certifications in the world, regarded as a top professional credential in the field of occupational safety and health. This certificate is issued by the Board of Certified Safety Professionals - BCSP from the USA and is recognized far beyond the US borders, especially in Asia. Requirements for CSP are a minimum bachelor's diploma, 4 years of safety experience, some BCSP Qualified Credential like CRSP, NEBOSH diploma or similar, and passing the CSP exam. The Associate Safety Professional – ASP is another certificate issued by BSCP, on a lower level than CSP. Requirements for ASP are a bachelor's degree in any field or a college degree in safety, health, or environment, one year of safety experience, and passing of ASP exam.

For both certificates, there is a renewal process every five years by collecting enough points through attending conferences and seminars, becoming a member of professional organisations, taking safety-related courses, or by BCSPpro testing (BCSP, 2025).

UK

NEBOSH certificates are considered comparable to CSP certifications and are issued by the National Examination Board in Occupational Safety and Health, a leading global organization that awards qualifications in occupational safety, health, and environmental management. NEBOSH offers 21 different qualifications, categorized into four levels: Awards, Certificates, Diplomas, and Masters.

Awards and Certificates are entry-level qualifications, mainly representing an introduction to OHS, and serve as a stepping stone to some of the more advanced qualifications like NEBOSH's Diplomas and Masters. The International and National General Certificates in Occupational Health and Safety are among the most popular certificates issued by NEBOSH. The main difference between the two is that the National certificate is based on UK health and safety legislation, therefore intended for safety professionals working in the UK, while the International certificate is recognised globally, and intended for safety professionals working for international companies. The NEBOSH International General Certificate in Occupational Health and Safety has been very popular among Serbian safety professionals in recent years.

Like many NEBOSH certifications, these do not have specific educational prerequisites. They typically involve approximately two weeks of training, followed by an examination. Upon successful completion, candidates are awarded a certificate that does not have an expiration date or require renewal. The only stated requirement is proficiency in the English language.

NEBOSH's Diplomas and Masters are among some of the most valued professional certifications in the world and are recognised by many professional associations like the Board of Certified Safety Professionals, Institution of Occupational Safety and Health (IOSH), etc.

Another significant type of certification comes from the Institution of Occupational Safety and Health (IOSH), a global organization in the field of OSH based in the United Kingdom. IOSH is one of the largest global organizations that brings together OSH professionals, with over 50,000 members from 130 countries worldwide (IOSH, n.d.). The organization offers two professional certifications: the IOSH Level 3 Certificate in Occupational Safety and Health Principles and Practice, which serves as the entry-level qualification, and the IOSH Level 6 Diploma in Occupational Safety and Health Leadership and Management, which is intended for more experienced OSH professionals. Both certificates issued by IOSH are recognized globally. The IOSH certificate has no formal prerequisites, just to attend an IOSH level 3 course and pass an exam, while for the IOSH diploma, it is required to have prior qualification in OSH, like an IOSH or NEBOSH certificate, and work experience in OSH.

EU

In the European Union, efforts have been underway since 2001 to unify the certification process for health and safety at work professionals across all member states. For this purpose, the European Network of

Safety and Health Professional Organizations ENSHPO was established within the European Agency for Health and Safety at Work EU-OSHA. There are two certificates offered within this framework: European Occupational Safety and Health Manager EurOSHM and European Occupational Safety and Health Technician EurOSHT. To get the EurOSHM certificate individual must meet the following requirements (ENSHPO, 2013a):

- Bachelor's or equivalent as a minimum;
- OHS training courses (250 h);
- OHS functions experience of 2 years and experience after OHS training; and
- Membership in a national association that is part of ENSHPO.

The EurOSHT certificate requirements are the following (ENSHPO, 2013b):

- Secondary education as a minimum;
- OHS training courses (120 h);
- OHS function experience of 4 years for secondary education and 2 years for higher education, and experience after OHS training; and
- Membership in a national association that is part of ENSHPO or employment in a company that is a member of a national association.

The recertification process of ENSHPO requires certified holders to meet Continuing Professional Development goals in three years.

Australia

The Australian Institute of Health & Safety - AIHS is responsible for the certification of health and safety professionals in Australia. Since AIHS is a member of INSHPO, its certification process is in line with INSHPO's OHS Professional Capability Framework. A health and safety professional in Australia can get one of the following three certificates: Certified OHS Practitioner, with the following requirements: diploma or advanced diploma of OHS and 3 years as OHS practitioner; Certified OHS Professional with the following requirements: Bachelor of OHS, graduate diploma of OHS or master of OHS and 3 years as OHS professional; and Certified Chartered OHS Professional with the following requirements: master of OHS and 10 years in senior OHS role. Certified OHS Practitioners/Professionals have to pass a capability assessment by using an online self-assessment tool, so there is no real exam. AIHS requires that all OHS roles complete Continuing Professional Development in three years for recertification.

Canada

The Board of Canadian Registered Safety Professionals - BCRSP is an organisation responsible for the certification of health and safety professionals in Canada. Two types of certificates can be acquired from BCRSP: Canadian Registered Safety Professional – CRSP with the following requirements: minimum bachelor diploma with sufficient professional development in occupational health and safety or a 2-year diploma in occupational health and safety, 4 years of experience in occupational health and safety roles and passed CSRP exam; and Canadian Registered Safety Technician – CRST with the following requirements: 1-year occupational health and safety certificate or 2-years in any discipline, or a 2-year diploma in occupational health and safety, 1-year work experience with at least 35% OHS duties, candidates with 2-year OHS diploma are not required to have work experience, candidates with non-OHS diplomas must demonstrate professional development in OHS, and passing CRST exam. Recertification is done every 5 years with mandatory participation in a professional development program.

CONCLUSION

Compared to other countries, OSH professionals in Serbia are not required to have work experience before they can get an Advisor or Associate for Safety and Health at Work certificate. Instead, candidates must satisfy formal educational criteria and successfully pass the corresponding certification examination. Although this constitutes progress relative to previous regulatory conditions, it is anticipated that Serbia will progressively seek alignment with the ENSHPO standards concerning professional roles within the OSH system. A notable advancement is the introduction of mandatory continuous professional development for OSH practitioners. However, the regulatory mechanisms governing this requirement remain to be fully defined through subsidiary legislation. Furthermore, the practical implementation and efficacy of continuous professional development programs warrant further observation.

In jurisdictions reviewed, a significant degree of harmonization exists regarding occupational titles within the OSH domain. Typically, certification eligibility is contingent upon the acquisition of a defined period of professional experience. Continuous education programs exhibit substantial consistency, with variability primarily observed in the recertification intervals, ranging from three to five years across different countries. An unexpected observation pertains to the NEBOSH certification, a highly regarded international credential, which does not impose formal educational prerequisites. Instead, emphasis is placed on training completion and proficiency in the English language.

The regulatory framework in Serbia inadequately addresses the roles of individuals with lower levels of formal qualification. Specifically, individuals lacking tertiary education are precluded from obtaining any form of certification in the OSH field, indicating a potential area for policy development to ensure inclusivity and professional development pathways for a broader range of practitioners.

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REFERENCES

Board of Certified Safety Professionals BCSP. (2025). *Recertification Guide, 19th edition*. BCSP Publication.

ENSHPO (2013a). *Certification standard for European Occupational Safety & Health Managers (EurOSHM)*.

ENSHPO (2013b). *Certification standard for European Occupational Safety & Health Technicians* (*EurOSHT*).

Hale, A. (2019). From national to European frameworks for understanding the role of occupational health and safety (OHS) specialists. *Safety Science*, *115*, 435-445. https://doi.org/10.1016/j.ssci.2019.01.011

Hale, A. R., Hudson, D., & Pryor, P. (2020). The evolution of a global, professional capability framework covering the role, contribution and status of Occupational Health and Safety (OHS) professionals: Editorial, introduction and discussion. *Safety Science*, *122*, 104509. https://doi.org/10.1016/j.ssci.2019.104509

Institution of Occupational Safety and Health (IOSH) (n.d.) *IOSH Level 3 Certificate*. https://iosh.com/qualifications-and-courses/qualifications/iosh-certificate

International Network of Safety and Health Practitioner Organisations INSHPO. (2017). *The Occupational Health and Safety Professional Capability Framework: A Global Framework for Practic*e. International Network of Safety and Health Practitioners Organisations (INSHPO). Park Ridge, IL, USA.

Occupational Safety Law (1998) Official Gazette of RS, no. 42/1991, 53/1993, 67/1993, 48/ 1994, and 42/1998.

Provan, D. J., & Pryor, P. (2019). The emergence of the occupational health and safety profession in Australia. *Safety Science*, *117*, 428-436. https://doi.org/10.1016/j.ssci.2019.04.036

Pryor, P., Hale, A., & Hudson, D. (2019). Development of a global framework for OHS professional practice. *Safety Science*, 117, 404-416.

https://doi.org/10.1016/j.ssci.2019.04.033

Rulebook on the program, manner, and cost of preparation and taking of the professional exam for performing the duties of coordinators for safety and health matters at the project preparations stage and the professional exam for performing the duties of coordinators for safety and health matters at the execution stage (2015) Official Gazzete of the RS, no. 113/2023, 58/2014 and 111/2015.

Safety and Health at Work Law (2023) Official Gazzete of the RS, no. 35/2023.

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OCCUPATIONAL HEALTH AND SAFETY – HOW TO ACHIEVE EFFECTIVE PERFORMANCE EVALUATION

Abstract: *Occupational health and safety (OHS) is not a phenomenon of the modern world and has deep roots in history. The history of occupational safety can be divided into several phases of development. EU-OSHA estimates that the social cost of work-related injuries and diseases is 3.9% of global GDP and 3.3% of EU GDP. The loss of GDP in the EU is the lowest of all regions according to the classification of the World Health Organization (WHO). In these challenging times, when the world of work is experiencing various rapid changes, the evaluation of the performance of occupational health and safety is becoming increasingly important. It is necessary to monitor various performance indicators at different levels and functions and to use different methods. A review of recent scientific literature and OHS international standards in this area has been conducted. The article presents the latest considerations on how to achieve effective evaluation of OHS performance using international standards.*

Keywords: evaluation, indicators, occupational health and safety, performance

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INTRODUCTION

The history of occupational health and safety (OHS) can be divided into several phases of development, from the initial primitive work to the application of robots and artificial intelligence. Therefore, OHS is not a phenomenon of the modern world and has deep roots in history. EU-OSHA estimates that the social cost of work-related injuries and diseases is 3.9% of global GDP and 3.3% of EU GDP (Eurostat, 2024). The loss of GDP in the EU is the lowest of all regions according to the classification of the World Health Organization (WHO) (European Commission, 2021). In these challenging times, when the world of work is experiencing various rapid changes, the evaluation of the OHS performance is becoming increasingly important. It is necessary to monitor various performance indicators at different levels and functions and to use different methods.

Occupational health and safety is generally defined as the science of predicting, identifying, assessing and controlling hazards arising in or from the workplace that could impair the health and well-being of workers, taking into account the possible impact on the surrounding communities and the general environment (Wolff, 2007). A wide range of skills, knowledge and analytical capacity are needed to coordinate, implement, and monitor all elements and indicators to protect workers (Alli, 2008).

Economically, morally, and legally, OHS has become an important issue. Companies are trying to remain profitable in an increasingly competitive global economy. For these companies, addressing the issue of worker safety and health can mean more than good business practice; it can help in new business successes. Therefore, strong safety and health programs with continuous monitoring and evaluation of indicators can further contribute to business development (Friend & Kohn, 2007).

Effective OHS management requires appropriate and reliable measurement of OHS performance. Various indicators are used to measure performance. According to ISO 45004:2024, indicators are variables that can be measured or described, representing the status or a characteristic of operations, processes, management, and conditions or outcomes.

Indicators designed to measure OHS performance in companies are intended to provide information on the extent to which the desired outcome has been achieved or on the quality of the processes leading to that outcome. Different types of indicators are used to measure the success of OHS, which show the inputs, processes, and outcomes of OHS (Pawłowska, 2015).

Indicators that reflect OHS outcomes and are applied during the reactive monitoring process, with a focus on measuring losses, are called trailing indicators. In the literature on this topic, the term *outcome indicators* (Health and Safety Executive, 2001) is used in addition to the term *negative performance indicators* (Bottomley, 2001) or lagging indicators (Dyck & Roithmayr, 2001). Various researchers emphasize that timely and accurate analysis of these indicators is essential for successful prevention (Karwowski et al., 1988). These indicators are easy to calculate based on

data collected in the company in accordance with legal requirements (Health and Safety Executive, 2006). Latency indicators can provide information about the effectiveness of actions taken in the past, but do not allow for their immediate monitoring and correction.

Indicators that show input data and processes belong to the group of leading indicators (Nelson, 2008) and are most often called positive performance indicators (National Occupational Health and Safety Commission, 1994).

Over the years, various guidelines have been developed to support companies in measuring OHS performance, among which those of the British Health and Safety Executive (Health and Safety Executive, 2001) (Health and Safety Executive, 2006) and Australian National Health and Safety Commission (Department of Employment and Workplace Relations, 2005) are particularly noteworthy.

A new dimension and significance to the assessment of OHS performance are given by the requirements related to non-financial reporting on corporate sustainability ESG, i.e. the requirements of the ESRS S1 and ESRS S4 standards (ESRS, 2024).

So, regardless of whether an organization is a public company, a private enterprise, or a non-profit organization, effective OHS management can contribute to business success (O'Neill & Wolfe, 2017).

METHODOLOGY

Aim, tasks and research methodology

The problem that has been identified in this area is the lack of recent knowledge on how to achieve effective OHS performance evaluation. The aforementioned problem is manifested through the small number of studies in this area, but also the low level of understanding of the area. Given the identified problem, the aim of this research is to investigate and demonstrate how to achieve effective OHS performance evaluation.

In accordance with the set objective, the research tasks are to

- collect data on the areas and process of OHS evaluation;
- identify the most significant OHS performance indicators;
- analyze the levels and functions at which indicators are collected;
- present how to achieve effective OHS performance evaluation.

The research methodology used in this study involves the application of various scientific methods. A combination of deductive and inductive analysis is used to classify and summarize the basis of the research subject. The method of studying the content of scientific and professional literature analyzes the content that considers the evaluation of performance. The description method describes the essential features and elements of the research subject. The synthesis method draws conclusions.

Hypotheses

Based on the identified problem and the set research objective, hypotheses were set that will be confirmed or rejected based on the research results:

H1: Each level or function in a company has its own group of OHS performance indicators.

H2: There are factors that can lead to wrong conclusions in the process of evaluating OHS performance.

H3: It is possible to achieve effective OHS performance evaluation.

RESULTS AND DISCUSSION

Occupational health and safety

Occupational health and safety are the key aspects of organizational management, aimed at ensuring safe and healthy working conditions. Effective performance evaluation in the field of occupational health and safety involves systematic processes of monitoring, measuring, analyzing, and improving working conditions. According to ISO 45004:2024, performance evaluation is essential for determining whether planned objectives are being met, including the continual improvement of occupational health and safety, compliance with legal and other requirements, and the achievement of defined safety goals (ISO 45004:2024).

In the Republic of Croatia, the field of occupational health and safety is primarily regulated by the Occupational Health and Safety Act (OG 71/14, 118/14, 94/18, 96/18), which imposes the obligation on employers to implement occupational safety measures. The Regulation on Risk Assessment (OG 112/14, 129/19) defines the conditions, methods, and procedures for risk assessment, which serves as the foundation of effective occupational health and safety management.

ISO 45004:2024 emphasizes the use of various evaluation tools, including inspections, pre- and post-activity reviews, incident investigations, audits, and management reviews. As stated in ISO 45004, inspections enable quick and efficient determination of the current state regarding the application of risk controls and regulatory compliance (International Organization for Standardization, 2024). The Croatian legislative framework is fully aligned with these recommendations.

The effectiveness of occupational health and safety management largely depends on the definition of clear performance indicators. Indicators can be classified as leading, which are proactive and predictive of future performance (e.g. employee participation in training for safe work practices), and lagging, which reflect past events (e.g. workplace injury rate) (International Organization for Standardization, 2024). The use of both types provides a comprehensive overview of performance. For example, Croatian companies regularly monitor indicators such as the frequency rate of occupational injuries and occupational diseases, thereby fulfilling legal obligations and providing a basis for improvements in occupational safety.

ISO 45004 also highlights potential adverse effects related to the selection and application of indicators, such as underreporting of incidents due to fear of consequences or financial incentives that may compromise data accuracy. Therefore, it is essential to maintain a transparent and supportive reporting culture within the organization, actively involving workers at all levels to ensure data accuracy and the effectiveness of safety management (International Organization for Standardization, 2024).

In practice, comprehensive evaluation of occupational health and safety enables organizations to identify and correct deviations from planned safety outcomes. Effective assessment processes include regular collection and analysis of data related to workplace incidents, exposure levels, and the effectiveness of implemented safety measures. Internal and external audits provide critical feedback, allowing for rapid adaptation to changing conditions and regulatory requirements.

Integrating a structured assessment of occupational health and safety aligned with ISO 45004 and Croatian legal requirements equips organizations with robust mechanisms for enhancing workplace safety and health. Continuous monitoring, proactive use of indicators, and effective internal communication foster a culture of safety, resulting in risk reduction and improved overall organisational performance.

OHS performance evaluation

Performance evaluation encompasses a process or set of processes that compares the outcomes achieved by organizations against pre-established objectives. These objectives may include the continuous improvement of occupational health and safety (OHS) performance, the achievement of OHS-related goals, and compliance with legal and other obligations.

When conducting performance evaluation, organizations should consider various sources of information that can serve as input data. To achieve set objectives, it is advisable to use diverse sources of information to ensure a concise and comprehensive assessment, as relying on a single source may lead to incomplete or inaccurate conclusions. The purpose of performance evaluation is to help organizations determine the extent to which their objectives have been achieved.

Performance evaluation is essential for effective OHS management and supports better decision-making within organizations. For example, it enables organizations to

- assess whether top management demonstrates commitment and support for OHS management;
- identify which processes are achieving planned results and which are not;
- detect deviations in processes or activities affecting OHS performance, as well as the causes of such deviations;
- recognize opportunities for improvement or the need to take action to enhance processes (International Organization for Standardization, 2024).

In conducting performance evaluations, organizations must consider all business processes, such as procurement, production, logistics, the effectiveness of the OHS management system, and organizational assumptions and safety culture that influence employee behaviour. It is especially important to identify incorrect assumptions, such as the belief that incidents are always the result of unsafe worker behaviour or that a low rate of accidents automatically indicates a high level of workplace safety.

The evaluation process includes setting objectives, determining measures for their achievement, monitoring results through various tools and information sources, and taking corrective or improvement actions. Regular monitoring, analysis, and assessment ensure the organization responds to identified issues and unforeseen consequences.

Furthermore, organizations may use various data sources and methods, including

- ***Inspections:*** A quick way to check working conditions, the use of personal protective equipment, and control effectiveness;
- ***Pre- and post-activity reviews:*** Analysis of planned and actual working conditions, safety measure effectiveness, and training needs;
- ***Exposure assessments and workers' health surveillance:*** Monitoring harmful factors such as hazardous chemicals, biological and physical hazards (e.g. noise), and ergonomic risks to prevent adverse effects;
- ***Safety meetings and focus groups:*** Discussions at different organizational levels to gather feedback and identify opportunities for improvement;
- ***Surveys and interviews:*** Questionnaires and interviews with workers can reveal issues such as inadequate training, psychosocial risks, and other relevant concerns.

Collecting data on injuries, accidents, and occupational diseases helps understand risks and the effectiveness of protective controls. Organizations must be cautious, as a low number of reported injuries may not reflect the real situation but rather indicate a lack of awareness or fear of reporting.

Incident analysis helps understand root causes and supports the implementation of corrective measures. In this context, organizations should avoid placing sole blame on workers and instead consider broader factors, such as work organization and resource allocation.

Results from internal and external audits and management reviews are key to identifying system weaknesses and improvement opportunities. The goal of evaluation is the continuous improvement of safety, health, and working conditions and the achievement of set goals through data analysis and action based on findings (International Organization for Standardization, 2024).

OHS performance indicators

To monitor and measure the status of processes, management, and outcomes, organizations should use

performance indicators. Indicators may be applied at various levels, including the entire organization, management, specific departments, processes, or tasks, and should cover various types of risks.

The selection of indicators must align with OHS objectives and policies. Roles and responsibilities for performance evaluation should be clearly defined and communicated. Indicators may be general for benchmarking against other organizations or specific to the organization's context.

Key features of indicators

- Meaningful, measurable, and aligned with organizational goals;
- Sensitive to change;
- Verifiable and comparable;
- Useful for monitoring short- and long-term changes, understandable at the operational level, and tailored to different organizational functions (International Organization for Standardization, 2024).

Table 1. *Indicators at various levels/functions within the organization (source: International Organization for Standardization, 2024)*

Level or function	Example indicators
Organization/Top Management	Injury and illness frequency rates and trends. Aggregate results of health surveillance (while maintaining data confidentiality). Degree of worker involvement (e.g. participation in performance/risk assessment, improvement proposals).
OHS Management System / Responsible Personnel	Scope of OHS management system implementation. Percentage of objectives achieved. Percentage of equipment changes requiring consequence review. Effectiveness test results of OHS improvement programs.
Departments / Managers	Degree of implementation of risk reduction activities. Percentage of risks reduced or eliminated, or opportunities implemented. Effectiveness of on-site inspections.
Processes and Tasks / Supervisors	Percentage of procedures updated as scheduled. Percentage of competent workers available for a specific task compared to required number.
Worker Participation	Percentage of concerns or suggestions submitted. Percentage of participation in OHS discussions. Percentage of incidents reported.

Indicators may lose relevance over time due to changes in organizational context, such as legislative updates, process changes, or risk evolution. Therefore, they must be regularly reviewed and adapted to remain effective. Quantitative indicators, such as the percentage of implemented corrective actions, can be complemented with qualitative indicators, such as findings from analyses, as performance evaluation evolves.

Types of indicators

- ***Leading indicators*** focus on activities that can improve future performance (e.g. number of trained workers).
- ***Lagging indicators*** measure past performance (e.g. number of workplace injuries).
- ***Quantitative and qualitative indicators*** provide objective data; qualitative indicators enable deeper process analysis (International Organization for Standardization, 2024).

Inadequate selection or use of indicators can result in incorrect reporting or misinterpretation. Organizations must recognize and manage risks associated with insufficient or excessive reporting to maintain credibility in performance evaluation processes.

Benchmarking enables comparison with other organizations to improve processes. However, contextual differences must be considered, particularly between sectors. Properly used, benchmarking can be highly beneficial.

These indicators and approaches support systematic and effective OHS performance evaluation and contribute to continuous improvement.

Table 2. *Examples of unintended consequences due to misinterpretation/misuse of indicators (source: International Organization for Standardization, 2024)*

Influencing Factors	Potential Unintended Consequences
Lack of worker participation	Reduced engagement and trust in OHS matters (e.g. fewer suggestions for improvement)
Indicators not aligned with organizational strategy	Lack of senior management support for OHS issues
Focus only on frequent incidents	Neglect of low-frequency but high-impact potential incidents
Poor communication with stakeholders	Inappropriate indicator selection or result misinterpretation
Complex indicators	Lack of support if stakeholders cannot understand them
Universal global indicators	Unreliable results when used across diverse locations without accounting for context (e.g. legal requirements, work practices, culture)
Cost-driven indicator selection	Ineffective indicators leading to poor decision-making and weaker OHS outcomes
Financial and other incentives	Distorted reporting or under-/over-reporting may result in incident reports from a limited group only.

Integration of OHS performance evaluation into business processes

Despite technological progress and the development of OHS management systems, creating a sustainably safer work environment still largely depends on developing and strengthening safety culture. Compliance with legal requirements, implementation of OHS management systems, and active management of cultural change are key elements for achieving a positive safety culture (Kim et al., 2016).

In this context, ISO 45004:2024 emphasizes the importance of continuous evaluation of OHS measures as a fundamental tool for improving OHS performance. Systematic monitoring and analysis enable not only compliance but also the development of a proactive safety approach essential for sustaining safety culture within the organization.

Implementing and improving workplace safety culture reduces the frequency of accidents and injuries, thereby lowering operational costs and losses. As safety culture is an integral part of organizational culture and structure, it is also a vital component of OHS performance evaluation (Palačić, 2010).

Organizations should use performance evaluation to verify the alignment of planned outcomes with business plans and expectations. Improvements in OHS performance may also serve to assess and enhance other business processes, particularly since OHS management is an integrated part of organizational operations.

Accordingly, organizations should integrate OHS monitoring processes into business processes and systems. It is also highly advisable and important to assign responsibility for monitoring and measuring business processes across all levels of management

Examples of integration and alignment activities

- The process of selecting and conducting performance evaluations, including indicators, proactively assesses potential unintended consequences and negative impacts on other business sectors.
- OHS system inspections and internal audits are integrated with other management systems (e.g. quality, environmental, energy).
- Consistent methods are used to investigate incidents affecting OHS, environment, and quality.
- Equipment damage reports include potential OHS and environmental impacts.
- Performance evaluation and corrective action processes are aligned across management systems, with common issues identified and addressed.
- Surveys on organizational culture related to OHS, including psychosocial factors and psychological well-being, safety, and health, can provide insights into quality, environmental impact, productivity, and workforce retention.
- OHS equipment is included in the general calibration program.
- Worker exposure monitoring is integrated with indoor air quality workshops to address OHS performance issues and identify improvement opportunities.
- Consideration of cost, quality, productivity, and OHS in performance evaluation processes (procurement, contractors, suppliers) (International Organization for Standardization, 2024).

Acting on results

Following the analysis and assessment of results, organizations should prioritize actions by considering the following:

- The potential impact on OHS performance;
- Compliance with legal and other OHS-related requirements;
- Alignment with the organization's strategic direction;
- Opportunities for improving OHS management;
- Results and consequences of external OHS performance assessments (e.g. contractual compliance, recognition by authorities, or maintenance of OHS certification) (International Organization for Standardization, 2024).

CONCLUSION

Effective OHS management requires appropriate and reliable measurement of OHS performance. Various indicators are used to measure performance. According to ISO 45004:2024, indicators are variables that can be measured or described, representing the status or a characteristic of operations, processes, management, and conditions or outcomes.

Over the years, various guidelines have been developed for measuring OHS performance. Of course, each organization needs to determine for itself how to effectively measure OHS performance. Regardless of whether the organization is a public company, a private enterprise, or a not-for-profit organization, effective OHS management can contribute to business success. Therefore, it is very important to strive towards achieving the effectiveness of OHS evaluation.

The aim of this research was achieved. Also, the set hypotheses were confirmed. The paper showed how to achieve an effective evaluation of occupational safety.

A potential continuation of the presented research is to conduct empirical research on the application of OHS performance evaluation.

REFERENCES

Alli, B. O. (2008). *Fundamental principles of occupational health and safety*. International Labour Organization. Geneva.

Bottomley, B. (2021). OHSMS Performance measures that add up. Occupational health and safety management systems. Proceedings of the First National Conference, WorkCover NSW. 131–150. http://www.workcover.nsw.gov.au/formspublications/publications/documents/ohs_management_systems_4231.pdf.

Department of Employment and Workplace Relations. (2005). *Guidance on the use of positive performance indicators to improve workplace health and safety*. Commonwealth of Australia. http://www.safeworkaustralia.gov.au/sites/SWA/about/Publications/Documents/150/GuidanceOnUseOfPPIs_2005_PDF.pdf.

Dyck, D. & Roithmayr, T. (2024). Great safety performance: an improvement process using leading indicators. AAOHN J. 12(52). 511–520.

European Commission. (2021). *The European Pillar of Social Rights Action Plan.* Luxembourg. Publications Office of the European Union. https://op.europa.eu/webpub/empl/european-pillar-of-social-rights/en/index.html

European sustainability reporting standards (ESRS). ANNEX I to Commission Delegated Regulation (EU) 2023/2772 supplementing Directive 2013/34/EU of the European Parliament and of the Council as regards sustainability reporting standards. Official Journal of the European Union 22 December 2023 including the corrigendum published on 18 April 2024. https://xbrl.efrag.org/e-esrs/esrs-set1-2023.html

Eurostat: *Database, data for common economic sectors in the EU-15 (1994-2009) and for all economic sectors in the EU-27 (2010-2018).* https://ec.europa.eu/eurostat/data/database

Friend, M. A. & Kohn, J. P. (2007). *Fundamentals of occupational safety and health*. Government Institutes. Linham.

Health and Safety Executive. (2001). *A guide to measuring health and safety performance*. http://www.hse.gov.uk/opsunit/index.htm.

Health and Safety Executive. (2006). *Developing Process Safety Indicators. A step-by-step guide for chemical and major hazard industries*. http://antarisconsulting.com/docs/guides/unit_a/A3_HSG254_Developing_Process_Safety_Indicators.pdf.

International Organization for Standardization. (2024). *ISO 45004:2024: Occupational health and safety management — Guidelines on performance evaluation*. ISO. https://www.iso.org

Kim, Y., Park, J., & Park, M. (2016). Creating a culture of prevention in occupational safety and health practice. *Safety and Health at Work, 7*(2), 89–96 https://doi.org/10.1016/j.shaw.2016.02.002

Karwowski, W., Rahimi, M., & Mihaly T. (1998). Effects of computerized automation and robotics on safety performance of a manufacturing plant. *Journal of Occupational Accidents*. 10. 217–233.

National Occupational Health and Safety Commission. (1994). *Positive performance indicators for OHS: beyond lost time injuries. Part 1*. Commonwealth of Australia. doi:10.1080/10803548.2005. 11076645.

Nelson B. (2008). Inspections and severity: two safety leading indicators that you can use today. *Occup Health Saf.* 6. 87–90. http://www.indsci.com/docs/Press/OHS_0708.pdf.

O'Neill, S., Wolfe, K. (2017). Measuring and reporting on work health & safety. Safe Work Australia. Canberra.

Palačić, D. (2010). Istraživanje razvoja i utjecaja kulture sigurnosti na sustav upravljanja sigurnošću. *Sigurnost, 52*(2), 105–112. https://hrcak.srce.hr/file/84104

Pawłowska, Z. (2015). Using lagging and leading indicators for the evaluation of occupational safety and health performance in industry. *International Journal of Occupational Safety and Ergonomics*. 21(3). 284-290, DOI: 10.1080/10803548.2015.1081769

Wolff, J. (2007). Introduction: What is the value of preventing a fatality? In: Lewens, T. (eds.) *Risk: Philosophical Perspectives*. London. Routledge.

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ENVIRONMENTAL PROTECTION GOALS AND SCOPE OF POLICIES IN THE EUROPEAN UNION BY 2030

Abstract: *Environmental protection is one of the key focuses of the European Union's activities, operating at various levels – from policy and legislation to financial investments. The European Green Deal, the EU's main environmental policy plan, aims for Europe to become the first climate-neutral continent by 2050. This involves reducing carbon dioxide emissions, transitioning to renewable energy sources, investing in green technology, strengthening environmental legislation, and more. The Eighth Environmental Action Program, adopted in alignment with the European Green Deal, provides the framework for EU environmental policy until 2030. It sets the priority goals for environmental protection until 2030 and the conditions necessary for their achievement. At the same time, it forms the basis for the European Union's contribution to achieving the United Nations Agenda for 2030 and its sustainable development goals. This paper analyzes six priority goals of the Eighth Environmental Action Program and the progress made toward achieving them, monitored through 26 indicators. The research results indicate that the European Union has successfully achieved some goals, but there are goals that require significantly greater efforts and resources to be fully realized.*

Keywords: Eighth Environmental Action Program, European Union, goals, results

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INTRODUCTION

One of the key priorities in the overall policy framework of international organizations – particularly that of the European Union – is the protection of the environment (Ilić Petković, Ilić Krstić, & Jovanović, 2016). In line with this commitment, the European Union adopted the European Green Deal (2019), a document outlining its strategic plan and objectives in the field of environmental protection policy. The European Green Deal is the EU's main environmental policy plan, and it has its roots in a long-standing tradition of EU energy and climate legislation and policymaking (Agostini, 2024). It serves as an initial overarching framework for the Union's key environmental policies and measures, and all future EU activities and policies are expected to contribute to the realization of the objectives set forth in the European Green Deal. Recognizing that environmental degradation poses a serious threat not only to the European continent but also to the entire planet, the European Union has developed the European Green Deal with the aim of transforming the Union into a modern, resource-efficient, and competitive economy. The Deal seeks to ensure the following: no net emissions of greenhouse gases by 2050, economic growth decoupled from resource use, and that no person and no place is left behind (EU, 2025).

Based on the European Green Deal, the Eighth Environment Action Programme (2022) was adopted. This document establishes the framework for the European Union's environmental protection policy up to the year 2030. It defines the priority objectives of environmental policy for this period, as well as the necessary conditions for their achievement. At the same time, it serves as the foundation for the European Union's contribution to the implementation of the United Nations 2030 Agenda for Sustainable Development.

This paper analyzes the six priority objectives of the Eighth Environment Action Programme. It examines and assesses the progress achieved thus far in their implementation. The results are monitored using 26 indicators. The data obtained aim to indicate the extent to which the European Union has been successful in achieving the defined objectives, the obstacles encountered in the process, as well as the opportunities for enhancing the effectiveness of their implementation by the target year – 2030.

OBJECTIVES OF THE EIGHTH ENVIRONMENT ACTION PROGRAMME

The Eighth Environment Action Programme (8th EAP) establishes a system of activities and measures aimed at implementing the European Green Deal. The European Commission is obligated to report annually to the European Parliament and the Council on the measures undertaken within the framework of the Programme and to outline potential future actions. The governance mechanism of the 8th EAP includes annual monitoring, evaluation, and reporting on the progress made toward achieving its six priority objectives, based on 26 key indicators. The long-term priority objective of the 8th EAP, as stated in the 8th EAP 2050 (2019), is: "By 2050 at the latest, people live well, within the planetary boundaries in a wellbeing economy where nothing is wasted, growth is regenerative, climate neutrality in the Union has been achieved and inequalities have been significantly reduced. A healthy environment underpins the wellbeing of all people and is an environment in which biodiversity is conserved, ecosystems thrive, and nature is protected and restored, leading to increased resilience to climate change, weather- and climate-related disasters and other environmental risks. The Union sets the pace for ensuring the prosperity of present and future generations globally, guided by intergenerational responsibility."

To support the achievement of the objectives set out in the 8th EAP, a set of indicators has been selected to measure long-term outcomes within the EU and its Member States. The chosen set of indicators corresponds to the structure of the Programme and comprises 26 indicators in total. Each specific priority objective is monitored using two indicators, except for biodiversity, which is assessed using three indicators. In addition, five indicators are used for monitoring environmental pressures, enabling conditions, and the long-term priority objective set for 2050.

MONITORING RESULTS AND PROSPECTS FOR ACHIEVING THE OBJECTIVES BY 2030

According to the data from the European Environment Agency (EEA, 2025b), starting with the first indicator – Total net greenhouse gas emission trends and projections in Europe – net greenhouse gas (GHG) emissions in the EU-27 decreased by 31% between 1990 and 2022, including emissions from international transport as regulated by EU legislation. Preliminary estimates suggest a further record year-on-year reduction of 8% in 2023, representing significant progress toward achieving climate neutrality within the European Union. This downward trend in net GHG emissions reflects the gradual strengthening of policies aimed at reducing emissions over the past two decades. The overall decline can primarily be attributed to a transformation in energy production methods, most notably a significant decrease in coal use and a corresponding increase in the deployment of renewable energy sources. There has also been a modest reduction in overall energy consumption, alongside substantial decreases in emissions from certain industrial production processes (EEA, 2020).

The second indicator – Greenhouse gas emissions from land use, land use change, and forestry (LULUCF) in Europe – shows that LULUCF activities resulted in the net removal of 236 million tonnes of CO_2 equivalent (MtCO2e) from the atmosphere in 2022, equivalent to approximately 7% of the EU's total annual greenhouse gas emissions (EEA, 2025b). The LULUCF Regulation establishes an EU-wide net removal target of an additional 42 MtCO2e by 2030, relative to the 2016-2018 average. However, projections submitted by Member States indicate that this target will not be met. Even when accounting for planned additional measures, the projections foresee a decline in net removals compared to the 2016-2018 baseline. The 2024 update of the National Energy and Climate Plans is expected to help bridge the gap toward achieving this target.

The third indicator, Climate-related economic losses, reveals that weather- and climate-related extreme events caused economic losses of assets estimated at EUR 738 billion in the EU between 1980 and 2023, with over EUR 162 billion (22%) occurring between 2021 and 2023 (EEA, 2025a). Statistical analyses indicate that economic losses have increased over time, with the last three years ranking among the top five years with the highest annual economic losses. Given that severe weather- and climate-related extreme events are expected to intensify further, it appears unlikely that these economic losses will decrease by 2030. The future cost of climate-related hazards depends on the frequency and severity of events, as well as additional factors such as the value of exposed assets and the effectiveness of implemented climate adaptation measures (Bednar-Friedl et al., 2022; Ranasinghe et al., 2021).

Regarding the fourth indicator, Drought impact on ecosystems, the EEA's European Climate Risk Assessment identifies Europe as the fastest-warming continent globally. In 2023, the drought impact on European ecosystems lessened compared to the previous devastating year. The aggregated drought-affected area within the European Union amounted to 143,513 km², exceeding the long-term average drought impact for the 2000-2020 period (EEA, 2025a). If global mitigation efforts and EU and national adaptation strategies are not effectively implemented, drought impacts are projected to increase.

The fifth indicator is Europe's material footprint. The Programme aims to significantly reduce the EU's material footprint to preserve valuable natural resources and mitigate environmental impacts such as climate change and biodiversity loss (IRP, 2019). Between 2010 and 2022, the per capita material footprint remained stable, followed by a 4.5% decline in 2023 (EEA, 2025a). Based on historical trends, it appears unlikely that the EU will achieve a substantial

reduction in per capita material footprint over the next decade unless the decrease observed in 2023 continues. Considerable efforts are required to reduce raw material extraction and consumption by transitioning to goods and services with lower material intensity.

The sixth indicator is Waste generation, which has historically mirrored trends in economic growth. Although recent stability and some decoupling of waste generation from economic growth are encouraging, the latest data suggest that the correlation between economic growth and waste generation persists. Consequently, a substantial reduction in waste generation by 2030 remains unlikely.

The seventh indicator is Premature deaths due to exposure to fine particulate matter ($PM_{2.5}$) in Europe. The European Commission's Zero Pollution Action Plan sets a target to reduce the health impacts of air pollution by at least 55% by 2030, compared to 2005 levels. Between 2005 and 2022, the number of premature deaths in the EU attributable to $PM_{2.5}$ decreased by 45%. If this trend continues, the target is likely to be met and potentially exceeded.

The eighth indicator is Nitrate levels in groundwater in Europe. Despite legislative measures addressing nutrient pollution, the average nitrate concentration in groundwater across the European Union has remained largely unchanged between 2000 and 2022 (EEA, 2025a). At present, it appears unlikely that the current trend will be sufficient to meet EU regulatory obligations or achieve the goal of a 50% reduction in nutrient losses.

The next indicator is Terrestrial protected areas and marine protected areas in Europe's seas. By the end of 2022, protected areas covered 26.1% of EU land, with 18.6% designated as Natura 2000 sites and an additional 7.5% under other complementary national designations. The EU Biodiversity Strategy for 2030 sets a target of protecting at least 30% of EU land by 2030. However, it is currently uncertain whether this target will be achieved unless the rate of designation of protected areas more than doubles by 2030.

Regarding the indicator Marine protected areas in Europe's seas, the EU has made significant progress in designating new marine protected areas, both within the Natura 2000 network and through complementary national designations. As a result, the coverage of marine protected areas has more than doubled. Nevertheless, substantial efforts will be required to meet the EU Biodiversity Strategy target of protecting at least 30% of EU seas by 2030. At present, it appears unlikely that this target will be met.

The Common Bird Index in Europe is another biodiversity-related indicator. Long-term trends show that between 1990 and 2022, the index for 168 common bird species declined by 14% within the EU. The status of bird populations has been subject to extensive long-term monitoring in Europe, much of which has been conducted through voluntary efforts. This exemplifies how citizen science can be effectively harnessed through targeted approaches and clearly defined monitoring methods (Brlík et al., 2021). However, at present, it seems unlikely that the decline in common bird populations will be reversed by 2030.

The indicator Increasing forest connectivity is critical for supporting biodiversity. The EU's average forest connectivity was 80.6% in 2021, representing a 0.8% decrease since 2018. It is unlikely that forest connectivity will increase by 2030.

The indicator EU's primary energy consumption by end users showed a decline of 3.9% in 2023 compared to 2022, while final energy consumption decreased by 3.0% (EEA, 2025a). If the current rate of reduction persists, the EU is on track to meet its 2030 energy efficiency targets.

The next indicator, Circular Material Use Rate (CMUR) in Europe, reflects the EU's ambition to double the use of recycled materials, measured as a share of the economy's total material use, between 2020 and 2030, as outlined in the 2020 Circular Economy Action Plan. Although the CMUR has increased slightly over the past thirteen years – from 10.7% in 2010 to 11.8% in 2023 – it remains relatively low, indicating that the economy largely continues to follow a linear model (Eurostat, 2018).

The share of buses and trains in inland passenger transport in Europe serves as an indicator for the promotion of sustainable transport modes such as public transportation. Since 2005, the share of buses and trains in total passenger transport has remained relatively stable at around 17%. However, this figure sharply declined to 13% in 2020 due to COVID-19 pandemic-related travel restrictions and changes in mobility behaviour (Lozzi et al., 2022), followed by a gradual recovery during 2021 and 2022. The final indicator, agricultural area under organic farming in Europe, shows that the share of the EU's organically managed agricultural land increased from 5.9% in 2012 to 10.5% in 2022. This growth is driven by rising demand for organic products and supportive policy measures. Despite expectations for continued increases, current policies alone are insufficient to achieve the established targets for organic farming expansion.

The indicator Share of environmental taxes in total tax revenues in Europe reveals that, despite the critical role of environmental taxation in facilitating the transition to a greener economy, the share of environmental taxes within total revenues from taxes and social contributions in the EU declined from 6.0% in 2010 to 4.8% in 2022 (EEA, 2025a).

The next indicator, Fossil fuel subsidies in Europe, highlights that the Programme calls for an immediate phase-out of fossil fuel subsidies. These subsidies remained stable between 2015 and 2021. Although a significant portion of fossil fuel subsidies is scheduled to be eliminated by 2030, much of this reduction is associated with temporary crisis-related measures. Consequently, the EU is unlikely to make substantial progress in phasing out fossil fuel subsidies by 2030.

The indicator Environmental protection expenditure demonstrates that increasing spending on environment-

and climate-related activities can support the objectives of the European Green Deal. Such expenditures primarily cover efforts to reduce air, water, soil, and noise pollution, protect biodiversity, manage wastewater and waste, and support environmental research and development. Between 2018 and 2023, environmental protection expenditure in the EU increased from EUR 280 billion to EUR 357 billion. This figure is expected to continue rising as additional funding becomes available.

Green bonds in Europe, which finance projects addressing climate change and environmental issues, constitute the twentieth indicator. Green bonds accounted for only 0.3% of all bonds issued by corporations and governments in the EU in 2014. This share increased to 9.2% in 2022 but then declined to 6.8% in 2023. Despite this fluctuation, issuances of green bonds are expected to grow in alignment with the ambitious environmental and climate goals outlined in the European Green Deal.

The final indicator, the Eco-innovation Index in Europe, shows a 27.5% increase from 2014 to 2024, largely driven by improvements in resource efficiency. This steady upward trend is anticipated to continue, supported by the ambitious environment- and climate-related objectives set forth by the European Green Deal.

The final group of indicators pertains to the concept of living well within planetary boundaries and comprises five indicators. The first indicator, Net land take in cities and commuting zones in Europe, highlights that land conversion to artificial surfaces impairs ecological functions and reduces ecosystem resilience. Between 2012 and 2018, the annual net land take in these zones within the EU was 450 km². To achieve the EU's target of "no-net-land take by 2050," significant reductions in net land take are required in the coming years, which currently appears uncertain and challenging. The next indicator, Water scarcity conditions in Europe, shows that although water abstraction in the EU declined by 19% between 2000 and 2022, there has been no overall decrease in the area affected by water scarcity. In fact, the situation has worsened since 2010 (EEA, 2025a). This is further compounded by the expectation that climate change will increase the frequency, intensity, and impacts of drought events, rendering a reduction in water scarcity by 2030 somewhat unlikely. The Consumption footprint in Europe indicator reflects the EU's goal to significantly reduce its consumption footprint by 2030 and keep related environmental impacts within planetary boundaries. However, between 2010 and 2022, the EU's consumption footprint increased by approximately 8%, and projections indicate further growth by 2030, driven by economic growth and consumption patterns. Currently, the EU is not on track to sufficiently reduce its consumption footprint. The fourth indicator, Employment and gross added value of the environmental goods and services sector, increased from 2.1% of total employment in 2010 to 2.5% in 2021, with full-time equivalent employment in this sector reaching 5.2 million (EEA, 2025a). The sector's contribution to the EU economy, in terms of gross added value, also rose from 2.1% in 2010 to 2.5% in 2021, surpassing EUR 315 billion (in 2010 prices). The environmental goods and services sector is expected to constitute an increasing share of the EU economy in the coming years. The final indicator, Income-related environmental inequalities between regions associated with air pollution in Europe, uses $PM_{2.5}$ exposure as a reliable proxy for air pollution-related risk (Lim, S. S., et al., 2013). Despite improvements in air quality across both the wealthiest and the poorest EU regions between 2007 and 2021, disparities persist, with $PM_{2.5}$ concentrations consistently about one-third higher in the poorest regions.

Table 1. Outlook of meeting the targets by 2030

8th EAP indicators Monitoring targets	**Outlook of meeting the targets by 2030**			
	It is very likely	It is likely but uncertain	It is unlikely but uncertain	It is very unlikely
Reduce net GHG emissions by at least 55% by 2030 from 1990 levels		x		
Increase net GHG removals by carbon sinks from the LULUCF sector to -310 million tonnes CO_2 equivalent by 2030				x
Reduce overall monetary losses from weather and climate-related events			x	
Decrease the area impacted by drought and loss of vegetation productivity			x	
Decrease the area impacted by drought and loss of vegetation productivity			x	
Significantly decrease the EU's material footprint, by reducing the amount of raw material needed to produce the products consumed in the EU			x	
Significantly reduce the total amount of waste generated by 2030			x	

Reduce premature deaths from air pollution by 55% (from 2005 levels) by 2030	x			
Reduce nutrient losses by at least 50% in safe groundwater resources			x	
Legally protect at least 30% of the EU's land area by 2030			x	
Legally protect at least 30% of the EU's sea area by 2030			x	
Reverse the decline in populations of common birds			x	
Increase the degree of connectivity in forest ecosystems with a view to creating and integrating ecological corridors and increase climate change resilience			x	
Reduce by 2030 the primary and the final energy consumption levels to respectively 992.5 and 763 million tonnes of oil equivalent				x
At least 42.5% of energy from renewable sources in gross final energy consumption by 2030			x	
Double the ratio of circular material use by 2030 compared to 2020				x
Increase the share of collective transport modes (buses, coaches, and trains)			x	
25% of EU agricultural land organically farmed by 2030				x
Increase the share of environmental taxes in total revenues from taxes and social contributions	x			
Reduce environmentally harmful subsidies, in particular fossil fuel subsidies, with a view to phasing them out without delay			x	
Increase spending by households, corporations, and governments on preventing, reducing and eliminating pollution and other environmental degradation	x			
Increase the issuance of green bonds to boost public and private financing for green investments		x		
Increasing eco-innovation as a driver for the green transition	x			
No net land take by 2050			x	
Reduce water scarcity			x	
Significantly decrease the EU's consumption footprint, i.e. the environmental impact of consumption				x
Increase the share of green employment in the whole economy	x			
Increase the share of the green economy in the whole economy	x			
Reduce environmental inequalities and ensure a fair transition			x	

Source: Authors

Table 1 provides a clear and more comprehensive view of all the listed indicators and an assessment of the possibility of achieving the set goals to which the indicator relates within the stipulated time frame.

CONCLUSION

It is an indisputable fact that the European Union sets numerous precise and ambitious targets in the field of environmental policy. This also applies to the goals established within the Eighth Environment Action Programme. This Programme defines 26 indicators to monitor the achievement of the specified objectives. These indicators can be grouped into eight categories, depending on the Programme's targets they relate to: climate change mitigation, climate change adaptation, a regenerative circular economy, zero pollution and a toxic-free environment, biodiversity and ecosystems, environmental and climate pressures related to EU production and consumption, enabling conditions, and living well within planetary boundaries (Luisa, 2025).

The results of the conducted research indicate that some indicators show a very high likelihood of achieving their respective targets by 2030, others suggest a moderate probability with some degree of uncertainty, while there are also indicators for which the likelihood of target achievement is very low (EEA, 2025b). For example, indicators such as premature deaths due to exposure to fine particulate matter, environmental protection expenditure, the eco-innovation index, employment in the environmental goods and services sector, and gross value added of the environmental goods and services sector demonstrate a high probability of target achievement. Indicators including greenhouse gas emissions, the share of environmental taxes in total tax revenues, and the share of green bonds in total issued bonds suggest a probability of achievement, albeit with some uncertainty.

A significant number of indicators fall into the category where there is a moderate probability of achieving the targets, but with a greater likelihood of failure. These include climate-related economic losses, drought impacts on ecosystems, raw material consumption, total waste generation, nitrates in groundwater, designated terrestrial protected areas, designated marine protected areas, the common bird index, forest connectivity, the share of renewable energy in gross final energy consumption, the share of buses and trains in inland passenger transport, fossil fuel subsidies, land take, the water exploitation index plus, and environmental inequalities. Finally, indicators such as greenhouse gas emissions from land use, land-use change and forestry, energy consumption, circular material use rate, area under organic farming, and consumption footprint indicate a high probability that the targets will not be met.

All of the above leads to the conclusion that, although the EU has set significant environmental policy targets for 2030, it remains uncertain whether most of these will be achieved within the given timeframe. Indeed, for the majority, the likelihood of failure is higher. However, the European Green Deal itself is designed to provide a strategic direction for the EU's environmental policy, emphasizing the importance of continuously striving toward the set goals. Therefore, even if not all targets are met by the deadline – and it is almost certain that some will not be – this should not be regarded as a failure. The very idea of the European Union setting such ambitious targets significantly contributes to establishing international standards in environmental protection (Jovašević, 2009), and their ambition should serve as a motivation for even more determined action by the EU and its member states in the direction of environmental protection.

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REFERENCES

Agostini, F., et al. (2024). *Report: The EU Green Deal: 2024 edition.* European University Institute.

Bednar-Friedl, B., et al. (2022). Chapter 13: Europe. In: Pörtner, H. O., et al. (eds.), *Climate change 2022: Impacts, adaptation and vulnerability.* Contribution of Working group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Brlík, V., et al. (2021). Long-term and large-scale multispecies dataset tracking population changes of common European breeding birds. *Scientific Data 8*(1), 21. https://www.nature.com/articles/s41597-021-00804-2

EU. (2019). The 8th Environment Action Programme: Measuring progress towards the attainment of the Programme's 2030 and 2050 priority objectives. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022DC0357

EU. (2019). The European Green Deal. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52019DC0640

EU. (2025). Delivering the European Green Deal. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en

European Environmental Agency (EEA). (2020). *Trends and drivers of EU greenhouse gas emissions, EEA Report*. European Environment Agency.

European Environmental Agency (EEA). (2025a). Live versions of 8th EAP headline indicators. https://www.eea.europa.eu/en/topics/at-a-glance/state-of-europes-environment/environment-action-programme

European Environmental Agency (EEA). (2025b). European Union 8th Environment Action Programme: Monitoring report on progress towards the 8th EAP objectives. https://www.eea.europa.eu/en/analysis/publications/european-union-8th-environment-action-programme/european-union-8th-environment-action-programme/@@download/file

Eurostat. (2018). *Circular material use rate — calculation method*. Publications Office of the European Union.

Ilić Petković, A., Ilić Krstić, I., & Jovanović, M. (2016). Political and legal significance of citizens and public opinion in environmental protection. *Facta Universitatis, Series: Working and Living Environmental Protection, 6*(3), 225-238.

IRP (2019). *Global Resources Outlook 2019: Natural resources for the future we want*. International Resource Panel.

Jovašević, D. (2009). European standards and environmental protection. *European Legislation, 8*(27-28), 125–141.

Lim, S. S., et al. (2013). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet 380*(9859), 2224–2260.

Lozzi, G., et al. (2022). *Relaunching transport and tourism in the EU after COVID-19 — Part VI: Public transport*. European parliament, Directorate-General for Internal Policies of the Union.

Luisa, M. (2025). *Delivering the EU Green Deal: Progress towards targets*. European Commission.

Ranasinghe, R., et al. (2021). Climate change information for regional impact and for risk assessment. In: Masson-Delmotte, V., et al. (eds.), *Climate change 2021: The Physical science basis. Contribution of Working group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

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REVIEW PAPER

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ECOLOGICAL AND ECONOMIC ASPECTS OF RESOURCE MANAGEMENT IN NATIONAL PARKS OF SERBIA

Abstract: *As important protected areas, national parks of Serbia face the increasing challenge of sustainable natural resource management. This paper explores opportunities to enhance the existing management through an integrated approach, focusing on the synergy between biodiversity conservation and the economic valorisation of ecosystem services. Through a combination of strategic document analysis, a review of scientific literature, and empirical case studies in selected national parks, this research critically assesses current methodologies and proposes an innovative methodological framework. Within the case studies, qualitative and quantitative methods will be employed for a detailed analysis of biodiversity status, identification of priority ecosystem services, and assessment of their economic potential. The aim of the research is to define concrete policy and practice recommendations for improving the integrated management of national parks in Serbia and ensuring long-term biodiversity conservation, while sustainably valorising ecosystem services for the benefit of local communities and society as a whole.*

Keywords: biodiversity, ecosystem services, valorisation, integrated management, national parks of Serbia

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INTRODUCTION

National parks are the most strictly protected areas in the Republic of Serbia, encompassing ecosystems of exceptional biodiversity, landscape value, and cultural significance. Covering approximately 1.5% of the national territory, the five designated national parks: Tara, Kopaonik, Fruška Gora, Đerdap, and Šar Mountain form the ecological backbone of the country and are classified primarily under IUCN categories II and V (Avramović, 2014). These protected areas play a crucial role in conserving endemic and relict species, maintaining ecological balance, and offering a wide array of ecosystem services.

Despite their ecological importance, Serbian national parks face increasing pressures stemming from unsustainable resource use, underfunded conservation frameworks, and insufficient integration of socio-economic objectives into management plans (Milutinović, 2019). Challenges such as unregulated tourism, illegal logging, inadequate waste management, and weak enforcement mechanisms threaten both biodiversity and the long-term provision of ecosystem services (CIB, 2021). Moreover, economic valuation of ecosystem services is rarely applied in practice, which limits the visibility of their contribution to human well-being and local economies (Avramović, 2005).

A prevailing characteristic of natural resource management in these areas is the dominance of conventional (sectoral) approaches, which often prioritise short-term economic gains over long-term ecological sustainability. Consequently, the current paradigm fails to acknowledge the interdependence between ecosystem health and sustainable development (Adžemović, 2016). Recent policy recommendations and academic discourse advocate for a shift toward integrated management strategies that reconcile biodiversity protection with economic valorisation, particularly through participatory governance and the application of ecosystem-based models (WWF Adria, 2017; Milutinović, 2019).

This paper aims to explore the ecological and economic aspects of natural resource management in Serbian national parks by employing a multidisciplinary framework. Through strategic document analysis, literature review, and selected case studies, the research identifies critical shortcomings in current practice and proposes a comprehensive methodological framework that integrates biodiversity conservation with sustainable economic utilisation of ecosystem services.

THEORETICAL BACKGROUND

Ecosystem Services and Their Classification

Ecosystem services represent the benefits that humans derive from functioning ecosystems, and they are typically classified into four broad categories: provisioning (e.g. food, water, timber), regulating (e.g. climate regulation, flood control), cultural (e.g. recreation, spiritual value), and supporting services

(e.g. soil formation, nutrient cycling) (MEA, 2005). In the context of national parks, these services are particularly significant due to the high level of biodiversity and relatively undisturbed natural processes.

The recognition of ecosystem services as a measurable and valuable output of protected areas has significantly contributed to redefining conservation strategies. Rather than focusing solely on preservation, contemporary management frameworks now seek to ensure the sustainable delivery of ecosystem services for the benefit of current and future generations (Ruiz-Frau et al., 2017).

Economic valorisation of ecosystem services

Economic valuation is a crucial tool for quantifying the importance of ecosystem services and integrating them into policy and decision-making. Methods such as contingent valuation, cost-benefit analysis, and ecosystem accounting allow for the estimation of the monetary value of natural capital (Costanza et al., 2014). In Serbia, however, the application of these methods in national park management remains limited, often due to the absence of reliable ecological and socio-economic data (Avramović, 2005).

The lack of economic visibility of ecosystem services contributes to their undervaluation and, consequently, to resource mismanagement. A shift toward economic valorisation can help align conservation priorities with sustainable development goals by highlighting the real value that ecosystems provide to local communities and national economies (Milutinović, 2019).

Integrated natural resource management in protected areas

Integrated natural resource management (INRM) is an approach that combines ecological, social, and economic objectives into a unified framework. Unlike conventional sectoral management, INRM recognises the interconnectivity of ecosystem components and emphasises adaptive, participatory, and cross-sectoral decision-making processes (IUCN, 2013). The effectiveness of INRM has been demonstrated in numerous case studies globally, particularly in landscapes characterised by complex socio-ecological interactions.

In the context of Serbia's national parks, integrated management is essential for balancing conservation goals with the economic needs of local communities. This involves multi-level governance, transparent institutional arrangements, legal mechanisms, stakeholder participation, and effective monitoring and evaluation systems (WWF Adria, 2017; CIB, 2021).

METHODOLOGY

This research employs a qualitative-quantitative mixed-method approach aimed at critically evaluating the ecological and economic dimensions of resource management in Serbia's national parks. The methodology combines a review of strategic documents and scientific literature, field-based case studies, and expert evaluation to develop an integrated management framework tailored to the socio-ecological realities of the parks.

Document and policy analysis

The study begins with an analysis of national and international strategic and legal documents related to biodiversity conservation, protected area governance, and ecosystem service management. Key sources include the Law on National Parks (National Assembly of the Republic of Serbia, 2015), the Law on Nature Protection, Serbia's Biodiversity Strategy, as well as international conventions, such as the Convention on Biological Diversity (CBD) and the Aarhus Convention. The objective is to identify institutional gaps, overlapping responsibilities, and implementation inconsistencies that hinder effective management.

Literature review

An extensive review of peer-reviewed scientific literature, grey literature (institutional reports, NGO publications), and doctoral dissertations was conducted. Sources were selected for their relevance to ecological economics, conservation policy, and integrated resource management. Special emphasis was placed on studies addressing the valuation of ecosystem services, governance structures in protected areas, and participatory management models (Adžemović, 2016; Milutinović, 2019; Avramović, 2014; CIB, 2021).

Case studies

Three case studies were selected to reflect geographic, ecological, and governance diversity among national parks in Serbia:

- *Fruška Gora national park*, characterised by significant anthropogenic pressure and overlapping land uses;
- *Tara national park*, a model for forest ecosystem conservation with developing ecotourism initiatives;
- *Đerdap national park*, notable for its transboundary ecological value and conflicts arising from hydroelectric infrastructure.

For each park, data on biodiversity status, protected zones, land use dynamics, and economic activities (e.g. tourism, forestry, local enterprise) were collected through official reports, GIS maps, and publicly available monitoring data from the Institute for Nature Conservation of Serbia and the Environmental Protection Agency.

Stakeholder perspective and participatory elements

Where available, perspectives from local community representatives, park authorities, and NGOs were incorporated through desk-review of reports, user councils (WWF Adria, 2017), and previously conducted participatory studies. These sources help to assess how inclusive and responsive current management models are to stakeholder needs and ecological objectives. It should be noted that this

research relies on the analysis of these secondary data sources for stakeholder perspectives, as primary data collection through new interviews or surveys was beyond the scope of this particular study.

RESULTS AND DISCUSSION

Current state of natural resource management in Serbian national parks

Serbia's national parks (NPs) are characterised by rich biodiversity and diverse ecological functions, but their management is often constrained by overlapping competences, limited financial resources, and insufficient institutional coordination (Avramović, 2014).

In Fruška Gora NP, intense anthropogenic pressure, especially through tourism, agriculture, and illegal construction, has led to significant habitat fragmentation and ecosystem degradation (CIB, 2021). The management plan prioritises infrastructural development and timber extraction, often at the expense of conservation objectives.

Tara NP, by contrast, is considered an example of better-integrated conservation planning. It maintains stable populations of large mammals, such as the brown bear (*Ursus arctos*), and supports ecotourism initiatives based on biodiversity and landscape value. However, there is still a lack of systematic valuation of ecosystem services and their inclusion in economic planning (Milutinović, 2019).

In Đerdap NP, conflicts arise from the coexistence of protected natural values and large infrastructure such as the Iron Gate hydroelectric power plant. Changes in water levels have affected riparian ecosystems and fish habitats, yet management efforts remain limited in their capacity to reconcile ecological goals with energy and transport policies (Adžemović, 2016).

The main challenges of current practices include:

- *Fragmentation in the implementation of measures* – lack of coordination between different sectors often leads to overlaps or inconsistencies in measures.
- *Limited financial resources* – funds allocated for nature conservation and local infrastructure development are often insufficient.
- *Lack of integrated planning* – ecological and economic goals are not adequately aligned in existing management plans.
- *Insufficient involvement of local communities* – local communities are often not sufficiently included in decision-making processes, which can lead to conflicts of interest.

Primary ecological priorities in Serbia's national parks include:

- *Habitat protection and restoration* – implementing measures to preserve natural habitats and revitalize threatened ecosystems.
- *Biodiversity monitoring* – regular assessments of key species populations and identification of priority areas for conservation.
- *Control of invasive species* – mitigating the impact of invasive species that threaten local ecosystems.
- *Climate change adaptation* – introducing strategies to manage the effects of climate change on natural resources.

These activities require an interdisciplinary approach and ongoing collaboration between researchers, institutions, and local communities.

Valuation and prioritisation of ecosystem services

Across all three parks, provisioning services (e.g. timber, non-timber forest products, water) dominate management strategies, while regulating and cultural services remain undervalued or ignored. This reflects a broader trend in Serbian protected areas, where short-term extractive economic benefits are prioritised over long-term ecological sustainability (Avramović, 2014). For example, the potential of carbon sequestration in Tara's forests or the value of pollination services in Đerdap is neither quantified nor reflected in park revenue structures.

Furthermore, cultural ecosystem services – such as spiritual value, recreation, and educational use – are often acknowledged rhetorically but lack budgetary or operational support. In Fruška Gora NP, the zoning system allows construction in areas with high biodiversity value, which undermines the park's cultural and ecological integrity (CIB, 2021).

Toward integrated and participatory management

The lack of stakeholder involvement in decision-making processes has been repeatedly identified as a barrier to effective governance. While Serbia's Law on National Parks recognises the role of user councils, in practice these bodies lack authority and operate with limited transparency (WWF Adria, 2017). Successful examples from Tara NP show that participatory ecotourism models – where local residents are partners rather than passive beneficiaries – result in higher conservation effectiveness and community support.

The persistence of these governance gaps, despite formal commitments to participatory models, suggests deeper, systemic challenges. The prioritisation of extractive benefits is often not just a managerial decision but reflects the enduring influence of powerful economic sectors, such as forestry, energy, and large-scale tourism, whose national-level interests can overshadow conservation mandates. Furthermore, the weakness of participatory bodies like user councils may be linked to a legacy of centralised, top-down governance that is slow to yield effective decision-making power to local actors. Overcoming these entrenched issues requires more than policy reform; it necessitates a fundamental shift in political will and the

genuine empowerment of local communities and conservation authorities.

A shift toward integrated management would require:

- adoption of ecosystem service valuation as a standard practice in planning;
- introduction of multi-stakeholder decision-making mechanisms;
- transparent zoning revisions to prioritise ecological functionality; and
- targeted investments in capacity building for park authorities and local actors.

The integration of ecological indicators (e.g. habitat integrity, species richness) with socio-economic metrics (e.g. income from nature-based tourism, ecosystem service trade-offs) can provide a robust basis for adaptive management (MEA, 2005; Costanza et al., 2014).

National parks not only provide ecological benefits but also possess significant economic potential through ecosystem services that support local and regional development. Key ecosystem services include climate regulation, water purification, sustainable tourism, recreation, and provisioning of food and medicinal resources. However, their valuation and utilisation are often underdeveloped, limiting the contributions that national parks can offer to the economy.

Key economic components to consider are the following:

- *Valuation of ecosystem services* – assessing the economic value of services such as carbon sequestration, water filtration, and biodiversity maintenance.
- *Development of sustainable tourism* – providing tourism activities that are environmentally responsible yet economically viable.
- *Education and promotion* – raising awareness of the economic potential of national parks through campaigns and educational programs.
- *Partnerships with local communities* – engaging local populations in the production and services related to the parks, further contributing to local development.

In this paper, economic aspects were analysed through quantitative methods for assessing the economic value of ecosystem services and qualitative methods involving opinions from local actors and stakeholders. The focus is on identifying tangible pathways to amplify the economic role of national parks within sustainable development frameworks.

Limitations of the study

The authors acknowledge certain limitations that frame the findings of this research. The assessment of stakeholder perspectives, being based on a desk-review of existing documentation rather than primary data collection, may not fully capture the most current or nuanced views of all relevant parties. Therefore, the conclusions drawn in this area should be seen as indicative of trends found in publicly available reports and prior studies. Future research would significantly benefit from direct engagement with stakeholders through targeted interviews and surveys to validate and expand upon these findings, providing a more dynamic and detailed understanding for policy and management recommendations.

CONCLUSION

This paper has explored the ecological and economic aspects of resource management in Serbia's national parks through an integrated analysis of legal frameworks, management practices, and case study evidence. The findings confirm that while national parks possess significant biodiversity and ecosystem service potential, current management approaches often fail to achieve a balance between conservation and sustainable use.

Dominant practices remain extractive and sectorally fragmented, with limited application of economic valuation tools and insufficient stakeholder engagement. Provisioning services are prioritised, whereas regulating and cultural services remain under-recognised, leading to misaligned planning and resource allocation. Moreover, institutional mechanisms for participatory governance are either weak or underutilised, further limiting the responsiveness of management structures to ecological and community needs.

To address these gaps, the following recommendations are proposed:

- *Adopt ecosystem service valuation* as an integral component of management planning, using internationally recognised methodologies tailored to local conditions.
- *Reform zoning regulations* to reflect ecological priorities, especially in parks under high anthropogenic pressure.
- *Strengthen participatory governance*, particularly by empowering user councils and enhancing transparency in decision-making.
- *Integrate biodiversity and socio-economic indicators* into a unified monitoring and evaluation framework to support adaptive management.
- *Invest in capacity building* for park staff, local communities, and institutions responsible for national park oversight.
- *Align ecological and economic balance* by coordinating measures for nature protection with opportunities for the sustainable use of ecosystem services.
- *Implement participatory management* by actively involving local communities in the decision-making process to ensure economic benefits for the local population while respecting ecological principles.
- *Foster interdisciplinary collaboration*, connecting scientific disciplines such as ecology, economics, and sociology, to design sustainable management strategies.
- *Establish monitoring and evaluation* systems for the regular tracking of resource conditions and

evaluating the impact of implemented measures on ecological and economic aspects.

- *Develop education and awareness-raising* programs to inform local communities and the broader public about the importance of national parks and their economic potential.

Implementing these recommendations requires coordinated efforts among environmental authorities, park administrations, scientific institutions, and civil society. Only through integrated and evidence-based management can Serbia's national parks fulfil their dual mission: conserving biodiversity and contributing to the sustainable development of society.

Future research should prioritize the inclusion of primary stakeholder data and explore the development of ecosystem service-based financial instruments (e.g. green bonds, payment for ecosystem services) tailored to Serbian national parks.

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REFERENCES

Adžemović, M. (2016). *Primenjena ekologija i integrativna zaštita prirodnih resursa* [Doctoral dissertation, University of Novi Sad].
NARDUS: https://nardus.mpn.gov.rs/handle/123456789/7768

Avramović, D. (2005). *Ekonomsko-ekološki aspekti eksploatacije i gazdovanje zaštićenim prirodnim dobrima*. [Master's thesis, University of Niš]. Fakultet zaštite na radu u Nišu.

Avramović, D. (2014). *Menadžment prirodnim resursima nacionalnih parkova* [Doctoral dissertation, University of Niš].
NARDUS: https://nardus.mpn.gov.rs/handle/123456789/8388

Centar za istraživanje biodiverziteta (CIB) (2021). *Novi pogledi na upravljanje zaštićenim područjima prirode*. https://uzzs.org.rs/wp-content/uploads/2022/11/Novi-pogledi-na-upravljanje-zasticenim-podrucjima-prirode-CIB-11-2022.pdf

Costanza, R. et al. (2014). Changes in the global value of ecosystem services. *Global Environmental Change*, *26*, 152–158. https://doi.org/10.1016/j.gloenvcha.2014.04.002

IUCN (2013). *The IUCN Programme 2013–2016*. Gland, Switzerland: IUCN. 30 pp.
https://portals.iucn.org/library/sites/library/files/documents/WCC-5th-003.pdf

National Assembly of the Republic of Serbia (2015). *Law on National Parks.* (Official Gazette of the Republic of Serbia, No. 84/2015 and 95/2018).
https://www.paragraf.rs/propisi/zakon-o-nacionalnim-parkovima.html

Millennium Ecosystem Assessment (MEA) (2005). *Ecosystems and human well-being: Synthesis. Island Press*. https://www.millenniumassessment.org/documents/document.356.aspx.pdf

Milutinović, S. (2019). *Upravljanje prirodnim resursima*. Univerzitet u Nišu, Fakultet zaštite na radu u Nišu. https://www.znrfak.ni.ac.rs/SERBIAN/009-NAUKA/IZDAVASTVO-UDZBENICI/Slobodan%20Milutinovic/Milutinovic%20-%20Upravljanje%20prirodnim%20resursima%20-%20Final%20za%20stampu%20B5.pdf

Ruiz-Frau, A. et al. (2017). Current state of seagrass ecosystem services: research and policy integration. *Ocean & Coastal Management*, *149*, 107-115.
https://doi.org/10.1016/j.ocecoaman.2017.10.004

WWF Adria. (2017). *Saveti korisnika – Priručnik za upravljače zaštićenih područja*. WWF Adria. https://wwfint.awsassets.panda.org/downloads/saveti_korisnika___prirunik_za_upravljae_srb.pdf

Safety Engineering & Management in Industry

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REVIEW PAPER

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NEW CHALLENGES UNDER THE REVISED INDUSTRIAL EMISSIONS DIRECTIVE: FROM IPPC TO IED 2.0

Abstract: *The European Union's revised Industrial Emissions Directive (IED), introduces significant enhancements aimed at reducing pollution from large industrial installations and intensive livestock farms. This modernization aligns with the European Green Deal's Zero Pollution ambition, targeting a healthier environment and promoting industrial innovation. The updated IED extends its regulatory reach to additional sources of emissions. Notably, it now encompasses more large-scale intensive livestock farms, including the largest pig and poultry operations. This expansion is essential in mitigating nitrogen pollution across air, water, and soil. The Directive also brings the extraction of metals and large-scale battery production under its purview, addressing emerging industrial activities with significant environmental footprints. To analyze the impact and effectiveness of the updated IED, an online systematic review was conducted using peer-reviewed literature, official EU reports, and policy evaluations from 2020 to 2025. A comparative analysis was carried out to assess key changes against the previous IED (2010/75/EU), using case studies and reported data. Findings from the review highlight several important aspects of the directive, like stricter emission limits and target reductions. In a concluding sense, IED 2.0 success will depend on effective enforcement, industry cooperation, and technological innovation. Future research should focus on digital monitoring tools, financial sustainability models, and regulatory refinements to ensure long-term compliance and impact.*

Keywords: Integrated pollution prevention and control, Industrial emissions, Integrated permit, Operators

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INTRODUCTION

The genesis of the European Union's Integrated Pollution Prevention and Control (IPPC) Directive traces back to the mid-1990s, a time when the EU recognized the fragmentation and inconsistency of environmental regulation across Member States. Environmentally, the directive was conceived in response to the growing realization that industrial pollution was not a compartmentalized phenomenon. Rather than being confined to air, water, or soil separately, pollutants were increasingly found to migrate across environmental media, challenging the efficacy of traditional, single-medium regulatory approaches (Krämer, 2007). Throughout the 1970s and 1980s, a series of ecological crises such as the Seveso chemical disaster and extensive transboundary air and water pollution events highlighted the interconnectedness of environmental systems and the inadequacy of fragmented regulation. These events amplified the urgent need for a comprehensive, cross-media regulatory framework capable of addressing complex industrial impacts on the environment as a whole (Jordan, 1999). Parallel to these environmental concerns, social dynamics were shifting in ways that fostered receptivity to a more integrated regulatory instrument. Public awareness and environmental consciousness were rising steadily, particularly in Western Europe, where citizens and civil society organizations exerted increasing pressure on governments and supranational bodies to enforce stricter pollution control. The dissemination of the 1987 Brundtland Report and the proceedings of the 1992 Earth Summit in Rio de Janeiro were vital in reframing environmental degradation as a global challenge that required sustainable development and integrated solutions (Bruntland, 1987). Within the European context, the formation and deepening of the European Union brought with it new aspirations for policy harmonization, environmental equity, and cohesion among Member States. The IPPC Directive responded directly to the need to avoid regulatory discrepancies

that could undermine both environmental protection and the competitiveness of European industry. Technological progress also played an essential role in enabling and necessitating the IPPC framework. By the 1990s, advances in environmental engineering, monitoring systems, and process optimization had given rise to the concept of Best Available Techniques (BAT), which became the cornerstone of the IPPC regulatory architecture. The increasing availability and sophistication of cleaner production technologies made it both technically and economically feasible to reduce emissions at the source, rather than relying solely on end-of-pipe solutions. Moreover, digital data collection and environmental reporting tools began to allow for more integrated and transparent oversight of industrial operations, thus supporting the practical implementation of cross-media assessments and permitting procedures.

The convergence of these environmental, societal, and technological trajectories created the momentum for a paradigm shift in European industrial pollution control. Adopted in 1996 as Directive 96/61/EC, the IPPC Directive marked a paradigmatic shift from media-specific permitting (i.e., air, water, waste) toward an integrated approach to environmental protection. It mandated that industrial installations with significant pollution potential obtain integrated permits that considered the entire environmental performance of a facility. This holistic concept was grounded in the application of Best Available Techniques (BAT), which aimed to ensure a high level of environmental protection while taking into account economic and technical feasibility (EC, 1996).

The initial implementation of the IPPC Directive revealed both strengths and challenges. It successfully initiated a framework for industrial pollution control based on integration, but it also encountered uneven implementation across Member States. Varying interpretations of BAT, differences in permit conditions, and inadequate public participation mechanisms hindered its effectiveness. Moreover, the directive's flexibility, while politically expedient, led to regulatory asymmetry, undermining the level playing field among European industries (Firoiu et al, 2023).

In response to these deficiencies, the European Commission initiated a comprehensive review in the early 2000s. This effort culminated in the publication of the Thematic Strategy on Air Pollution and the review of the IPPC Directive and six related sectoral directives (collectively referred to as the "IPPC Daughter Directives"). These included directives on waste incineration, large combustion plants, and solvent emissions, among others. The review concluded that a unified legislative framework was necessary to enhance coherence, improve enforceability, and update environmental standards based on the evolving state of science and technology (EC, 2007).

This led to the adoption of the Industrial Emissions Directive (IED), Directive 2010/75/EU, which entered into force in 2011. The IED repealed and replaced the IPPC Directive and its daughter directives, consolidating and streamlining industrial emissions legislation within the EU. The IED strengthened the role of BAT, notably through the mandatory use of BAT conclusions (published as Commission Implementing Decisions), which became binding benchmarks for permit conditions. Importantly, the directive introduced the concept of "BAT-AELs" (BAT-associated emission levels), narrowing the scope for Member State discretion and improving environmental outcomes. The IED also enhanced provisions for compliance monitoring, public participation, and access to justice, aligning more closely with the principles of the Aarhus Convention. It incorporated stricter measures for environmental inspections and introduced the requirement for baseline reports and soil and groundwater monitoring for installations handling hazardous substances. These provisions addressed long-standing concerns about legacy pollution and the restoration of industrial sites. Between 2011 and 2020, the IED's implementation prompted further alignment among Member States and catalysed the development of sector-specific BAT reference documents (BREFs) across key industrial sectors. Nevertheless, challenges remained, particularly in terms of administrative burdens, the pace of BAT updates, and the integration of climate objectives. As the EU's environmental policy evolved toward decarbonisation and circular economy goals, the limitations of the IED in addressing greenhouse gas emissions and resource efficiency became more apparent (EC, 2010).

Recognizing these gaps, the European Commission launched a revision process in line with the European Green Deal and the Zero Pollution Action Plan. This culminated in a proposal for a revised IED in April 2022, which introduced several forward-looking provisions (EC, 2020). The proposed revision aimed to expand the scope of the directive to include more industrial sectors, notably extractive industries and large-scale livestock farming, which were previously either excluded or insufficiently regulated. Furthermore, it proposed a more dynamic, innovation-driven permitting process and stronger integration of environmental and climate performance benchmarks (EC, 2022).

Side activities significantly influenced the evolution of the IPPC and IED framework. These included the development of the EU's Environmental Technology Verification (ETV) scheme, horizontal strategies like the 7th and 8th Environmental Action Programmes, and environmental information systems such as the European Pollutant Release and Transfer Register (E-PRTR). The European Environment Agency (EEA) and the Joint Research Centre (JRC) played vital roles in knowledge consolidation, capacity building, and methodological support, particularly through the Seville Process, which coordinates the drafting of BREFs (EC, 2022).

From 1996 to 2025, the trajectory of the IPPC and IED directives reflects a gradual but determined shift toward

a more integrated, enforceable, and science-based approach to industrial pollution control in the EU. Their evolution demonstrates how regulatory frameworks can adapt to technological progress, socio-political pressures, and emerging environmental imperatives, moving from fragmented control to systemic governance of industrial emissions (Vasovic et al, 2016).

IPPC/IED IN NUMBERS

The number of installations regulated under IPPC and later IED has steadily increased. By the time IED entered into force in 2011, approximately 50,000 sites across industry types from energy and chemicals to farming held integrated permits (Pettersson & Söderholm, 2014). As of 2025, it's estimated that around 60,000 installations across the EU remain subject to IED permit requirements incorporating expanded activities like intensive livestock farming (Bjerg et al, 2019). Larger economies naturally host more regulated installations. Germany, France, Italy, Spain, and Poland each account for 5,000–7,000 permitted sites, while smaller Member States such as Slovenia or Malta have fewer than 500 IPPC/IED installations.

Table 1. *Estimated Number of IPPC/IED Permitted Installations (EU-BRITE, 2024)*

Year	Approx. number of operators
1996	35,000
2005	45,000
2011	50,000
2020	58,000
2025	60,000

Data collected during BREF reviews in sectors like waste-water, large combustion plants (LCPs), and animal farming indicate progress toward BAT-AEL compliance, though variance remains, for instance in:

- Waste-water treatment (2020): Typical BATAEL: Total P ≤ 0.4–5 mg N/l Many high-capacity plants report values towards upper limit, but several exceed it.
- Large Combustion Plants (2009 baseline): Dust: 77.6 kt actual → potential 55.1 kt under IED ELVs → lower BATAEL target yields further reductions (not quantified).
- Animal production (e.g., Sweden): Ammonia emissions per 'animal place' are ~1.83 kg NH_3/year-below the upper BAT-AEL of 2.6 kg NH_3/animal-place/year.

From 2005–2019, the EU-27 achieved:

- $PM_{2.5}$ ↓ 29%, PM_{10} ↓ 27%
- SO_2 ↓ 76%, NO_X ↓ 36%
- CH_4 ↓ 17%, NH_3 ↓ 8%
- Heavy metals like Ni, Hg, Pb all declined by 33–50%.

These reductions align broadly with the phased implementation of BAT-AELs under IED and demonstrate better-than-media-directive outcomes. For example, case studies suggest compliance with upper-end BAT range can reduce SO_2 by ~2,747 t/year and dust by ~286 t/year thus yielding monetized health benefits of €20–60 million annually in sectors like TiO_2 production (EU-BRITE, 2024).

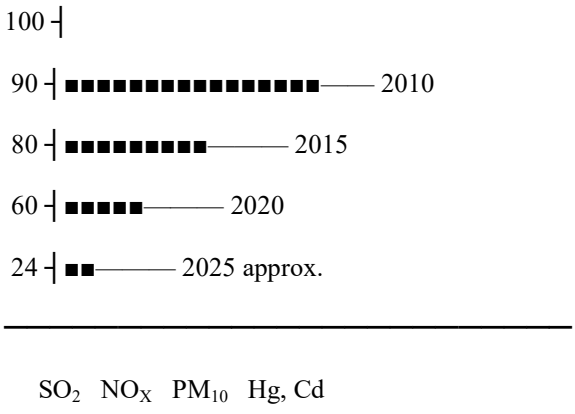


Figure 1. *EU-27 Air Pollutant Emissions Index (EU-BRITE, 2024)*

With the adoption of the IED, installations subject to IPPC/IED (≈ 60,000 across the EU) have been required to report pollutant discharges to water annually via the Industrial Emissions Portal (IEP), replacing the E-PRTR. These reports capture both direct emissions to surface waters and off-site transfers via sewage systems:

- In 2021, installations reported approximately 4.2 Mt of pollutants transferred to wastewater, including key substances like heavy metals, nitrogen, phosphorus, and persistent organics environment.
- This represents a 15 % decline from 2016 levels (≈ 4.9 Mt), highlighting improved source controls and tighter BAT-AELs for wastewater emissions.

Table 2. *EU-27 Wastewater Pollutant Discharges by IPPC/IED Installations (IEP, 2024)*

Year	Total Pollutants to Wastewater (Mt)	Change vs. Previous
2016	4.9	–
2018	4.6	– 6%
2020	4.4	– 11%
2021	4.2	– 15% vs. 2016

These reductions align with BAT-based permitting and sectoral BREFs that set stringent benchmarks on industrial wastewater treatment, nutrient removal, and heavy metal minimization, particularly in chemicals, metal production, and pulp-and-paper sectors. Uptake of end-of-pipe treatments, closed-loop systems, and water recycling also accelerated post-2010.

Beyond air and water, the IED also standardizes the management and off-site transfer of industrial waste generated by these installations. According to E-PRTR/IEP data and BREF guidance, IPPC/IED sites consistently report:

- In 2016, EU operators collectively transferred ≈ 12 Mt of industrial waste off-site, including both hazardous and non-hazardous streams.
- By 2021, that figure was around 11 Mt, a modest 8 % decline, reflecting gradual improvements in material efficiency, waste prevention, and on-site recycling promoted by BAT conclusions.

However, unlike air pollutant trends, the waste sector shows less rapid progress, partly due to heterogeneous implementation of BAT waste-management measures and the complexity of tracking waste streams.

Table 3. *EU-27 Industrial Waste Transfers via IPPC/IED (E-PRTR/IEP, 2024)*

Year	Total Industrial Waste Transferred (Mt)	% Recovered vs. Disposed
2016	12	~65 % recovered
2018	11.7	~67 %
2020	11.3	~70 %
2021	11.0	~72 %

Recovery rates, including materials recycled, composted, or used in energy recovery, increased from ~65 % (2016) to ~72 % (2021), signaling significant advances in circular-economy integration. These findings emphasize that while air pollution saw dramatic reductions under IPPC/IED, wastewater and industrial waste improvements, though real, were comparatively slower, underscoring ongoing challenges in resource efficiency and integrated pollution control.

Anyway, over the 1996–2025 period, the EU's IPPC and IED frameworks oversaw a 20,000–25,000 increase in regulated installations, with Germany, France, Italy, Spain, and Poland accounting for the majority. The progressive introduction of binding BAT-AELs, especially via sectoral BREFs, correlated with substantial emission declines: SO_2 (-76%), $PM_{10}/_{2.5}$ (~28%), NO_X (-36%), and heavy metals (~40–50%) from 2005 to 2019. Compliance with BAT-levels yields measurable health and environmental gains in many millions of euros annually while requiring annual corporate and public investment on the order of €1–3 billion. As of 2025, IPPC/IED remains instrumental in driving both technological deployment and deep emission reductions across EU heavy industry (*E-PRTR/IEP, 2024)*.

IED 2.0 KEY FEATURES

One of the most transformative aspects of IED 2.0 is the strengthening of the Best Available Techniques (BAT) framework, with a reinforced link between environmental performance levels and innovation trajectories. By extending the scope of BAT-associated environmental performance levels (BAT-AEPLs) and BAT-associated emission levels (BAT-AELs), and by introducing stricter compliance mechanisms, the directive incentivizes the continuous technological advancement of industrial installations. The directive explicitly promotes frontrunner technologies like emerging techniques (ETs) as part of an innovation-oriented regulatory design, enabling quicker deployment of cleaner and more efficient solutions through the Early Identification of Emerging Techniques (EDET) mechanism. This transformation logic is further embedded through the requirement that competent authorities must consider innovation potential in permitting decisions, thus mainstreaming eco-innovation within industrial modernization strategies (Truijens, 2021).

IED 2.0 also introduces the Industrial Emissions Portal (IEP) as a central tool for digital transformation, enabling the transparent monitoring of industrial pollution through enhanced data reporting, real-time emissions tracking, and greater public accessibility. This digital transition will facilitate data-driven decision-making, while also promoting accountability and benchmarking among states and industrial operators. Moreover, the extended application of the directive to new agro-industrial sectors and medium combustion plants broadens the regulatory coverage, ensuring that a larger portion of emissions-intensive activities are subjected to innovation-driven environmental performance improvements (Kunes et al, 2022).

Another critical outcome is the directive's contribution to circular economy transitions. IED 2.0 integrates resource efficiency indicators and mandates reporting on water, energy, and raw material usage, as well as on the generation and management of waste and by-products. This systemic approach promotes cross-sectoral synergies, encouraging industries to valorise waste streams, optimize input consumption, and reduce dependency on primary resources. In doing so, IED 2.0 reinforces the integrative approach to sustainable resource management, aligning emissions control with climate mitigation, biodiversity conservation, and zero-pollution targets (Kimmel, 2016).

Furthermore, the revised directive supports the development of environmental performance transformation plans (EPTPs) for installations with suboptimal compliance records. These plans are expected to create long-term innovation roadmaps tailored to each facility, linking regulatory obligations with research, investment, and deployment of cleaner technologies. Financially, the directive is anticipated to trigger increased investment in environmental technologies, retrofitting, and digital solutions, while also guiding public and private funding mechanisms, including the EU Innovation Fund and Just Transition instruments. In this way, IED 2.0 establishes a robust regulatory infrastructure to accelerate the industrial transition toward a more sustainable, innovative, and digitally integrated future. Through enhanced emission control, proactive innovation promotion, and synergies with circular economy strategies, the directive is

expected to yield significant environmental, technological, and socio-economic impacts across the European industrial area and beyond (Chen, 2024; Daddi et al, 2013).

CONCLUSION

In conclusion, although IED 2.0 sets a highly ambitious and transformative regulatory trajectory, its implementation is expected to face notable quantitative and systemic challenges. Estimates suggest that over 50,000 industrial installations across the EU will be subject to updated permitting requirements, with compliance costs projected to increase by 10–20% on average for affected sectors, particularly in energy-intensive industries. For small and medium-sized enterprises (SMEs), which comprise nearly 30–40% of IED-regulated facilities, the financial and technical burden of adopting advanced techniques and real-time monitoring systems could result in delayed compliance or requests for transitional arrangements. The revision introduces new digital reporting obligations through the Industrial Emissions Portal, which will require integration of standardized datasets from all implementing states, posing a significant data management and interoperability challenge, especially for countries with limited administrative capacities. Moreover, the update and incorporation of new BAT Reference Documents (BREFs), which currently take on average 6–8 years per cycle, may need to be significantly accelerated to align with the directive's tighter compliance deadlines, potentially straining the Technical Working Groups (TWGs) and national competent authorities. Additionally, delays in the identification and validation of Emerging Techniques (ETs) with only a limited number currently tracked under the Sevilla Process may affect the timely availability of innovative solutions for certain sectors. These quantitative constraints, combined with the necessity to align IED 2.0 with approximately 20 interrelated EU policies and directives, highlights the risk of phased or staggered implementation, unless adequately supported by EU-level funding mechanisms, technical assistance, and capacity-building programs. As such, while the directive has the potential to significantly reduce industrial emissions by up to 50% in certain pollutants by 2030, its real-world effectiveness will depend on the timely resolution of these operational and policy integration challenges.

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REFERENCES

Bjerg, B., Demeyer, P., Hoyaux, J., Didara, M., Grönroos, J., Hassouna, M., Amon, B., Sándor, R., Aarnink, A. J. A., & Ozkan-Gulzari, S. (2019). *Review of Legal Requirements on Ammonia and Greenhouse Gases Emissons from Animal Production Buildings in European countries*. 2019 ASABE Annual International Meeting, Boston, Massachusetts, United States. https://doi.org/10.13031/aim.201901070

Brundtland, G. H. (Ed.). (1987). *Our common future: The World Commission on Environment and Development*. Oxford University Press.

Chen, X. (2024). *The EU Regulatory Approach Regarding the Integrated Emissions Permit System. In: Towards an Integrated Environmental Permit in China*. Springer, Singapore. https://doi.org/10.1007/978-981-97-5188-4_3

Daddi, T., De Giacomo, M. R., Dils, E., Polders, C., Lepe, G. R., & Calvo, V. V. (2013). *Transferring the Integrated Pollution Prevention and Control (IPPC) Approach and Best Available Techniques (BAT) Concepts to Egypt, Tunisia and Morocco. Sustainability*, *5*(7), 2944-2959. https://doi.org/10.3390/su5072944

European Bureau for Research on Industrial Transformation and Emissions (EU-BRITE), formerly European IPPC Bureau (EIPPCB), https://eippcb.jrc.ec.europa.eu/about/more_information

European Commission. (1996). Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control. Official Journal of the European Communities, L257, 26–40. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31996L0061

European Commission. (2007). Proposal for a Directive of the European Parliament and of the Council on industrial emissions (integrated pollution prevention and control) (Recast) (COM (2007) 844 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52007PC0844

European Commission. (2020). Evaluation of the Industrial Emissions Directive (IED) (SWD (2020) 181 final). Publications Office of the EU. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020SC0181

European Commission. (2022). Proposal for a Directive of the European Parliament and of the Council on industrial emissions (recast) (COM (2022) 156 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022PC0156

European Parliament and Council of the European Union. (2010). Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control). Official Journal of the European Union, L334, 17–119. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32010L0075

Firoiu, D., Ionescu, G. H., Cismaș, L. M., Vochița, L., Cojocaru, T. M., Bratu, R.-Ș. (2023). *Can Europe Reach Its Environmental Sustainability Targets by 2030? A Critical Mid-Term Assessment of the Implementation of the 2030 Agenda. Sustainability*, 15(24), 16650. https://doi.org/10.3390/su152416650

Industrial Emissions Portal Regulation (IEPR), Regulation (EU) 2024/1244 of the European Parliament and of the Council of 24 April 2024 on reporting of environmental data from industrial installations, establishing an Industrial Emissions Portal and repealing Regulation (EC) No 166/2006 (Text with EEA relevance), PE/101/2023/REV/1, OJL, 2024/1244, 2.5.2024, ELI: http://data.europa.eu/eli/reg/2024/1244/oj

Jordan, A. (1999). *The implementation of EU environmental policy: A policy problem without a political solution? Environment and Planning C: Government and Policy, 17*(1), 69–90. https://doi.org/10.1068/c170069

Kimmel, J. (2016). *Assessing the Democratic Quality of New Modes of EU Governance: The Industrial Emissions Directive as a Test Case. European Political Science* 17: 240–257

Krämer, L. (2007). *EU environmental law* (6th ed.). Sweet & Maxwell.

Kunes, R., Havelka, Z., Olsan, P., Smutny, L., Filip, M., Zoubek, T., Bumbalek, R., Petrovic, B., Stehlik, R., & Bartos, P. (2022). *A Review: Comparison of Approaches to the Approval Process and Methodology for Estimation of Ammonia Emissions from Livestock Farms under IPPC. Atmosphere*, 13(12), 2006. https://doi.org/10.3390/atmos13122006

Pettersson, M., & Söderholm, P. (2014). Industrial Pollution Control and Efficient Licensing Processes: The Case of Swedish Regulatory Design. Sustainability, 6(8), 5401-5422. https://doi.org/10.3390/su6085401

Truijens, D. (2021). *Dual Lobbying in the Industrial Emissions Directive. In: Interest Groups and Experimentalist Governance in the EU*. Palgrave Studies in European Political Sociology. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-64602-8_4

Vasovic, D., Malenovic Nikolic, J., Janackovic, G. (2016). *Evaluation and Assessment Model for Environmental Management under the Seveso III, IPPC/IED and Water Framework Directive. Journal of Environmental Protection and Ecology*, 17 (1), 356-365. https://scibulcom.net/en/article/UvzJRB3JvNsO90IRTzGD

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ENVIRONMENTAL PROTECTION BY PRESERVING THE REQUIRED QUALITY OF SURFACE WATER

Abstract: *The paper provides an assessment of the water quality of the Danube River at the measuring station of Novi Sad as a function of oxygen consumption indicators in surface waters (BOD_5 and NH_4–N). The aim is to achieve the principle of sustainable water management of the Water Framework Directive (WFD). For surface waters, the main goal of the WFD is to achieve "good status", i.e., class II of ecological status of water quality, which shows a low level of changes in the ambient state of the environment. The calculated values of environmental protection indicators (BOD_5 =2.6 mg/l and NH_4–N =0.08 mg/l) at the observed measuring station place the water quality of the Danube into the required class II of the ecological status. The ecosystem approach indicates that the concentrations of the observed parameters BOD_5 and NH_4–N correspond to the target values of the required water quality of the Danube as an integral part of the environment.*

Keywords: environment, indicators of oxygen consumption, the Danube

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INTRODUCTION

Anthropogenic sources of river pollution can significantly affect the composition of river waters and sediments (Kašanin-Grubin et al., 2023). In economic and population terms, the most developed part of the Republic of Serbia is along the banks of the Danube, where the dominant polluters from industry are registered (Takić et al., 2012). The measuring station at Novi Sad was observed - an industrial centre where the refinery, chemical industry, and food industry are inflexibly located - which contributes significantly to the pollution of the Danube by the quantity and concentration of hazardous substances. By monitoring and preserving the required quality of the Danube water, continuous control of the state of the environment is ensured.

Water protection is considered to be the most comprehensively regulated area within the legislation of the European Union in the field of environmental protection. The European Union determined its long-term policy in the domain of water by adopting the Water Framework Directive (WFD). The WFD is the most important legal instrument in the field of water and a prerequisite for the successful realization of the concept of integral management of the environment. The Directive has formulated certain conditions that should enable the implementation of the adopted policy of sustainable use and protection of water. It should be emphasized that the WFD mandates the following goals: comprehensive protection of all waters, achievement of good water quality within 15 years, integral management of the river basin, combined approach regarding standards for limit values of permitted emissions and immissions, proper pricing and public involvement. For surface waters, the general goal of the WFD is to achieve "good status", i.e. class II ecological status of water quality, i.e. low level of natural changes that occur as a result of human activities (EC, 2000).

Surface water bodies such as rivers, lakes, and reservoirs play a vital role in maintaining ecological balance, supporting biodiversity, and providing essential resources for human activities, including drinking water supply, agriculture, industry, and recreation (UNESCO, 2021). However, increasing anthropogenic pressures − such as urbanization, industrial discharge, and agricultural runoff − pose a significant threat to water quality and to the resilience of aquatic ecosystems (EEA, 2020). In this context, continuous monitoring of water quality is crucial to ensuring that environmental standards are met and that water resources are preserved for future generations.

The Danube River, Europe's second-longest river and a crucial international waterway, flows through 19 countries and serves as a vital resource for over 80 million people. Its transboundary nature requires coordinated environmental policies and sustainable management efforts across national borders (ICPDR,

2021). In light of these challenges, the implementation of the WFD across Danube countries has provided a unified framework for monitoring, reporting, and improving water quality. Nevertheless, as highlighted by Hering et al. (2010), significant challenges remain in translating legal obligations into effective ecological outcomes, particularly in regions exposed to persistent pollution sources.

This paper evaluates the surface water quality of the Danube River at the measuring station in Novi Sad, Serbia, by analyzing two key indicators of organic pollution and oxygen consumption: biochemical oxygen demand over five days (BOD_5) and ammonium nitrogen (NH_4–N). These parameters are widely accepted in environmental monitoring as indicators of the degree of organic matter decomposition and the level of nutrient pollution, both of which affect the oxygen regime and ecological health of the water body (Chapman, 1996; Wetzel, 2001).

The main objective of this research is to determine whether the measured values of BOD_5 and NH_4–N are within the thresholds defined for Class II ecological status according to the WFD. Achieving and maintaining this water quality status is not only a legal obligation under the EU framework but also a key measure for environmental protection, public health, and regional sustainability. Through this case study, the paper highlights the importance of aligning local water management practices with European environmental policies, contributing to the broader goal of integrated river basin management and sustainable development.

METHODOLOGY

The paper analyzes selected surface water quality parameters, specifically oxygen consumption indicators BOD_5 and NH_4–N, which are defined as environmental status indicators according to the Rulebook on the National List of Environmental Protection Indicators (Rulebook, 2011).

BOD_5 represents the amount of dissolved oxygen required by microorganisms to biologically decompose organic matter in water over five days. It is a fundamental indicator of organic pollution in surface waters, as the required oxygen quantity is proportional to the amount of biodegradable organic substances present. Elevated organic pollution leads to increased microbial activity and oxygen consumption, which can result in oxygen depletion and anaerobic conditions. Under anaerobic conditions, nitrogen compounds are transformed into reduced forms, leading to increased concentrations of ammonium (NH_4–N), which is toxic to aquatic organisms above permissible limits.

Ammonium (NH_4–N) is formed as a result of the decomposition of nitrogen-containing organic matter. Its presence in surface waters is typically linked to domestic and industrial wastewater discharge, especially from untreated or poorly treated sewage. Elevated concentrations of ammonium can lead to toxic effects on aquatic fauna, particularly fish, depending on environmental conditions such as pH, water temperature, and salinity. Ammonium serves as an indicator of potential bacterial activity often associated with human and animal waste discharge into surface waters (Rulebook, 2011).

For this study, data were obtained from the publicly available annual reports on water quality published by the Serbian Environmental Protection Agency (SEPA, 2024). These reports contain systematic monitoring results of water quality parameters at the measuring station Novi Sad on the Danube River. The data cover monthly measurements during the year and are collected according to national standards harmonized with the Water Framework Directive (EC, 2000).

The analysis focuses on the values of BOD_5 and NH_4–N from the report, examining their compliance with the criteria for Class II ecological status as defined by national legislation and the WFD. The use of official monitoring data ensures the reliability of the results and allows for the evaluation of temporal trends in water quality parameters.

The research was conducted at the hydrological measuring station in Novi Sad, located on the Danube River. This site was selected due to its exposure to significant urban and industrial impacts. Namely, the measuring station at Novi Sad is strategically situated downstream of several significant industrial and urban centers. This includes refineries, chemical plants, and food processing industries, all of which contribute to the potential pollution load of the river. Moreover, the area is influenced by municipal wastewater discharges and agricultural runoff from surrounding lands (Takić et al., 2012; ICPDR, 2021).

Due to its economic importance and the intensity of anthropogenic activities along its banks, the Danube section near Novi Sad represents a critical point for water quality monitoring and environmental assessment. Continuous surveillance of water quality at this station provides valuable data that reflects both local pollution pressures and broader environmental trends in the Danube basin (EEA, 2020).

The hydrological characteristics of the Danube at Novi Sad, such as flow regime, temperature fluctuations, and seasonal variations, also play a role in shaping the water quality parameters analyzed in this study. Understanding the specific conditions of this area is essential for interpreting monitoring results and implementing effective water management strategies (ICPDR, 2021).

RESULTS AND DISCUSSION

The most recent published results of surface water monitoring provided by the Serbian Environmental Protection Agency for 2023 (SEPA, 2024), along with valid national legislation in the field of water, were used. The ecological classification of Danube water is determined in accordance with the methodology prescribed by the Regulation on emission limit values of polluting substances in surface and groundwater and deadlines for their achievement (Regulation, 2012)

which includes legislation in Serbia harmonized with the requirements of the WFD. The Danube belongs to Type 1 of large rivers with the dominance of fine sediment, for which the target concentrations of parameters for the corresponding classes of the ecological status of the water are defined by the current regulations (Table 1).

Table 1. *Limit values of oxygen consumption parameters (Type 1)*

Parameter	Class I	Class II	Class III	Class IV	Class V
BOD_5 (mg O_2/l)	2	5	7	52	>25
NH_4–N (mg/l)	0.1	0.1	0.6	1.5	>1.5

The calculated mean annual values of environmental protection indicators BOD_5 and NH_4–N place the water quality of the Danube at the observed measuring station into class II and I, respectively (Table 2). In summary, the water quality of the Danube at the measuring station Novi Sad corresponds to the required class II ecological status according to national regulations harmonized with the Water Framework Directive (EC, 2000).

Table 2. *Calculated values of oxygen consumption parameters and classification*

Parameter	Novi Sad	Class
BOD_5 (mg O_2/l)	2.6	II
NH_4–N (mg/l)	0.08	I

The concentrations of the observed parameters BOD_5 and NH_4–N correspond to the prescribed limit (target) values for Class II surface water quality. This class implies a low level of deviation from natural conditions, meaning that the anthropogenic impact is present but limited and does not significantly disturb the structure and function of aquatic ecosystems (EEA, 2020; Rulebook, 2011). The limit value of the required Class II represents the environmental quality standard expressed as a threshold concentration of pollutants in surface waters. These standards are set to protect aquatic life, maintain ecological integrity, and ensure safe usage of water for multiple purposes, including recreation and irrigation (ICPDR, 2021).

BOD_5, as an indicator of organic pollution and microbial oxygen demand, reflects the presence of biodegradable matter in water. The mean value observed at Novi Sad was below the 5 mg/l threshold set for Class II, which confirms a moderate level of organic load and sufficient oxygen availability for aquatic organisms (Chapman, 1996). This suggests that the self-purification capacity of the river is preserved, and that input from urban and industrial effluents is either properly treated or sufficiently diluted by river flow.

NH_4–N, which signals potential contamination by sewage or agricultural runoff, was well within the Class I limit (< 0.1 mg/l), indicating that ammonium levels are minimal and do not pose acute toxicity risks to aquatic fauna. This is particularly important because elevated ammonium concentrations can impair fish respiration and disrupt nitrogen cycling in aquatic ecosystems (Wetzel, 2001). The low NH_4–N value also implies that the wastewater treatment infrastructure upstream may be functioning effectively or that dilution conditions are favorable.

The fact that both parameters remain within acceptable limits across the observed period highlights a degree of stability and resilience in the Danube's aquatic system at Novi Sad. Class II ecological status, as defined by the Rulebook (2011), indicates that the vitality of the ecosystem has not been impaired, ensuring the preservation of the structure and functioning of the Danube's aquatic environment. Although BOD_5 places the water in Class II and NH_4–N in Class I, the final classification is determined by the worst parameter, in line with the “one out, all out” principle of the WFD (Hering et al., 2010). Therefore, the overall status remains at Class II, which still satisfies the "good status" criterion of the Directive.

However, it is important to note that this classification represents an average condition and does not exclude the possibility of temporal fluctuations or localized pollution events. Occasional peaks, especially during low-flow periods or after industrial discharges, could temporarily deteriorate water quality. Hence, continuous monitoring and improvement of wastewater management remain essential for the long-term protection of the Danube and the achievement of higher ecological status in the future.

The second class of ecological status of water quality (Class II) shows that the vitality of the ecosystem has not been impaired, thus preserving the quality of the structure and functioning of the Danube's aquatic system as an integral part of the environment.

CONCLUSION

The conducted analysis of selected environmental protection indicators BOD_5 and NH_4–N demonstrates that the Danube River at the measuring station in Novi Sad meets the criteria for Class II ecological status. While NH_4–N concentrations consistently fall within the Class I range, the slightly elevated BOD_5 values limit the overall classification, following the precautionary “one out, all out” approach mandated by the Water Framework Directive. This classification confirms that the water quality reflects a low degree of anthropogenic influence, with preserved ecological functionality and biological integrity.

This result is encouraging in the context of the Danube’s strategic importance for Serbia – as a source of drinking water, irrigation, industrial usage, recreation, and ecological balance. The Novi Sad region, as an urban and industrial hub, represents a

critical pressure point for river water quality, and the observed status reflects the combined effects of existing wastewater treatment practices, natural self-purification potential, and hydrological conditions.

The application of national legislation, particularly the Regulation on Emission Limit Values of Polluting Substances in Surface and Groundwater (Regulation, 2012), provided a robust legal framework for assessment. The classification by river type (Type 1 large lowland river with fine sediment) ensures that the ecological evaluation accounts for natural variability and specific environmental characteristics. The consistency of NH_4–N values with Class I norms points to satisfactory management of sanitary and agricultural sources of pollution, while BOD_5 remains an indicator that requires continued attention due to the complexity of its sources, which often include both point and diffuse inputs.

Despite the overall positive ecological status, it is important to emphasize that Class II represents a "good" condition but not a fully pristine one. The potential for temporary deterioration due to accidental discharges, hydromorphological alterations, or seasonal stress (e.g., low flow periods, and high temperatures) must be carefully managed. Regular and integrated water quality monitoring is therefore essential, along with targeted interventions in sectors with high pollutant loads.

In the broader context of the Danube River Basin, which spans 19 countries, this study underscores the value of transboundary water cooperation and harmonized data collection. Achieving and maintaining good ecological status requires alignment between local, national, and international efforts. Serbia's progress in implementing WFD principles contributes to the shared responsibility for protecting one of Europe's most vital river systems.

Future research should expand the analysis to include biological indicators (such as macroinvertebrates or phytoplankton), hydromorphological parameters, and emerging pollutants (e.g. microplastics, pharmaceuticals), which are increasingly relevant in ecological assessments. Moreover, coupling chemical data with ecological risk assessments and modeling of pollution sources could provide a more comprehensive understanding of river health and support evidence-based policy decisions.

Ultimately, safeguarding the required quality of the Danube's surface water is not merely a regulatory task - it is a strategic imperative for sustainable development, environmental protection, and the well-being of current and future generations across the Danube basin.

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REFERENCES

Chapman, D. (1996). *Water Quality Assessments – A Guide to Use of Biota, Sediments and Water in Environmental Monitoring* (2nd ed.). UNESCO/WHO/UNEP.

European Commission (EC) (2000). *Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy*. Official Journal of the European Communities. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32000L0060

European Environment Agency (EEA) (2020). *European waters: Assessment of status and pressures 2020*. https://www.eea.europa.eu/publications/state-of-water

Hering, D., Borja, A., Carstensen, J., Carvalho, L., Elliott, M., Feld, C. K., ... & van de Bund, W. (2010). The European Water Framework Directive at the age of 10: a critical review of the achievements with recommendations for the future. *Science of the Total Environment, 408*(19), 4007–4019. https://doi.org/10.1016/j.scitotenv.2010.05.031

International Commission for the Protection of the Danube River (ICPDR) (2021). *Danube River Basin Facts and Figures*. https://www.icpdr.org

Kašanin-Grubin, M., Vasić, R., Knežević, S., & Micić, R. (2023). Anthropogenic impacts on river sediment quality in the Danube basin. *Journal of Environmental Studies*, 48(2), 125–133.

Regulation (2012). *Regulation on emission limit values of polluting substances in surface and groundwaters and deadlines for their achievement* (Official Gazette of the RS, no. 50/2012).

Rulebook (2011). *Rulebook on the National List of Environmental Protection Indicators* ("Official Gazette of the RS", no. 37/2011).

Serbian Environmental Protection Agency (SEPA, 2024). *Results on Testing the Quality of Surface and Groundwater for 2023*; Ministry of Environmental Protection, Serbian Environmental Protection Agency: Belgrade, Serbia, 2024.

Takić, L., Marković, D., & Kostić, Z. (2012). Industrial pollution and surface water quality along the Danube in Serbia. *Environmental Monitoring Reports*, 23(4), 56–64.

Takić, D., et al. (2012). Industrial impacts on water quality of the Danube in Serbia. *Environmental Science and Pollution Research*, 19(4), 1167–1177.

UNESCO (2021). *UN World Water Development Report 2021: Valuing Water*. United Nations Educational, Scientific and Cultural Organization. https://unesdoc.unesco.org/ark:/48223/pf0000375724

Wetzel, R. G. (2001). *Limnology: Lake and River Ecosystems* (3rd ed.). Academic Press.

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ECOLOGICAL STATUS OF SURFACE WATER IN TERMS OF ENVIRONMENTAL PROTECTION INDICATORS

Abstract: *Current issues related to pollution of aquatic ecosystems necessitate an assessment of the water quality of the Danube River based on environmental protection parameters. This paper analyzes the concentrations of orthophosphate (PO_4–P) and nitrate (NO_3–N) in water, in accordance with the Rulebook on the National List of Environmental Protection Indicators (Official Gazette of RS, No. 37/2011), at the Radujevac monitoring station, which represents the river's exit point from Serbia. The calculated mean annual concentrations of the observed parameters (PO_4–P = 0.129 mg/L and NO_3–N = 0.96 mg/L) correspond to water quality class III and class II, respectively. The ecological status of the Danube River at the Radujevac station is classified as moderate (class III), due to the orthophosphate concentration exceeding the reference value. These results highlight the need for measures aimed at preventing pollution and improving the water quality of the Danube River in the context of environmental protection.*

Keywords: pollution of the Danube, nutrients, ecological status

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INTRODUCTION

Ecological status is an expression of the quality of the structure and functioning of aquatic systems belonging to surface waters, providing an essential basis for evaluating the overall state of the environment. It is a multidimensional concept that encompasses various biological, chemical, and physical parameters that collectively define the health of water ecosystems. This status reflects not only the condition of aquatic ecosystems but also the extent to which they have been affected by anthropogenic activities and natural processes. The Water Framework Directive (WFD, 2000), a cornerstone of EU water management policy, sets specific goals for surface waters, emphasizing the achievement of a high ecological status as a priority. Specifically, the main goal of the WFD is to ensure that water bodies attain class II of ecological status or better, where class II is defined as a state of water quality exhibiting low levels of natural changes, confirming that the environment remains largely intact and in a near-natural state. The Directive emphasizes the prevention of deterioration and enhancement of aquatic ecosystems, aiming to restore and protect the quality of water resources across the European Union (WFD, 2000).

The classification and monitoring of the ecological status of water bodies, in line with the WFD, are based on a range of environmental protection indicators. These indicators serve as a critical tool for assessing the health of aquatic ecosystems, identifying potential environmental stressors, and determining the effectiveness of management measures. The Rulebook (2011), which governs water quality management in Serbia, provides comprehensive guidelines for the classification of environmental protection indicators according to specific thematic units and areas. This document defines the relevant parameters that must be monitored to accurately evaluate the state of the environment, including key indicators for nutrient concentration in surface and groundwater.

In Serbia, the classification and monitoring process for surface waters involves key parameters such as orthophosphate (PO_4–P) and nitrate (NO_3–N) concentrations in rivers, as well as total phosphorus (P) and nitrate (NO_3–N) in lakes and reservoirs. These indicators are essential for understanding the spatial distribution of nutrients and their long-term trends. The concentration of orthophosphate and nitrates is particularly important because excessive nutrient loading, often a result of agricultural runoff, untreated wastewater, and industrial discharge, can lead to eutrophication. This process depletes oxygen levels in water, disrupts aquatic life, and fosters the growth of harmful algal blooms. As a result, these nutrient indicators serve as primary signals of water quality

degradation and are critical in identifying areas at risk of ecological damage. Furthermore, monitoring concentrations of NO_3–N in groundwater is essential to assess the broader implications of nutrient pollution on terrestrial ecosystems and drinking water quality.

The study and monitoring of these indicators provide valuable insights into the spatial variation of nutrient concentrations across Serbia's rivers and lakes, offering data on their temporal fluctuations and long-term trends. Such data are invaluable for detecting potential environmental risks and identifying regions requiring targeted interventions to prevent or mitigate further ecological degradation. Numerous studies have demonstrated that nitrogen and phosphorus are the principal contributors to the pollution of the Danube River and its tributaries. These studies underscore the critical importance of effectively managing nutrient inputs to protect aquatic biodiversity and preserve the ecological integrity of the river system (Mladenović-Ranisavljević et al., 2022; Savic et al., 2022).

In this context, phosphorus is often considered a limiting factor in freshwater ecosystems, as excessive concentrations can significantly alter the composition of aquatic flora and fauna, leading to imbalance and loss of biodiversity. Similarly, nitrogen compounds, particularly nitrates, pose a significant risk to water quality, contributing to both eutrophication and the contamination of water supplies, which has serious public health implications.

Given the importance of these nutrients, their monitoring is integral to sustainable water management, enabling the early detection of pollution trends and providing a scientific basis for policy-making aimed at improving water quality. Furthermore, the data generated from such monitoring efforts are critical in assessing the effectiveness of environmental regulations and identifying regions where additional mitigation measures are necessary.

In this work, the state of the water quality of the Danube River is assessed as a function of nutrients (orthophosphates and nitrates) at the exit point of the river flow from Serbia, monitoring station Radujevac. The selected measuring point, Radujevac, represents a key location at the exit of the Danube River from Serbia, making it highly significant for assessing water quality at the boundary between different ecological regions and geographical influences on the aquatic ecosystem. At this point, the Danube River marks a transition zone between the effects of inland activities and those of cross-border river flows. Therefore, the measurement of nutrient concentrations at this site is crucial. The Danube flows through several countries, exposing it to combined anthropogenic pressures, including industrial pollution, agriculture and urban waste.

At the Radujevac monitoring station, concentrations of nutrients such as nitrates and orthophosphates reflect the cumulative effect of all these activities, which manifests as changes in water quality and potentially threatens aquatic ecosystems.

Monitoring the levels of these nutrients at the exit point from Serbia enables the detection of the spatial distribution of pollution and provides a better understanding of the natural and anthropogenic factors influencing the river.

This is particularly relevant because the Danube, as one of the largest European waterways, connects many ecological regions and acts as a bridge between various aquatic systems and ecosystems. Precise measurement and analysis of nutrient concentrations at Radujevac allow for the detection of changes caused by human activities in real-time and offer insights into the long-term effects of eutrophication, often driven by excessive nitrogen and phosphorus inputs into the water.

Thus, this monitoring station is a critical point in defining the boundaries of ecological regions in the Danube River, as it helps determine whether water exiting Serbia has high or low levels of pollution, providing data that can serve as the basis for further research frameworks in the area of integrated water resource management and the formulation of protection strategies. The monitoring process at Radujevac not only contributes to the qualitative assessment of water quality, but also helps identify key intervention points for improving water quality management across the entire watershed.

METHODOLOGY

For precise classification of the ecological status of water, a classification system was used based on the following categories: very good, good, moderate, poor, and very poor. This classification system is used for an objective assessment of water quality based on physicochemical, biological, and hydromorphological parameters, as well as their interrelations. Each of the mentioned categories corresponds to specific standards, which are aligned with EU directives and regulations, such as the Water Framework Directive (WFD), which sets the basic guidelines for assessing and protecting aquatic ecosystems.

The classification was carried out by comparing the obtained data with the reference values prescribed for each of these categories. These values encompass specific limits for parameters such as nutrient concentrations, temperature changes, biodiversity, oxygen levels, pH, and the presence of pollutants. By considering all analyzed parameters and their interactions, the classification enables a precise determination of the current ecological balance in a given water body, providing insight into its functionality and resilience to various ecological and anthropogenic stressors.

For each category, specific boundary conditions are defined to encompass both chemical and biological aspects of water quality. For example, a very good ecological status is characterized by high biodiversity and minimal deviation from the natural state, while a very poor ecological status indicates serious degradation of the ecosystem, with high pollutant

concentrations, reduced biodiversity, and disrupted ecological balance. These classifications provide essential guidelines for water resource management and help in determining the necessary steps for water protection and restoration.

The classification of the ecological status of water is not based on a single parameter but results from a comprehensive analysis of all significant factors influencing water quality. For instance, high levels of nitrates may indicate eutrophication and a loss of biodiversity, while changes in water temperature can signal the negative effects of global warming. This holistic approach to classification allows for accurate and relevant decisions to be made regarding water protection strategies, and helps identify priority areas for the implementation of ecosystem restoration measures and pollution reduction.

For the purposes of the research, publicly available data from the annual surface and groundwater monitoring report published by the Environmental Protection Agency, Ministry of Agriculture and Environmental Protection of the Republic of Serbia (SEPA, 2024) were used. Based on the monthly measured values of the defined nutrient parameters, the average annual nutrient values were calculated, which, by comparative analysis with the current Regulation on emission limit values of polluting substances in surface and groundwaters and deadlines for their achievement (Regulation, 2012), ecologically classifies the state of the water quality of the Danube.

RESULTS AND DISCUSSION

Based on the monthly measurements conducted and published by the Serbian Environmental Protection Agency (SEPA, 2024), the average annual values of the parameters at the observed measuring station Radujevac in Serbia were calculated. The calculated values of the nutrient indicators were compared with the limit values of the quality classes defined by the Regulation, thus, the corresponding water quality class of the Danube River was determined. This enabled the assessment of the actual water quality at the observed measuring station. The calculated values, together with the prescribed limit values, are presented in Table 1.

Table 1. *Calculated and limit values of the observed parameters*

Parameter		**NO_3–N**	**PO_4–P**
Unit		mg/L	mg/L
Average annual values		0.96	0.129
The prescribed limit values and classification			
Class	I	1	0.02
	II	1	0.02
	III	6	0.2
	IV	15	0.5
	V	>15	>0.5

The average annual value of NO_3–N classifies water quality into class II, while the value of PO_4–P belongs to class III of the ecological status of water quality. Therefore, the overall water quality of the Danube River in terms of environmental protection indicators - nutrients corresponds to class III of the ecological status of water quality at the observed location of Radujevac.

The reasons for the elevated concentrations of NO_3–N and PO_4–P at the Radujevac measuring station, exceeding the prescribed limit values, are primarily linked to the increased nutrient input into the Danube River. A major contributor to this nutrient load is agricultural runoff, which plays a significant role in nutrient pollution of surface waters. The extensive use of chemical fertilizers containing nitrates and phosphorus in agriculture leads to an excess of nutrients that are carried off the land during rainfall events or irrigation. These nutrients, being in soluble forms like NO_3–N and PO_4–P, easily dissolve in water and are transported into nearby rivers. This issue is exacerbated in regions with soil erosion, as it increases the amount of nutrients being washed into water systems. This problem is particularly prominent in intensive agricultural areas, where the continuous application of fertilizers increases nutrient levels in local water systems, contributing to pollution.

In addition to agricultural runoff, municipal wastewater discharge and industrial effluents are significant factors in the pollution of the Danube. In regions with insufficient wastewater treatment capacity, municipal sewage treatment plants may fail to adequately remove nutrients before they are released into the river. With the growth of urbanization, there is an increase in the volume of wastewater, much of which contains nitrates and phosphates from household waste, detergents, and other domestic activities. This problem is especially notable in areas where wastewater treatment infrastructure is outdated or not functioning optimally. Similarly, industrial discharges, particularly from food processing, textile, and chemical manufacturing industries, can contribute to nutrient pollution when wastewater containing phosphorus and nitrogen compounds is released into the water.

The combination of these sources-agricultural runoff, municipal wastewater, and industrial discharges-significantly increases the concentration of nitrates and orthophosphates in the Danube, particularly at the exit point from Serbia. This nutrient pollution, if not addressed, can lead to serious environmental consequences, such as eutrophication, which promotes harmful algal blooms, depletes oxygen levels in water, and disrupts the balance of aquatic ecosystems. It also poses risks to human health, as increased nutrient levels in the water can affect the quality of drinking water and ecosystem services that the river provides to local communities.

Addressing these challenges requires integrated management approaches, such as improving agricultural practices, upgrading wastewater treatment

facilities, and strict regulation of industrial discharges. By reducing nutrient inputs from these key sources, it is possible to mitigate the impact of pollution and improve the ecological status of the Danube River.

CONCLUSION

The ecological status of the Danube River at the Radujevac measuring station was classified as moderate (class III), primarily due to the observed concentration of PO_4–P exceeding the reference values for this category. This classification signals a significant environmental issue, as elevated levels of orthophosphate are a clear indicator of nutrient pollution, which is largely a result of human activities such as agricultural runoff and insufficiently treated wastewater. The presence of excess nutrients, especially phosphates, leads to eutrophication, a process that disrupts the natural balance of aquatic ecosystems, impairs water quality, and may severely affect biodiversity.

The results from this study underline the urgent need for stronger protective measures to prevent further degradation of the water quality in the Danube River. These measures should be implemented not only at the exit point of the river in Serbia but also along its entire stretch through the country. The findings emphasize that the current state of water quality reflects broader issues that must be addressed on a national and regional scale to mitigate the ongoing impact of pollution.

A key recommendation from the research is the alignment of Serbian water management practices with European directives, particularly the Urban Wastewater Treatment Directive (91/271/EEC) and the Nitrates Directive (91/676/EEC). These directives provide guidelines for effectively managing wastewater and controlling nitrate pollution originating from agricultural sources. By ensuring the proper implementation of these directives, Serbia could significantly reduce the entry of harmful nutrients into the river, thereby alleviating the eutrophication problem and improving the overall health of the aquatic environment.

The study further emphasizes the necessity of adopting sustainable water management practices, which encompass both preventive and corrective actions. These include better management of agricultural fertilizers, enhancing the capacity of wastewater treatment plants, and improving monitoring and enforcement of environmental regulations. Adopting principles of Integrated Water Resources Management (IWRM, 2000) would help ensure a holistic approach, addressing all factors affecting the water quality, and promoting long-term sustainable solutions.

The adoption of these measures would not only contribute to improving the ecological status of the Danube River, but also ensure its continued ability to deliver essential ecosystem services. These services include providing a habitat for diverse species, serving as a source of freshwater for human consumption, supporting agriculture, and maintaining recreational areas. In doing so, it would help maintain the ecological integrity of the river, which is critical for the well-being of both local populations and the broader environment.

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REFERENCES

Integrated Water Resources Management (IWRM): Global Water Partnership. (2000). *Integrated water resources management*. Global Water Partnership. https://www.gwp.org/en/About/more/what-is-iwrm/

Mladenović-Ranisavljević, I., Vuković, M., Stefanović, V., Takić, Lj. (2022). Multicriteria Decision Analysis of Sites with increased nutrient contents in water. *Water*, 14 (23): 3810.

Regulation (2012). *Regulation on emission limit values of polluting substances in surface and groundwaters and deadlines for their achievement* (Official Gazette of the RS, no. 50/2012).

Rulebook (2011). *Rulebook on the National List of Environmental Protection Indicators* ("Official Gazette of the RS", no. 37/2011).

Savic, R., Stajic, M., Blagojevic, B., Bezdan, A., Vranesevic, M., Nikolic Jokanovic, V., Bubalo Kovačić, M. (2022). Nitrogen and Phosphorus Concentrations and Their Ratios as Indicators of Water Quality and Eutrophication of the Hydro-System Danube–Tisza–Danube. *Agriculture*, 12.

Serbian Environmental Protection Agency (SEPA, 2024). *Results on Testing the Quality of Surface and Groundwater for 2023*; Ministry of Environmental Protection, Serbian Environmental Protection Agency: Belgrade, Serbia, 2024.

The Urban Wastewater Treatment Directive (91/271/EEC): European Parliament & Council of the European Union. (1991). *Council Directive 91/271/EEC of 21 May 1991 concerning urban wastewater treatment*. Official Journal of the European Communities, L 135, 40-52. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31991L0271

The Nitrates Directive (91/676/EEC): European Parliament & Council of the European Union. (1991). *Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources*. Official Journal of the European Communities, L 375, 1-8. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31991L0676

Water Framework Directive (WFD, 2000): *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy*. https://environment.ec.europa.eu/topics/water/water-framework-directive_en

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SMART HELMET – EVOLUTION OF PERSONAL PROTECTIVE EQUIPMENT

Abstract: *Safe and healthy work is a crucial prerequisite for good productivity and the success of companies. In addition to ongoing employee education, it is necessary to implement all measures to minimize risk to employees or reduce it to a statistical error. One such measure is the use of personal protective equipment. Injuries to employees' heads account for a significant percentage of accidents caused by mechanical factors or the effects of electricity. The primary step in preventing such accidents, when it comes to personal protective equipment, is to wear an appropriate protective helmet. Continuous technological improvement has been applied across various production processes and has also improved occupational safety. An example of this is a smart protective helmet, which maintains all the safety features of a traditional helmet while elevating the work process. Besides facilitating employees' daily tasks, it also contributes to enhancing their safety by monitoring vital parameters and potential dangers they might encounter.*

Keywords: personal protective equipment, smart protective helmet, mobile networks, high-resolution camera, sensors

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INTRODUCTION

In an industrial environment, worker safety has become a top priority. Many employees are not sufficiently aware of occupational safety and the possible dangers they may encounter. One of the frequent injuries that occurs during work and manipulations during various production processes is a head injury.

Numerous data on occupational accidents show that the most common causes of head injuries are blows from falling objects and blows against sharp and hard objects. Head injuries caused by mechanical factors can affect the skin, skull, brain, and neck of the employee. In extreme cases, these injuries can lead to permanent disability or even death. It is not always possible to eliminate such risks only with appropriate organizational solutions or collective protective equipment.

In power plants, in addition to head injuries caused by mechanical action, injuries can also occur as a consequence of the harmful effects of electricity.

The safe and stable operation of power plants is directly related to the safety of their employees. Work on fixing plant and equipment malfunctions always represents a safety risk for all employees. Employees in other industrial branches, such as construction, railways, mechanical engineering, etc. are also exposed to the potential dangers of electricity.

In addition to the safety rules that must be followed by all employees in the workplace, wearing personal protective equipment (PPE) is of essential importance for the safe and healthy work of all employees. Personal protective equipment refers to any equipment intended to be worn or held by people at work that protects them from one or more risks to their health and safety, as well as any accessory designed to meet this objective (Ministry of Economy of the Republic of Serbia, 2020). All PPE should be used as a last resort to reduce risk, considering that the risk cannot be eliminated.

Protective helmets are one of the most commonly used pieces of PPE (Oshwiki, 2025). They are worn to protect the head from:

- impact from objects falling from above, by resisting and deflecting blows to the head;
- hitting fixed dangerous objects at the workplace;
- lateral forces – depending on the type of helmet chosen;
- open flames, splashes of molten metal, electric shock, and high temperatures.

In general, hard hats or helmets should:

- resist the penetration of objects;
- absorb shocks;
- be waterproof and slow burning; and

- contain instructions that explain the proper adjustment and replacement of the suspension and headband.

PPE designed to protect the whole body or part of it from the effects of electric current must provide sufficient isolation from the voltage to which the user may be exposed under the most unfavourable conditions.

To achieve adequate protection, the materials from which the PPE is made must be selected, designed, and installed in such a way as to ensure that the electric current that penetrates through the protective sheath is reduced and always below the maximum allowed value (Ministry of Economy of the Republic of Serbia, 2020).

Several factors must be considered when designing PPE:

- the risk of direct contact with a live conductor;
- possible harmful electrical parameters and limit values;
- skin moisture;
- the effect of contact with used chemicals such as solvents, the effect of mechanical degradation/aging, and climatic environmental factors during the normal use of PPE.

The marking of the protection class on PPE for professional use, intended for protection against electric shock, is necessary to ensure traceability and information about the scope of use and the required periodic checks.

In addition to electric shock, other risks associated with short-circuiting should be considered, such as thermal and mechanical risks.

Depending on the risk, PPE is classified into three categories (Official Gazette, 2025).

Category I includes the following minimal risks:

1) surface mechanical action;
2) contact with milder cleaning agents or prolonged contact with water;
3) contact with hot surfaces whose temperature does not exceed 50°C;
4) eye damage due to exposure to sunlight;
5) atmospheric influences that are not extreme.

Category II includes risks that are not listed in categories I and III.

Category III includes risks that can cause death or serious and permanent damage to health from:

1) substances and mixtures that are dangerous to health;
2) an atmosphere with a lack of oxygen;
3) harmful biological agents;
4) ionizing radiation;
5) environments with high temperature, the effect of which can be compared to that of air temperature of +100°C or higher;
6) environments with a low temperature, the effects of which can be compared to those of air temperature of -50°C or lower;
7) falls from a height;
8) electric shock and working under voltage;
9) drowning;
10) cuts when working with a manual chainsaw;
11) high-pressure jets;
12) gunshot wounds or stab wounds;
13) harmful noises.

According to the previous classification, PPE intended for areas where there is a potential danger of electric shock and working under voltage must meet all the conditions prescribed for category III.

TYPES OF SAFETY HELMETS

The most common and basic form of PPE that aims to protect the employee's head is the industrial safety helmet (ISS, 2025a). These types of helmets consist of a shell, a belt, and a headband.

The helmet shell is the hard outer part of the helmet and is usually made of polyethylene, ABS (acrylonitrile butadiene styrene - thermoplastic), or fiberglass reinforced with polyester resins. The main function of the shell is to protect against a falling object or striking the user's head.

The harness is the inner part of the helmet, consisting of a system of straps made of woven straps or polyethylene. The main purpose of the harness is to absorb the energy from impact with the shell and to distribute the force evenly across the wearer's head, minimizing the risk of injury to the wearer (Oshwiki, 2025).

There are industrial workplaces where the risk of head injuries is so high that industrial safety helmets compliant with SRPS EN 397 (ISS, 2025a) are insufficient to provide an adequate level of protection. Examples of industrial sectors where such jobs exist include mining and construction. In such cases, the conducted risk assessment would identify that employees must be equipped with high-performance industrial protective helmets, i.e. helmets that comply with SRPS EN 14052 [SRPS EN 14052:2013 – High performance industrial helmets].

These helmets have the following features (Oshwiki, 2025):

- They provide the same level of shock absorption as industrial helmets, even though they are exposed to an impact with twice the energy compared to them;
- They protect the head from vertical and lateral impacts (industrial helmets do not have lateral support);
- They provide an increased level of protection against the impact of sharp objects.

Electrically insulating helmets

If the helmet is designed to offer electrical insulation protection, it must meet the requirements of SRPS 50365 (ISS, 2025b; ISS, 2025c).

To mitigate the risk of hazardous electrostatic charge accumulation, helmets shall incorporate one of the following protective measures (SIST, 2025):

- Use of Dissipative Materials: Employ materials with dissipative properties that can be reliably earthed, typically via contact with the wearer, ensuring effective discharge of electrostatic charges;
- Use of Insulating Materials with Low Chargeability: Utilize insulating materials that exhibit minimal tendency to accumulate static charge through triboelectric interactions with clothing under normal operating conditions. If insulating materials are present, electrostatic charging tests shall be performed using fabrics from both ends of the triboelectric series. In cases where corona discharge and leather glove whipping tests are omitted, it must be explicitly stated in the user documentation that the helmet is not suitable for environments where electrostatic charging exceeds levels typical of manual rubbing;
- Non-Accessible Insulating Components: Insulating materials located in areas of the helmet that are not accessible during operation are exempt from triboelectric charging tests, as they are not subject to mechanical interaction or friction.

In addition, any accessible isolated conductive components within the helmet are considered isolated capacitances and must comply with the requirements specified in IEC TS 60079-32-1 (ISS, 2025d).

FROM PASSIVE GEAR TO ACTIVE SAFETY SYSTEMS

The rapid development of science and technology has enabled the application of adequate technological solutions to improve occupational safety and protection in the form of modernized PPE. The three main requirements when designing intelligent protection are personnel safety, equipment safety, and environmental safety. The combination of video intelligence and wireless communication was aimed at active warning, intelligent decision-making, and automatic inspection, improving the ability of people to detect faults, the ability to control operations and maintenance, possibilities of emergency warning and response, remote control, and the like.

One of the representatives of intelligent protection is a smart helmet (Figure 1).



Figure 1. *Smart helmet (Ouxiang International Limited, 2025; Jepower, 2025)*

Smart helmets have been widely applied in the power industry (Figure 2), railways (Figure 3), construction (Figure 4), steel industry, docks, etc. In some industries, such as aerospace and energy, workers or managers using smart helmets can command and solve problems in real time. Smart safety helmets provide a high level of protection, preventing workers from head impacts, stab wounds, and other injuries (Ouxiang International Limited, 2025; Jepower, 2025; Elefine, 2025).



Figure 2. *Smart helmet in the power industry (Ouxiang International Limited, 2025; Elefine, 2025)*



Figure 3. *Smart helmet in railways (Railpro, n.d.)*



Figure 4. *Smart helmet in construction (Palladino, 2017)*

The smart helmet is an intelligent mobile operating terminal that supports secure communication via mobile and Wi-Fi networks. It has integrated high-speed processors, a high-resolution camera, a wireless communication module, various sensors, and the like (Figure 5).

The high-resolution camera has video recording, picture taking, storage, and night light functions. Recording can be used for evidence gathering, remote guidance during maintenance, security monitoring, intelligent early warning, etc. (Ouxiang International Limited, 2025).

The smart helmet can make real-time audio and video calls and real-time video surveillance. Communication with other devices, such as smartphones or computers, via mobile network, Wi-Fi, or Bluetooth is enabled (Jepower, 2025). A smart helmet can transmit audio and video material to the dispatch centre in real time. A person wearing a smart helmet can initiate an audio or video call with the centre with the push of a button. The

communication is two-way, so the dispatcher can initiate a call from a remote location at any time and simultaneously record images displayed by multiple smart helmets. Two-way communication is not limited to a small area, which significantly facilitates work in remote and less accessible areas (Elefine, 2025).



Figure 5. *Smart helmet functions (Ouxiang International Limited, 2025)*

They usually contain multiple sensors, such as accelerometers, gyroscopes, temperature sensors, and perception sensors. These sensors are used to detect environmental parameters, such as temperature, humidity, and light.

They can record various parameters, e.g. workers' working hours, location, task performance, and other data, and transmit this information to the centre for analysis (Jepower, 2025; Elefine, 2025).

They have the option of GPS positioning and the option of multiple alarms, such as a safety alarm, a fall alarm, a crash alarm, a helmet removal alarm, a silent alarm, and other functions.

The automatic alarm function is essential, as it enables immediate recognition of dangerous and unwanted situations, and timely action and assistance on the spot (Elefine, 2025).

Some smart helmets can be equipped with Augmented Reality (AR) or Virtual Reality (VR) functions, providing workers with more intuitive job guidance and better training (Jepower, 2025).

The smart AR helmet may have a brainwave interface, heart rate monitoring, and other functions. The brainwave collection function can monitor the worker's physical fitness and emotions in real-time, and judge and give an early warning for further fitness for work. Safety accidents often occur when personnel work in harsh environments (Ouxiang International Limited, 2025).

Smart safety helmets usually have built-in batteries and charge management systems. In this way, full mobility and long-term use were achieved. The design is adapted to the comfort of workers when wearing it. They are made of light and breathable materials to increase comfort during long hours of wear (Jepower, 2025).

CONCLUSION

All employees working in areas where there is a possible risk of head injury from impact, falling or flying objects, or electric shock and burns, must be protected by protective helmets. Protective helmets must be worn when performing most construction work, work near lifting equipment (cranes, etc.) and suspended loads, and work in forestry, tanks, wells, shafts, tunnels, etc.

In some situations, protective helmets serve as the basis for other types of PPE, i.e. are used together with other PPE, e.g. hearing protection, face shields, or respiratory protection equipment.

All work related to the selection, maintenance, training for safe use, inspections, and maintenance of the register of protective helmets is the responsibility of the employer. A risk assessment may stipulate that the user must wear a protective helmet during the entire shift. Also, the employee is responsible for using protective equipment for its intended purpose. He will also be obliged to inform the employer or the appropriate occupational health and safety representative of any defects in this equipment. However, it should be remembered that the use of helmets does not eliminate dangerous factors, but only reduces the severity of their consequences.

Thanks to their technology, smart helmets have become an excellent tool for performing essential and everyday tasks, without diminishing the safety role they play as a representative of PPE. With their capabilities, they raised occupational safety and health to a higher level.

They can be used in power inspections, site inspections, remote operations, explosion monitoring, rescue and disaster relief, remote guidance for maintenance, police forces (interventions, traffic, patrols), coast guard forces, fire control, emergencies, etc.

They are equally useful both for real-time communication and for archiving data collected from the field, as well as for the safety of the employees themselves. They are particularly suitable for evidence gathering, remote guidance during maintenance, security surveillance, early warning, real-time communication, and real-time video surveillance. They raise the safety of employees to a higher level by determining the location of employees in real time and by alarming both employees and the control centre, which contributes to timely action and on-site assistance. Some smart helmets monitor the wearer's vital functions and assess the mental and physical state of employees at a given moment.

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REFERENCES

Elefine. (2025). *Smart safety helmet with HD camera, built-in WiFi/4G/GPS/SOS positioning, live video network camera*. https://www.elefinetech.com/smart-safety-helmet-with-hd-camera-built-in-wifi-4g-gps-sos-positioning-live-video-network-camera/

ISS. (2025a). *SRPS EN 397:2021 – Industrial protective helmets*.

ISS. (2025b). *SRPS EN 50365:2024 – Live Working – Electrically insulating helmets for use on low and medium voltage installations*.

ISS. (2025c). *SRPS EN 50365:2024/AC:2025 – Live Working – Electrically insulating helmets for use on low and medium voltage installations (Amendments)*.

ISS. (2025d). *IEC TS 60079-32-1:2013/AMD1:2017 ED1 - Amendment 1 – Explosive atmospheres – Part 32-1: Electrostatic hazards, guidance*.

Jepower. (2025). *4G smart hard hat with camera: Live streaming camera for construction*. https://www.jepower.net/4g-smart-hard-hat-with-camera-live-streaming-camera-for-construction_p81.html

Ministry of Economy of the Republic of Serbia. (2020). Rulebook on personal protective equipment (Official Gazette of the Republic of Serbia, No. 23/2020).

Oshwiki. (2025). *Protective helmets – requirements and selection*. https://oshwiki.osha.europa.eu/en/themes/protective-helmets-requirements-and-selection

Ouxiang International Limited. (2025). *Smart helmet product details*. http://www.oxiang.com.cn/Product/0792182543.html

Palladino, T. (2017, March 8). *Trimble brings mixed reality to the construction site with DAQRI smart helmet*. Mixed Reality News. https://mixed.reality.news/news/trimble-brings-mixed-reality-construction-site-with-daqri-smart-helmet-0176463/

Railpro. (n.d.). *The smart helmet is an advantage to digitalizing quality checks in the railway infrastructure*. Retrieved 22 June 2025, from https://www.railpro.online/en_GB/blog/item/the-smart-helmet-is-an-advantage-to-digitalizing-quality-checks-in-the-railway-infrastructure-1319/

SIST. (2025). *prEN 397:2022 – Industrial protective helmets*. https://cdn.standards.iteh.ai/samples/68307/d4a868b3e1b34603af634138d32ec100/oSIST-prEN-397-2022.pdf

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RISK ASSESSMENT OF ENVIRONMENTAL HAZARDS DUE TO OIL TANK FIRE: A NUMERICAL STUDY

Abstract: *The global demand for oil and its derivatives has conditioned their storage in large-capacity reservoirs. However, regardless of preventive fire protection measures, their storage presents certain risks, including potential oil leaks and ignition. This paper examines a fire incident in an above-ground crude oil tank located within the storage area of the Pančevo Oil Refinery as a case study. The Large Eddy Simulation (LES) method of the Fire Dynamic Simulator (FDS) software package has been used to investigate the effects of fire temperature and heat flux on the surrounding environment. The simulation results were used to assess how fire parameters influence the potential spread of fire to neighboring tanks and surrounding buildings. The dimensions of the potentially endangered zones around the refinery complex were determined by comparing calculated heat flux values with the valid standards for exposure to the heat radiation of fire. The results of this study are important not only for assessing the risk to nearby tanks containing oil derivatives but also for assessing human safety - both for individuals in close proximity to the fire and for firefighters and rescuers involved in firefighting operations.*

Keywords: fire, Fire Dynamics Simulator, temperature, heat flux, endangered zone

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INTRODUCTION

In the petrochemical industry, many flammable liquids are usually stored in large-capacity storage tanks. However, the fire and explosion hazards are one of the main risks associated with their storage. Namely, accidents such as leakage and diffusion can occur during the crude oil storage process. Leaking oil or oil vapour can rapidly trigger a fire or explosion when exposed to an ignition source (Wu and Chen, 2016).

If a fire accident occurs in an area with large crude oil tanks, the domino effect may be triggered, which may escalate into disastrous consequences. Abdolhamidzadeh et al. (2011) showed that about 80% of domino accidents caused by fire were the result of pool fires.

On the other hand, a pool fire emits a huge quantity of heat into the surroundings. Namely, burning pools can sustain combustion long enough to generate thermal radiation, posing risks to exposed individuals and neighbouring objects. The effects of thermal radiation are a function of the heat flux and the duration of exposure.

Many researchers have investigated the impact of fire heat flux on people and buildings. Mudan (1984) reported that an incident flux of 1.7 kW/m^2 will not even cause pain, regardless of exposure time. Babrauskas (1979) suggested that the radiant heat tolerance curve indicates a clear exposure limit of 2.5 kW/m^2 for a person without personal protective equipment. Assael and Kakosimos (2010) found that the radiant heat flux of 4.0. kW/m^2 will cause second-degree burns in 20 s. A study on protective clothing for emergency responders in petrochemical plants found that firefighter personal protective equipment could provide safe exposure up to 3 min at 4.6 kW/m^2, with critical limits reached around 5 kW/m^2, indicating insufficient protection beyond this threshold (Heus and Denhartog, 2017). The United States Federal Safety Standards for Liquefied Natural Gas Facilities (1980) suggest an acceptable level of 5 kW/m^2 for direct exposure of persons. At this incident flux, exposure time on bare skin before unbearable pain is about 13 s and second-degree burns may occur in about 40 s. This level can, therefore, be used as a criterion for injury. The level of about 10 kW/m^2 may be used in determining the hazard zone for fatality.

High intensities of the thermal radiation also damage surrounding buildings and facilities. Cozzani et al. (2006) analyzed the thermal response process of different atmospheric storage tanks under the action of

thermal radiation. The results showed that when the radiation intensity is less than 15 kW/m^2, the storage tank fails after more than 10 minutes, and when the radiation intensity is less than 10 kW/m^2, the storage tank failure time is greater than 30 min.

High heat radiation levels cause high temperatures in environments that can be harmful to human safety. According to Hoschke (1981), exposure to thermal radiation of 4.0 kW/m² causes pain within 15 seconds, and bare skin sustains burns within 30 seconds. Havenith and Daanen (2013) suggested a maximum skin temperature for pain of 43-45 °C. Hatton and Halfdanarson (1982) showed that skin burns can occur at skin temperatures from 44°C.

In this study, the following heat flux values were adopted as criteria for injury and mortality: 10 kW/m^2 at which exposure for more than 60 s results in death; 5 kW/m^2 which leads to second-degree burns at exposure for more than 60 s; 2 kW/m^2 which leads to a feeling of pain on the skin surface at exposure for more than 60 s (Jones et al., 2013). On the basis of the results of previous studies, it was also suggested that the maximum skin temperature of 43 °C is a relatively safe limit to prevent harmful skin burns. A heat flux of 12.6 kW/m² was also used as the threshold for the ignition of most hydrocarbon combustible materials in the construction industry.

Numerical analysis of the pool fire, as part of the risk analysis and accident modeling, is commonly conducted using various Computational Fluid Dynamics (CFD) tools. Therefore, this study employed the CFD Large Eddy Simulation (LES) method to assess the risk to adjacent tanks, structures, and people, including firefighters involved in firefighting activities. The FDS software package and its graphical user interface PiroSym were used to simulate the intensities of heat fluxes and temperatures in the environment within the storage area of the Pančevo Oil Refinery.

METHODOLOGY

Numerical method

This research was carried out using FDS open-source software with its graphical interface Pyrosim, developed by the National Institute of Standards and Technology. The hydrodynamic model within FDS solves numerically a low Mach number form of the Navier-Stokes equations appropriate for thermally-driven flows, as follows (McGrattan et al. 2023)

Conservation of mass:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{u}) = 0; \qquad (1)$$

Conservation of momentum:

$$\rho\left(\frac{\partial \vec{u}}{\partial t} + \frac{1}{2}\nabla|\vec{u}| - \vec{u} \times \omega\right) + \nabla p - \rho g = \vec{f} + \nabla \tau; \qquad (2)$$

Conservation of energy:

$$\frac{\partial}{\partial t}(\rho h) + \nabla \cdot (\rho h \vec{u}) = \frac{\partial p}{\partial t} + \vec{u} \cdot \nabla \rho - \nabla \vec{q}_r + \\ + \nabla(k \nabla T) + \sum_i \nabla(h_i \rho h D_i \nabla Y_i) \qquad (3)$$

where, ρ is density, $\vec{u}$ is a velocity vector, ω is z-direction velocity, p is pressure, g is acceleration of gravity, $\vec{f}$ is external force vector, τ is velocity viscous force tensor, h is sensible enthalpy, $\vec{q}_r$ is radiative heat flux, k is conductivity, T is temperature, D_i is diffusion coefficient, Y_i is mass function of i-th component, and t is time.

Energy transport (Eq. (3)) consists of convection, conduction and radiation. Convection of heat is accomplished via the solution of the basic conservation equations. Gains and losses of heat via conduction and radiation are represented by the divergence of the heat flux vector. The equation associated with the radiative part, $\vec{q}_r$ is the Radiative Transport Equation (RTE) for an absorbing, emitting, and scattering medium, as follows:

$$s \cdot \nabla I_\lambda(x,s) = -[k(x,\lambda) + \sigma_s(x,\lambda)] I_\lambda(x,s) + \\ + B(x,\lambda) + \frac{\sigma_s(x,\lambda)}{4\pi} \int_{4\pi} \Phi(s,s') I_\lambda(x,s') ds', \qquad (4)$$

where: $I_\lambda(x,s)$ is radiation intensity at wavelength λ, s is direction vector of the intensity, $k(x,\lambda)$ is local absorption coefficient, $\sigma_s(x,\lambda)$ is scattering coefficient, $B(x,\lambda)$ is emission source term, describing how much heat is emitted by the local mixture of gas, soot and droplets/particles, $\Phi(s,s')$ is a scattering phase function.

Simulation set-up

In this research, the storage complex of the Pančevo Oil Refinery was selected as a case study for modeling fire dynamics and thermal radiation of a flame to the surrounding environment (Figure 1).



Figure 1. *Pančevo Oil Refinery area*

In order to save simulation time, a segment of the storage area was designed for CFD LES simulations. A computational domain (334 m wide, 337 m long, and 30 m high) was designed for numerical simulation. The ground level of the domain was set as a solid boundary while the other boundaries were designed as open boundaries, allowing free flow of the air and smoke in order to simulate the real conditions of fire impact on the surrounding environment.

Accidental fires originating from fuel leaks typically develop into a large pool fire. Above-ground reservoir with crude oil as a large pool fire was set as a buoyancy source. This research simulates the most unfavourable scenario, assuming that the tank ruptured and that oil spilled into a bund with dimensions of 90 m x 90 m. The fire affected both the oil in the tank and the oil in the bund.

Oil is a mixture of hydrocarbons, with octane (C_8H_{18}) regarded as the main compound. Therefore, according to the FDS reaction database (McGrattan et al. 2023), a reaction type of "N-octane" was specified for generating heat from the fire source.

The heat release rate of a fire is generally quantified by the fire source area and heat release rate per unit area (HRRPUA). The fire source was situated in the tank with 21700 tons of crude oil. Therefore, the heat release rate per unit area (HRRPUA) is 2500 kW/m^2, assuming steady-state conditions for octane combustion.

The T-Square fire was used for the fire growth in the simulations. The ultrafast model was applied to the growing model of the fire source.

The accuracy of LES simulation is largely dependent on the grid size, which should be fine enough to include the turbulence scales associated with the largest eddy motions. To ensure consistency and efficiency in the simulations, a uniform grid size of 1.0 in the three spatial directions was adopted. This approach provides an efficient balance between accuracy and computational resources, allowing for an effective simulation of the entire fire scenario. The number of grid cells was 3376740 (334x337x30 in the x, y and z direction, respectively).

In order to assess the dimensions of the potentially endangered zones, virtual incident heat flux gauges and temperature gauges were placed on the surfaces of fire-exposed tanks (B, C and D), energy facilities and facilities for chemical preparation of water and condensate polishing facing the burning tank A (Figure 2).

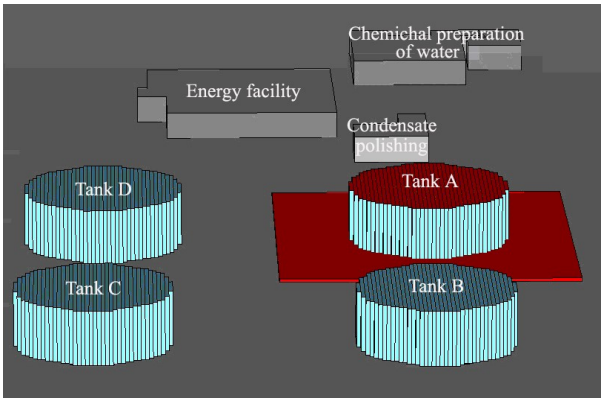


Figure 2. *Fire-exposed objects*

Since this type of fire is a strong buoyancy source with high velocity, the simulations did not consider the effect of the inertial force of wind on the flow of the fire plume. Therefore, the instantaneous or "real" perpendicular wind was specified, e.g., an initial velocity boundary condition of 0.3 m/s with a uniform profile was set at the right side of the simulation domain. The ambient temperature was set to 303 K in the whole computational domain.

To better understand the situation after the combustion of a large crude oil storage tank, the simulation time was set to 3600 s.

RESULTS AND DISCUSSION

Fire dynamics

The maximum values of radiation heat flux of fire flame and hot combustion products from a burning tank with flammable liquids are observed during the fully-developed fire phase. Therefore, for the investigation of fire spreading, it is very important to predict the dynamic regime of the fire. The simulation results of fire dynamics of crude oil are shown in Figure 3.

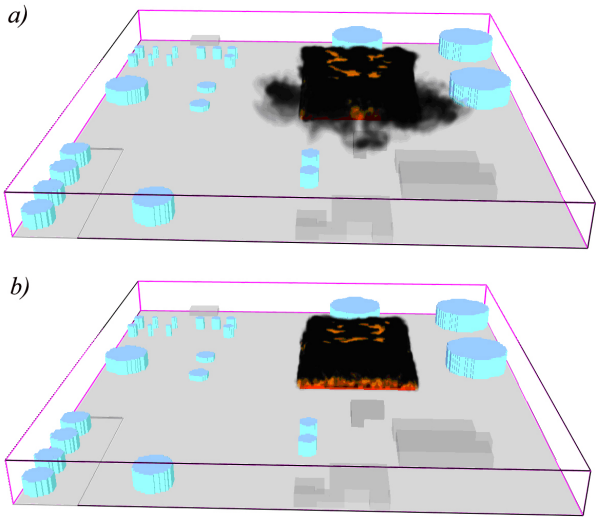


Figure 3. *Fire dynamics: a) 32 s; b) 1800 s*

Since crude oil is a flammable substance, after the tank A caught fire, the flame on the surface of the oil spread rapidly, forming a full-surface fire with stable combustion. However, after the burning oil was poured from the tank into the bund, the fire was also spread to the spilled oil inside the bund.

In this way, the burning surface area was increased, allowing the fire to rapidly reach a steady, fully developed phase characterized by sustained flaming combustion of oil at a constant rate. As a result, there was a large quantity of heat released during the fire. Namely, the heat release rate (HRR) reached a maximum of 21 GW in a short time period, and after that, it had a constant value. A high heat release rate (HRR) resulted in more intense combustion and a greater impact of the fire plume's heat flux on the surrounding environment.

It should be noted that the bund is located under ground level and has the necessary volume to accommodate the entire oil from the tank. Therefore, it prevents the fire from spreading further.

Heat fluxes

After a full-area pool fire occurs in a large crude oil storage tank and its bund, it will have a direct impact on adjacent storage tanks and facilities. The impact range of radiative heat around the fire source is represented by time-averaged incident heat flux fields as shown in Figure 4.

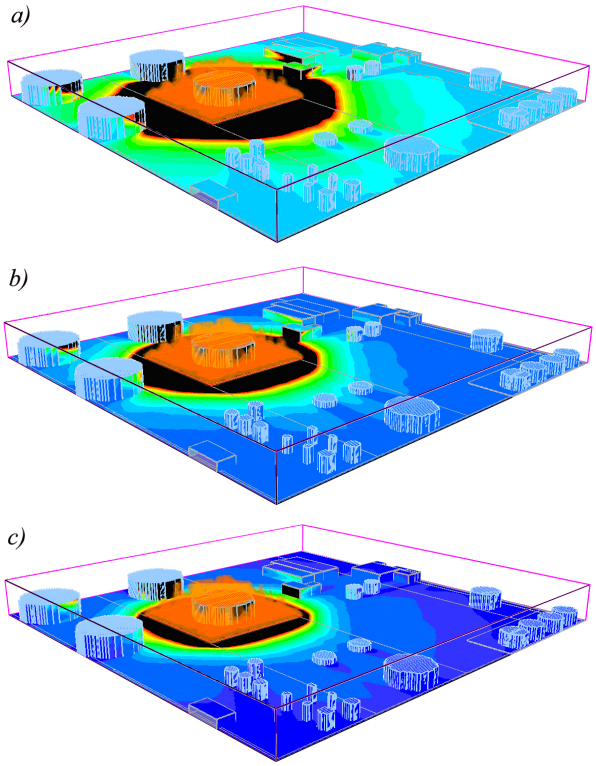


Figure 4. *Field distribution of heat fluxes: a) 2 kW/m^2; b) 5 kW/m^2; c) 10 kW/m^2*

According to the simulation results, the dimensions of the potentially endangered zones inside the storage area of the Pančevo Oil Refinery are given in Table 1.

Table 1. *Endangered zones from fire flame radiation*

Hazard level	Distance from the pool fire
Red (10.0 kW/m^2)	62 m
Orange (5.0 kW/m^2)	77 m
Yellow (2.0 kW/m^2)	101 m

As can be seen in Table 1, the diameter of the zone in which the incident heat flux value is higher than 2 kW/m^2 is about 101 m. In this zone, skin pain can be expected after exposure lasting more than 60 seconds. The zone with an incident heat flux of 5 kW/m2 and more, i.e. a heat flux that can cause second-degree burns when exposed for more than 60 s, has a diameter of 77 m. The area where incident heat flux values exceed 10 kW/m² — a level that may lead to fatal outcomes with exposure longer than 60 seconds — has a diameter of 62 meters.

Tank B, Tank D and the condensate polishing facility are located within endangered zones. Numerical results of the intensity of incident heat fluxes on adjacent tanks and the facade surfaces of facilities exposed to fire are shown in Figures 5 and 6.

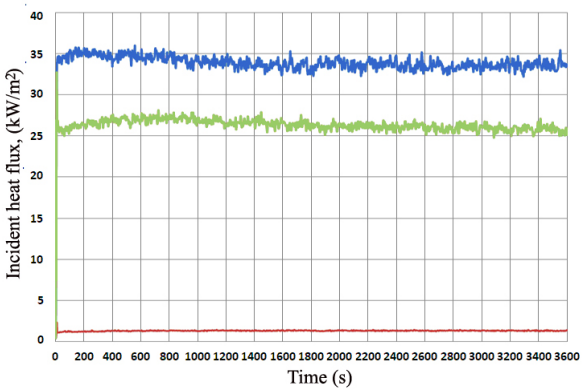


Figure 5. *Incident heat flux:* - Tank D; - Tank B; - Tank C

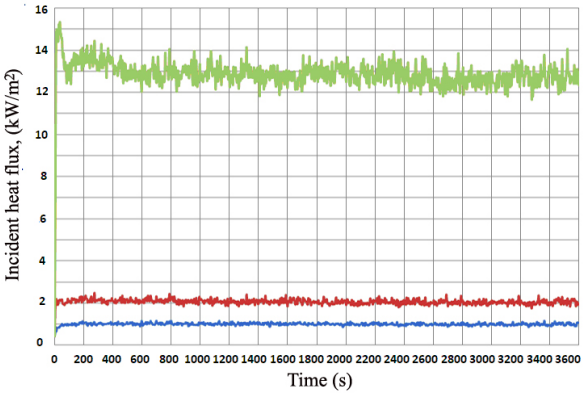


Figure 6. *Incident heat flux:* - condensate polishing facility; - energy facility; - facility of chemical preparation of water

The highest values of incident heat flux measured on the surfaces of objects in the immediate vicinity of the burning tank were recorded on the crude oil tanks D and B (35.5 kW/m^2 and 26.5 kW/m^2, respectively). At the condensate polishing facility, a heat flux value of approximately 15 kW/m^2 was recorded. These high heat flux values require the implementation of adequate fire protection measures. Generally, the tanks directly affected by the heat radiation need to be cooled by using the fixed cooling system of the tanks themselves. At other facilities within the impact zone, no higher heat flux values were recorded that would require the implementation of fire protection measures.

Temperatures

The separation distance between the burning tank and other tanks and facilities affects the thermal radiation dose received by the adjacent tanks and facilities. The temperatures on the surfaces of neighbouring objects exposed to fire radiation are directly dependent on thermal fluxes on their surfaces. The average values of temperatures on tanks and facilities are given in Figures 7 and 8.

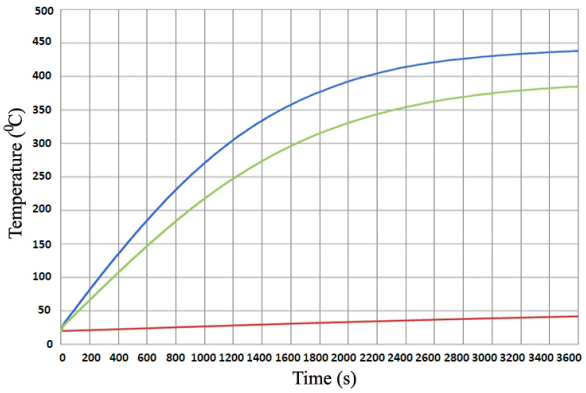


Figure 7. *Temperature:* - Tank D; - Tank B; - Tank C

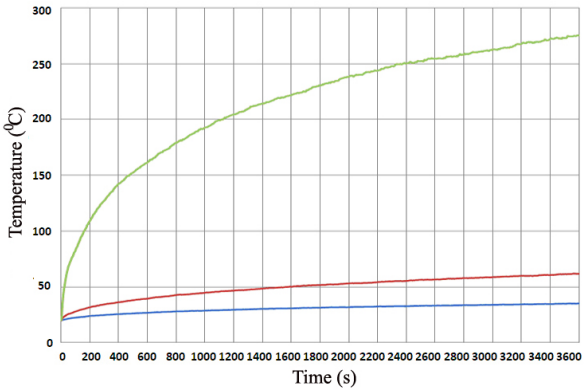


Figure 8. *Temperature:* - condensate polishing facility; - energy facility; - facility of chemical preparation of water

Temperatures measured by sensors on the surfaces of objects in the immediate vicinity of the burning tank indicated that the highest temperatures were recorded on crude oil tanks D and B (438 °C and 385 °C, respectively), as well as on the condensate polishing facility, where a temperature of 275 °C was recorded. No higher temperatures were recorded on other objects in the affected zone.

Since it is very important to assess the risk for individuals in close proximity to the fire, the field distribution of temperatures higher than 44 °C is given in Figure 9.

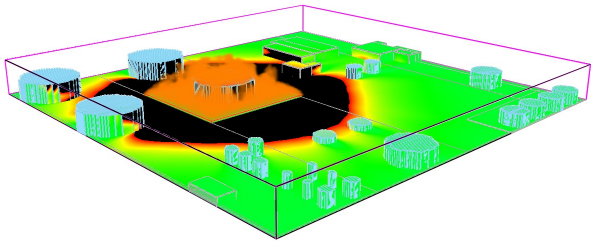


Figure 9. *Field distribution of temperature higher than 44 ^0C*

Analyzing the spatial distribution of temperatures of 44 °C and above, i.e., temperatures that can cause pain on human skin after exposure exceeding 60 s, it is observed that the affected zone has a diameter of 112 m. This can be considered to be the closest distance from a burning tank that people can approach without proper protective clothing.

CONCLUSION

CFD simulations were carried out with the aim of studying the fire incident in an above-ground crude oil tank. The FDS LES model was employed to investigate the effects of fire heat flux and temperature on the surrounding environment. The main conclusions can be summarized as follows:

- The heat released during the fire is very high because the spilling of burning oil from the tank caused the fire to also spread to the oil contained within the bund.
- The thermal radiation dose received by the adjacent tanks and facilities decreases with the increase of the separation distance from the burning tank.
- The temperatures on the surfaces of neighbouring objects exposed to fire are directly dependent on incident heat fluxes on their surfaces.

Numerical results are important, not only for the vulnerability of surrounding tanks and facilities in case of fire, but also for planning safe separation distances between tanks for storing flammable liquids. They also provide useful data for developing appropriate firefighting tactics during tank fire incidents, helping to identify safe zones for positioning equipment and personnel.

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REFERENCES

Abdolhamidzadeh, B., Abbasi, T., Rashtchian, D., & Abbasi, S. A. (2011). Domino effect in process-industry accidents – An inventory of past events and identification of some patterns. *Journal of Loss Prevention in the Process Industries*, 24(5), 575-593.

Assael, M. J. & Kakosimos, K. E. (2010). *Fires, explosions, and toxic gas dispersions - Effects calculation and risk analysis*, CRC Press, 349 p.

Babrauskas, V. (1979). *Full-scale Burning Behavior Of Upholstered Chairs*. NIST Interagency/Internal Report (NISTIR); National Institute of Standards and Technology.

Cozzani, V., Gubinelli, G. & Salzano, E. (2006). Escalation threshold in the assessment of domino accidental events. *Journal of Hazardous Materials*, 129, 1-21.

Hatton, A. P., & Halfdanarson, H. (1982). Role of Contact Resistance in Skin Burns. *Journal of Biomedical Engineering*, 4, 97-102.

Havenith, G. & Daanen, H. A. M. (2013). Practical guidelines for the management of the risks of heat stress during work. Sdu (in Dutch).

Heus, R. & Denhartog, E.A. (2017). Maximum allowable exposure to different heat radiation levels in three types of heat protective clothing. *Industrial Health*, 55, 529-536.

Hoschke, B.N. (1981). Standard and specifications for firefighters' clothing. *Fire Safety Journal*, 4(2), 125-137.

Jones, R., Lehr, W., Simecek-Beatty, D. & Reynolds, R. M. (2013). ALOHA (Areal Locations of Hazardous Atmospheres) 5.4.4, U.S. Department of Commerce, 96 p.

McGrattan, K., Hostikka, S., Floyd, J., McDermott, R., Vanella, M. & Mueller E.(2023) *Fire dynamics simulator (Version 6) technical reference guide, volume1: Mathematical model*, 209 p., NIST Special Publication. https://pages.nist.gov/fds-smv/manuals.html

Mudan, K. S. (1984). Thermal-radiation hazards from hydrocarbon pool fires. *Progress in Energy and Combustion Science*, 10(1), 59-80.

PART 193 - Liquefied Natural Gas Facilities: Federal Safety Standards. United States Office of the Federal Register.

Wu, D., & Chen, Z. (2016). Quantitative risk assessment of fire accidents of large-scale oil tanks triggered by lightning. *Engineering Failure Analysis*, 63, 172-181.

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DETERMINING VEHICLE FIRE HAZARD USING MCDM METHODS BASED ON BIOECOLOGICAL CRITERIA

Abstract: *Multi-criteria decision making (MCDM) methods can be applied to determine the hazard of vehicle fires from the point of view of protecting people and the environment, if experimental data are known for different types and models of vehicles from the measurements of harmful gases, toxic metals and compounds, and hazardous substances in smoke, soot, and ash from fires. Weighting methods are used in order to determine the weights of these criteria. This paper presents the results of applying the BWM (Best-Worst Method) as a weighting method and the PROMETHEE (Preference Ranking Organization METHod for Enrichment of Evaluations) as a multi-criteria decision making method for determining the fire hazard in the case of ICEV (internal combustion engine vehicles) and BEV (battery electric vehicles) fires. The results show that BEV fires are more dangerous than ICEV fires from a bioecological point of view.*

Keywords: fire hazard, electric vehicles, multi-criteria decision making method, weighting method

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INTRODUCTION

Electric vehicle (EV) fires are very difficult to be extinguished and require a large amount of extinguishing material. EV fires are particularly dangerous because they can re-ignite suddenly, days after the initial fire. One way to prevent re-ignition is to allow the vehicle to burn completely, but this is not the case in practice, as fire suppression and extinguishment are often required. Large amounts of waste water, extinguishing agents dissolved in this water, and various toxic materials are the harmful consequences of vehicle fires for human health and the environment. If the data for released harmful gases, toxic metals, and hazardous substances in smoke, soot, and ash, for different types and models of vehicles (Lecocq et al., 2012) are known from the experimental measurements, then vehicle fire hazards may be ranked based on bioecological criteria.

Multi-criteria decision-making (MCDM) methods (Huang et al., 2011) can be applied to rank the vehicle fire hazard, from the point of view of protecting people and the environment (Javor, 2024). One of the MCDM methods is PROMETHEE (Preference Ranking Organization Method for Enrichment of Evaluations), developed by Brans et al. (1984). In this paper, the Best-Worst method (BWM) (Rezaei, 2015a;i 2015b; Rezaei, 2016), as the weighting method, and PROMETHEE II (Brans & Mareschal, 2005), as the MCDM method, are used.

PROBLEM FORMULATION

If water is used for extinguishing EV fire, it can suppress the fire and cool the vehicle, but it can cause electrical faults and react with the lithium in the Li-Ion batteries, thus releasing various toxic gases and leaving toxic water after extinguishment (Sun et al., 2020). Flammable gases can also be released, and re-ignition can also result in an explosion. Although the primary task is to reduce the temperature of a battery that is overheated, access to the batteries in EVs is a significant problem. The batteries are hermetically sealed to prevent moisture and dust from entering and armoured to ensure resistance to mechanical shock. Therefore, water used for extinguishing only affects visible flames and the external surface of the battery pack, as well as the materials surrounding it. Tests have shown that around 10,000 litres of water are needed to extinguish a fire in the entire vehicle, which also depends on the size, type, and location of the battery. The flow rate of about 200 l/min for cooling and extinguishing the fire is high. This can generate large amounts of wastewater. Large amounts of fire extinguishing agents will also be dissolved in this water, which is why it is necessary to find the optimal proportion of the agents used for extinguishing. In order to minimize wastewater and prevent it from polluting the environment in an uncontrolled manner, firefighting submersion pools and containers are used. The burning vehicle is transferred into them and immersed in a sufficient amount of water. The

laboratory measurements (Truchot et al., 2016; Lönnermark and Blomqvist, 2006) of burning products usually include harmful gases, toxic metals and compounds, and hazardous substances in smoke, soot, and ash. Besides waste water, the environmental consequences of EV fires include toxic gases (CO_2, CO, NO, NO_2, HF, HCl, HCN, THC, etc.) and vapours released in the air, various metals in the soot (Al, Cd, Pb, Co, Cr, Cu, Li, Mn, Ni, Zn, etc.), as well as organic compounds of polycyclic aromatic hydrocarbons and water-soluble anions (F^-, Cl^-, Br^-), present in soot and ash. Multi-criteria optimization methods can be applied to determine the hazard of ICEV (internal combustion engine vehicle) and BEV (battery electric vehicle) fires, from the point of view of protecting people and the environment.

THE BEST-WORST METHOD

The BWM is a subjective weighting method used for determining the weight coefficients of the alternatives' criteria. It is based on the comparison of decision criteria, whereby the decision maker determines the best criterion (most desirable/important), the worst criterion (least desirable/important), and preferences between the criteria.

When applying BWM, the best criterion is taken as the most important from the point of view of protecting people and the environment from vehicle fires, and the worst is taken as the least important. Fire hazard criteria may be grouped, for instance, into: (1) toxic metals, (2) combustion and heat release, (3) harmful gases, and (4) anions of halogen elements in soot and ash. The first group has 9 criteria: Al, Cd, Co, Cr, Cu, Mn, Ni, Pb, and Zn. The second group has 6 criteria: PAHG (polycyclic aromatic hydrocarbons in gas), DMS (dry mass in soot), Li (lithium as a light alkali metal that affects the explosiveness of fire), PAHS (polycyclic aromatic hydrocarbons in soot), THR (total heat released), and EHC (effective heat of combustion). The third group includes 9 criteria: CO_2, CO, THC, HF, HCl, HBr, SO_2, NO, and NO_2. The fourth group has 6 criteria: FS (F^- anion in soot), ClS (Cl^- anion in soot), BrS (Br^- anion in soot), FA (F^- anion in ash), ClA (Cl^- anion in ash), and BrA (Br^- anion in ash).

There are 30 criteria in total. For individual criteria in the groups, weight coefficients were obtained by applying BWM Linear Solver v2.0, and afterwards, also using BWM, weight coefficients were obtained for each of the 4 groups. The resulting weight coefficients were obtained by multiplying the group coefficient with the individual weight coefficient of the criterion. The consistency of the solution is achieved, because the consistency ratio (CR) is less than the corresponding threshold, for each group of criteria (Figure 1).

In the first group of criteria (toxic metals), Cd was selected as the most important criterion, and Al as the least important. The order of metal toxicity was taken based on biological and chemical specifications (Nieboer and Richardson, 1980). Preferences were determined for all other criteria in relation to Cd, and then in relation to Al, using ratings from 1 to 9. The results are obtained for the weights of 9 criteria and the consistency of the solution is achieved.

In the second group of criteria (combustion and heat release parameters), THR was selected as the most important criterion, and PAHS as the least important. Preferences were determined for all other criteria in relation to the most important criterion, and then in relation to the least important criterion, using ratings from 1 to 9. The results are obtained for the weights of 6 criteria.

In the third group of criteria (harmful gases), CO was selected as the most important and CO_2 as the least important. Preferences were determined for all other criteria in relation to the most important criterion, using ratings from 1 to 9. Then, preferences of the other criteria in relation to the least important criterion were determined, using ratings from 1 to 9. The results are obtained for the weights of 9 criteria. Ranking of vehicle fires based only on harmful gases is presented in Javor et al. (2024) for other experimental data.

In the fourth group of criteria (halogen metal anions in soot and ash), FA (anion F^- in ash) was selected as the most important criterion, and BrS (anion Br^- in soot) as the least important. Preferences were determined for all other criteria in relation to them, using ratings from 1 to 9. The results are obtained for the weights of 6 criteria.

Group Number = 4	Group 1	Group 2	Group 3	Group 4
Name of the group of criteria	TOXIC METALS	COMBUSTION AND HEAT RELEASE	HARMFUL GASES	HALOGEN METAL ANIONS

Select the Best	COMBUSTION AND HEAT RELEASE
Select the Worst	HALOGEN METAL ANIONS

Best to Others	TOXIC METALS	COMBUSTION AND HEAT RELEASE	HARMFUL GASES	HALOGEN METAL ANIONS
COMBUSTION AND HEAT RELEASE	6	1	3	9

Others to the Worst	HALOGEN METAL ANIONS
TOXIC METALS	4
COMBUSTION AND HEAT RELEASE	9
HARMFUL GASES	7
HALOGEN METAL ANIONS	1

Weights	TOXIC METALS	COMBUSTION AND HEAT RELEASE	HARMFUL GASES	HALOGEN METAL ANIONS
	0,119170984	0,590673575	0,23834197	0,05181347

Input-Based CR	0,208333333	Consistency level is acceptable
Associated Threshold	0,2681	

Figure 1. *Grades and weights of the criteria groups and consistency ratio*

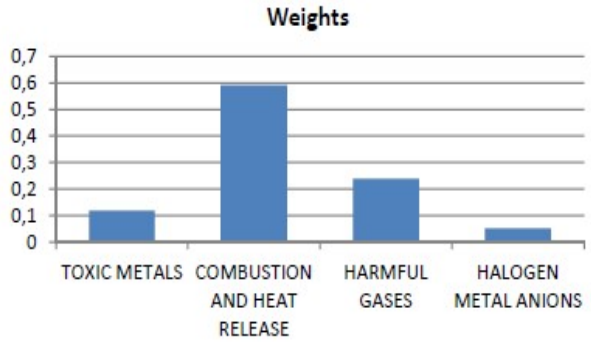


Figure 2. *The weight diagram of groups*

For the groups of criteria, BWM was applied and the second group was selected as the most important and the fourth group as the least important. Preferences were determined for the remaining groups in relation to them, using ratings from 1 to 9. The results obtained for the group weights are shown in Figure 2. The consistency of the solution was achieved.

RANKING OF VEHICLE FIRE HAZARDS BY USING THE PROMETHEE II METHOD

The PROMETHEE method was introduced by Brans and Mareschal in 1982, and they developed the program PROMETHEE-GAIA (Brans and Mareschal, 2014-2024). The result of the ranking of the three alternatives of vehicle fires using the PROMETHEE II method is shown in Figure 3.

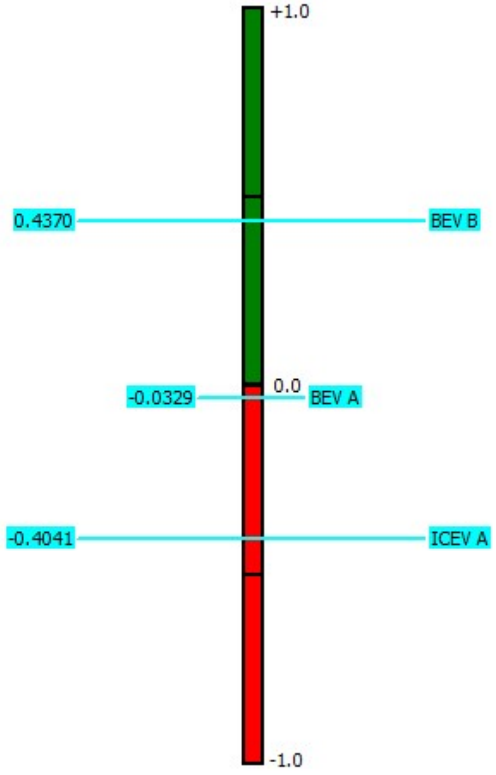


Figure 3. *Fire hazard ranking of ICEV A, BEV A, and BEV B vehicles using the PROMETHEE II method*

Fire of the BEV B is the most hazardous case, whereas fire of ICEV A is the least hazardous case. The net flows are calculated from the positive and negative flows, for each alternative *i*, as given in

$$\mathrm{Ph}_i = \mathrm{Ph}_i^{+} - \mathrm{Ph}_i^{-}. \quad (1)$$

The results are presented in Table 1.

After applying the PROMETHEE II method, the result of vehicle fire ranking shows that the most dangerous fire from a bioecological point of view is the BEV B vehicle fire, followed by the BEV A vehicle fire, while the ICEV A vehicle fire is the least dangerous for people and the environment. The complete ranking of these fires is given in Figure 3.

It should be noted that when conducting experiments, fires of different vehicles may have different durations, as well as different mass losses (Willstrand et al., 2020), which can significantly affect the ranking results. This difference was pronounced in fires of BEV B and BEV A vehicles, but not between ICEV A and BEV A.

Table 1. *Ranking of vehicle fire hazards*

Rank	Alternative	Ph_i	Ph_i^{+}	Ph_i^{-}
1	BEV B	0.4370	0.7128	0.2758
2	BEV A	-0.0329	0.4835	0.5165
3	ICEV A	-0.4041	0.2923	0.6963

CONCLUSION

Multi-criteria decision-making method PROMETHEE was applied in this paper for ranking the vehicle fire hazards, from the point of view of protecting people and the environment. Besides waste water due to extinguishment, the environmental consequences of vehicles fires included toxic gases (CO_2, CO, NO, NO_2, HF, HCl, HCN, THC, etc.) and vapours released in the air, various metals in soot (Al, Cd, Pb, Co, Cr, Cu, Li, Mn, Ni, Zn, ...), as well as organic compounds (polycyclic aromatic hydrocarbons) in gas and soot, and water-soluble anions (F^-, Cl^-, Br^-), present in both soot and ash.

Experimental results of three vehicle fire tests for burning products in smoke, soot, and ash, as well as the total heat released and effective heat of combustion, were used as criteria for ranking by the PROMETHEE method. BWM was used as the weighting method of 30 criteria classified into 4 groups. The criteria were weighted based on metal toxicity, total heat release and effective heat of combustion, and the concentrations and harmfulness of gases and halogen metal anions.

The results of the three vehicle fire tests were used to present the procedure. The result of the ranking, based on the applied method, confirmed that, from the bioecological point of view, fires of electric vehicles are more dangerous than fires of conventional vehicles.

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REFERENCES

Brans, J. P., Mareschal, B. (2005). PROMETHEE methods. In: Figueira, J., Greco, S., Ehrgott, M. (Eds.), Multiple Criteria Decision Analysis: State of the Art Surveys, Springer Science & Business Media, Inc., 163–196.

Brans, J. P., Mareschal, B., Vincke, Ph. (1984). PROMETHEE: A new family of outranking methods in multicriteria analysis. In: Brans, J. P., (Ed.), Operational Research '84, North-Holland, Amsterdam, 477-490.

Brans, J. P., Mareschal, B., (2014-2024) PROMETHEE-GAIA https://bertrand.mareschal.web.ulb.be/promethee.html

Huang, I. B., Keisler, J., Linkov, I. (2011). Multi-criteria decision analysis in environmental science: ten years of applications and trends. *Science of the Total Environment*, 409 (19), pp. 3578–94, doi:10.1016/j.scitotenv.2011.06.022, PMID 21764422.

Javor, D. (2024) *Multicriteria optimization of the microgrid using V2G technology*, Doctoral Dissertation, Faculty of Electronic Engineering, Niš

Javor, D., Krstić, D., Raičević, N. (2024) *Ranking of Vehicle Fire Risk Based on Harmful Gas Emissions*, 9th International Professional and Scientific Conference "Occupational Safety and Health", Karlovac University of Applied Sciences, September 18-21, 2024, Zadar, Croatia, ISSN 2975-3139, pp. 598-604, https://www.vuka.hr/_download/repository/Book%20of%20Proceedings%202024%5B1%5D.pdf

Lecocq, A., Bertana, M., Truchot, B. and Marlair, G. (2012) Comparison of the fire consequences of an electric vehicle and an internal combustion engine vehicle, *International Conference on Fires in Vehicles - FIVE 2012*, Chicago, United States, Vol. 2012, No. 2, pp. 183–194

Lönnermark, A., Blomqvist, P. (2006) Emissions from an automobile fire, *Chemosphere*, no. 62, pp. 1043-1056

Nieboer, E., Richardson, D. H. S. (1980) The replacement of the nondescript term 'heavy metals' by a biologically and chemically significant classification of metal ions, *Environmental Pollution Series B, Chemical and Physical*, vol. 1, no. 1, pp. 3–26, https://doi.org/10.1016/0143-148X(80)90017-8

Rezaei, J. (2015a) *Best Worst Method*. https://bestworstmethod.com

Rezaei, J. (2015b) Best-worst multi-criteria decision-making method, *Omega*, Vol. (2015) No. 53, pp. 49–57, https://doi.org/10.1016/j.omega.2014.11.009

Rezaei, J. (2016) Best-worst multi-criteria decision-making method: Some properties and a linear model, *Omega*, Vol. (2016) No. 64, pp. 126-130

Sun, P., Bisschop, R., Niu, H. and Huang, X. (2020) A Review of Battery Fires in Electric Vehicles. *Fire Technology*, vol. 56, pp. 1361–1410, https://doi.org/10.1007/s10694-019-00944-3

Truchot, B., Fouillen, F. and Collet, S. (2016) An experimental evaluation of the toxic gas emission in case of vehicle fires, *Proc. of 7th ISTSS*, Montreal, Canada, pp. 419-429

Willstrand, O., Bisschop, R., Blomqvist, P., Temple, A., Anderson, J. (2020) Toxic gases from fire in electric vehicles, *RISE*, Report 2020:90, ISBN: 978-91-89167-75-9, p. 240, Borås

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ESSENTIAL CHARACTERISTICS OF WALLS WITH FIRE PERFORMANCE

Abstract: *The report analyses the requirements for walls with fire performance, viewed through the prism of Regulation No. Iz-1971 on the Construction and Technical Rules and Norms for Fire Safety in the Republic of Bulgaria. It provides detailed information regarding the classification of fire resistance and reaction to fire. Lightweight partition structures and the determination of their maximum permissible construction height are thoroughly discussed. The relationship between fire resistance classification and factors such as load-bearing capacity, space layout, intended use, and wall material is discussed.*

Keywords: fire performance of walls, fire resistance of walls, reaction to fire of walls, maximum height of walls

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INTRODUCTION

Walls with fire characteristics are the main passive measures, as specified in Ordinance No. Iz-1971 of 29.10.2009 on building-technical rules and norms to ensure safety in case of fire, and applied in the construction of buildings in the Republic of Bulgaria (Ordinance No. Iz-1971 of 29.10.2009 on building-technical rules and regulations for ensuring fire safety, OJ No. 96 of 4 December 2009, as subsequently amended and supplemented, OJ No. 91 of 29.10.2024). The correct definition of the performance of their necessary characteristics, the incorporation of assessed constructions, and building according to the requirements are crucial for fulfilling the objectives of all regulations aimed at ensuring safety in case of fire.

The essential characteristics of the walls for which there are requirements in the regulations are:

1) resistance to fire
2) reaction to fire
3) permissible wall height (lightweight partitions).

FIRE RESISTANCE CLASSES

For walls, the main criteria of fire resistance are R (load-bearing capacity), E (Integrity) and I (insulation). Walls can be analysed in terms of whether they are load-bearing or non-load-bearing, their spatial arrangement, their fire safety purpose (obstacles in the path of fire spread), and the material of which they are constructed.
The relationship of these factors to their fire resistance can be explained in the following way:

Classification of walls according to load-bearing capacity

Depending on the load-bearing capacity determined by the designer of the structural part, the wall may be:

- load-bearing - wall designed to carry the applied load (EN 1365-1 Fire resistance tests for loadbearing elements - Part 1: Walls, 2013). The fire resistance class is indicated by all three criteria R (load-bearing capacity), E (Integrity) and I (insulation) - REI;
- non-load-bearing - this is a wall which, except for supporting its own weight, is not designed to carry any additional load (EN 1364-1 Fire resistance tests for non-loadbearing elements - Part 1: Walls, 2015). The fire resistance class is indicated by criteria E (Integrity) and I (insulation) - EI.

Classification of walls depending on location

Depending on its space location, walls can be:

- internal - located inside the building. These walls can be either load-bearing (REI) or non-load-bearing (EI);
- external - a wall forming the external envelope of a building (EN 1364-1 Fire resistance tests for non-loadbearing elements - Part 1: Walls, 2015). In some cases, it may also be the curtain walling of a building which provides, by itself or together with the building structure, all the normal functions of an external wall but without having any load-bearing characteristics within the building (EN 13830:2015+A1:2020 Curtain walling - Product standard, 2020). In Regulation No. Iz-1971, note 5 to Tab. 3, there is an assumption that for external load-bearing walls, instead of the class REI, the REW criteria could be defined with the classes defined in columns 3 and 4 of Table 3 of the same Regulation. An element that meets the thermal insulation criterion I is also considered to meet the W requirement for the same period (EN 13501-2 Fire classification of construction products and building elements - Part 2: Classification using data from fire resistance and/or smoke control tests, excluding ventilation services, 2023).

Classification of walls depending on the purpose for fire safety

Depending on the purpose of fire safety (barriers in the way of fire spread), the following types of walls are defined:

- walls to separate fire sectors - REI (EI) 120;
- brandmauern - REI (EI) 120;
- fire protection walls - REI (EI) 60;
- walls of fire protection vestibules - REI (EI) 60;
- walls to separate safe areas - REI (EI) 120;
- general purpose external walls (Table 3) - REI (EI);
- general purpose internal walls (Table 3) - REI (EI) and etc.

Types of walls according to the materials used

Based on the material used for wall construction, the following main types are used:

- reinforced concrete;
- brick (silicate, ordinary and hollow baked bricks, aerated concrete);
- sandwich panels;
- wooden;
- lightweight partitions;
- glass;
- mixed type.

However, the material from which they are made is only relevant to the characteristic Class of reaction to fire.

For a structural element to be defined as a wall (partition), it must necessarily enclose a space. If it is not adjacent to the structures enclosing it, it should not be considered as a wall, as it can fulfil neither a load-bearing, partitioning, nor an insulating function.

In the construction of the Republic of Bulgaria, only walls with fire resistance on both sides are allowed (Article 9, paragraph 6 of Ordinance No. Iz-1971) (see Figure 1).

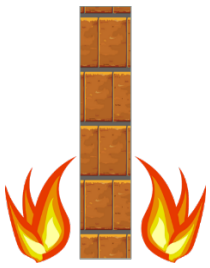


Figure 1. *Two-sided fire impact on the walls*

The fire resistance of the walls, according to Article 10, paragraph 2 of Ordinance No. Iz-1971, can be determined in the following three ways:

- tests (results of tests actually carried out);
- calculations (the norms and methods for design and calculation from the system of standards "Structural Eurocodes", introduced as EN 1990 (EN 1990 Eurocode - Basis of structural design, 2003)
- comparisons (Annex 5 of the same Regulation).

All three methods are applicable to walls with fire characteristics.

REACTION TO FIRE CLASS

Determining the reaction to fire class of walls, for example, concrete and brick, is easy, but for multi-component structures, it is a more complex process. These are sandwich panels and lightweight walls. The basic rule is that the reaction to fire class (RtF) is determined by taking into account the worst RtF of the main materials incorporated in the wall profiles, wood, wool, etc. The determination of the RtF of the materials of which the walls are constructed can be made in the following two ways:

- tests (results of tests actually carried out);
- comparisons (Annex No. 6 of Ordinance No. Iz-1971
- construction products for which testing is not required).

It is important to note that the material used to construct the walls has only RtF and no fire resistance rating. Fire resistance is only a characteristic of the partition element itself, and not of the materials used to build it.

An example of a wall constructed of timber and a wall constructed of gypsum board is given in Figure 2:

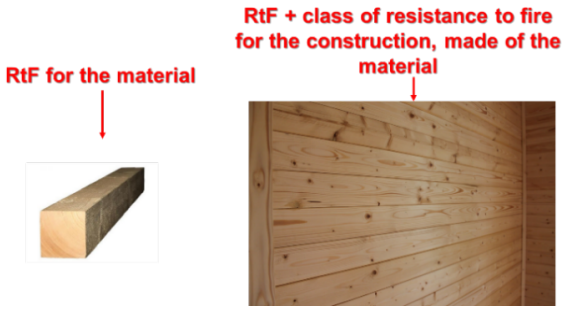


Figure 2. *RtF and fire resistance class of walls*

The only exception to this rule is for walls constructed of glazed (glass) elements.

Harmonised product standards exist for almost all types of glass and glazing units. Two of the essential characteristics included in these standards (especially for glazing units and multi-layer glazing) are reaction to fire and resistance to fire. However, it is important to understand that these characteristics are only indicative. The glass manufacturer decides which standard to use to determine them (most often as a wall). Glass and glazing shall have a permanent marking indicating these two characteristics.

However, when they are incorporated into a wall, door, roof or floor construction, or similar structure, the final building product, which is the wall, door, roof, slab etc., must be tested according to the appropriate standard and assigned its own fire resistance class. This class may be different from the class of the incorporated glass (glazing) (see Figure 3).



Figure 3. *Fire resistance class of glass and glass wall*

PERMISSIBLE WALL HEIGHT

This is the third characteristic related to the fire characteristics of the walls. Its determination is required only for internal non-load-bearing lightweight partitions, according to the Orders No-02-14-252 (Order of the Minister of Regional Development and Public Works No RD-02-14-252, 10.03.2021) and RD-02-14-229 (Order of the Minister of Regional Development and Public Works No RD-02-14-229, 25.02.2022).

A lightweight partition is a thin-walled steel structure (profile construction) to which one or more panels are fixed, either on one or both sides. There may also be a wool filling.

The maximum permissible height is the lesser of the height under static and dynamic loading without fire load and the height under fire load. The occurrence of a fire is a single event and the tested (calculated) maximum allowable height is important, but the wall is subjected to daily use and it should have the necessary strength and resistance under normal conditions.

The Order No. RD-02-14-229/25.02.2022, which provides the working procedure for the estimation of these heights, is based on a calculation algorithm developed by the MPA Braunschweig Institute, commissioned by the German Gypsum Industry Association (Association, 04.2016).

The algorithm is designed with several valid boundary conditions for Germany for the static, dynamic and console loads accompanying the daily operation of the wall, as follows:

Static loads

These are different deflections f, to which the walls are assigned depending on the maximum wall height h - $f \leq h/500$, $h/500 < f \leq h/350$, $h/350 < f \leq h/200$.

This classification should not be identified with a specific requirement for strain limitation as a determinant of serviceability. Practical construction experience in recent decades has shown that lightweight partition walls at the usual storey heights (2.40 m to 4.00 m) do not exhibit defects in limiting deflection to $f \leq h/200$ (2 cm deflection at a wall height of 4.00 m) (see Figure 4).

In order to ensure the absence of defects also at higher wall heights (from 4.00 m to 12.00 m), the bending is limited to the ratio h/350 (deviation of 3.4 cm at a wall height of 12 m). At a ratio of h/200, the deflection would be 6 cm, which is already too much at these heights.

In isolated cases (e.g., deformation-sensitive wall claddings), it is recommended to apply an aggravated bending criterion $f \leq h/500$ or, in some cases, an absolute bending limitation.

Dynamic loads

Examples of such loads are vibrations caused by the rhythmic pushing of the wall by many people, construction activity, etc.

This staggering effect is particularly noticeable in very high, free-standing claddings that are fixed on one side only. Although the stability of these claddings/shaft walls is guaranteed, subjectively, they can be perceived as operationally unsuitable. However, revision of existing structures for this reason is not necessary. Technically, this effect, which is a consequence of the dynamic loading, can be excluded if the truss structure is point-fixed backwards, e.g., to the rough wall or to the steel truss.

By applying a properly selected equivalent static load, the stability of the wall and thus its natural frequency of oscillation can be increased. In German practice, an equivalent surface load of 0,285 kN/m² (28,5 kg/m²) has proven to be justified.

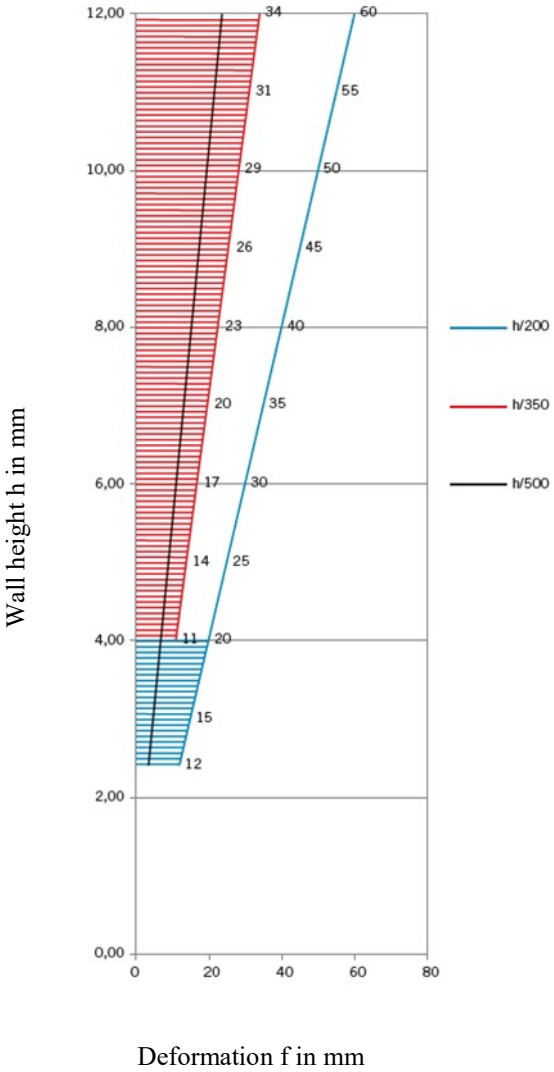


Figure 4. *Maximum wall deflection f as a function of height h.*

Equivalent surface load (wind load)

The equivalent surface load of 0.285 kN/m² (28.5 kg/m²) also includes the wind load criterion according to DIN 1055-4 (DIN 1055-4 Action on structures - Part 4: Wind loads) and EN 1991-1-4 (EN 1991-1-4 Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions, 2005) under the following boundary conditions:

- building height $h \leq 18$ m;

- wind zone 3, inner zone;
- back pressure q = 0,95 kN/m²;
- load coefficient c_{pi} = - 0,3 (for one-sided loading);
- surface wind load value, determined by the following formula:

$$w = c_{pi} \text{ x } q = 0{,}3 \text{ x } 0{,}95\ kN/m^2 = 0{,}285\ kN/m^2 \quad (1)$$

Console loads

For example, wall-mounted wardrobes or shelves transfer their weight to the base of the wall, while tightly installed cable runs beneath ceilings place stress on the upper wall fixings.

The maximum recommended height for console loads is 1.65 m, and this should be taken into account if cantilevered loads are applied at greater heights.

For partition walls, DIN 18183-1 (DIN 18183-1 Partitions and wall linings with gypsum boards on metal framing - Part 1: Cladding with gypsum plasterboards) defines console loads of 0.7 kN/m (70 kg/m). The condition is that the line of application of the loads is a maximum of 30 m from the wall surface. It may be applied at any random location on the wall provided that the thickness of the sheathing on each side of the wall is ≥ 18 mm.

For wall claddings (shaft walls), console loads are normatively limited to 0.4 kN/m (40 kg/m), regardless of the thickness of the cladding. However, numerous examples from practice show that often within a single room, heavier console loads are attached to all walls. For this reason, it is recommended that for both partition walls and shaft walls (wall claddings), calculations are made with increased console loads of 0.7 kN/m (70 kg/m) and that a thickness of ≥ 18 mm (exactly as for partition walls) is assumed when sizing shaft walls (wall linings).

CONCLUSION

This report provides a systematization of the wall types depending on their fire characteristics, purpose in the building and the materials used in their construction. The characteristics are in accordance with the regulatory requirements for new buildings and construction sites in the Republic of Bulgaria, namely Regulation No. Iz-1971. In addition, lightweight partition structures and the determination of their maximum permissible building height, depending on the different loads to which they are subjected in normal operation and under fire impact, are thoroughly considered.

REFERENCES

Association, G. G. (04.2016). Heights of lightweight partitions - slots, connections, doors and openings Revision 8.

DIN 1055-4 Action on structures - Part 4: Wind loads. (n.d.).

DIN 18183-1 Partitions and wall linings with gypsum boards on metal framing - Part 1: Cladding with gypsum plasterboards. (n.d.).

EN 13501-2 Fire classification of construction products and building elements - Part 2: Classification using data from fire resistance and/or smoke control tests, excluding ventilation services. (2023).

EN 1364-1 Fire resistance tests for non-loadbearing elements - Part 1: Walls. (2015).

EN 1365-1 Fire resistance tests for loadbearing elements - Part 1: Walls. (2013).

EN 1990 Eurocode - Basis of structural design. (2003).

EN 1991-1-4 Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions. (2005).

EN EN 13830:2015+A1:2020 Curtain walling - Product standard. (2020).

https://bauhaus.bg. (n.d.). Retrieved 09 02, 2024, from https://bauhaus.bg/greda-rettenmeier/p/10704

https://bg.jenesis-glass.com/insulated-glass/. (n.d.). Retrieved 09 02, 2024, from https://bg.jenesis-glass.com/insulated-glass/

https://euroglass-bg.com. (n.d.). Retrieved 09 02, 2024, from https://euroglass-bg.com/bg/product/stykleni-pregradni-steni-za-ofis_9

https://ibuilders-bg.techinfus.com. (n.d.). Retrieved 09 02, 2024, from https://ibuilders-bg.techinfus.com/vagonka/sosna/

Order of the Minister of Regional Development and Public Works No RD-02-14-229. (25.02.2022).

Order of the Minister of Regional Development and Public Works No RD-02-14-252. (10.03.2021).

Ordinance No. Iz-1971 of 29.10.2009 on building-technical rules and regulations for ensuring fire safety. (OJ No. 96 of 4 December 2009, as subsequently amended and supplemented, OJ No. 91 of 29.10.2024).

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ORIGINAL SCIENTIFIC PAPER

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DEMOLITION WORKS OF BUILDING STRUCTURES

Abstract: *Demolition is one of the most dangerous construction operations, which often results in fatal and/or severe injuries to construction workers. Risks of injury and death can be minimized if a demolition project is well-planned. This paper discusses the main hazards associated with demolition work, types of site investigations for buildings slated for demolition, hazardous substances that may be present during demolition, demolition methods, and potential on-site hazards that can occur during demolition, among other considerations.*

Keywords: demolition of buildings, demolition waste, demolition methods, construction site hazards

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INTRODUCTION

Demolition of construction structures is undertaken due to the need to clear space for the construction of a new building or to use the land for other purposes, for various economic, technical, safety, or environmental reasons. The deterioration of a building or the need to repurpose the area it occupies is a common reason for demolition, especially in developed urban environments. The need for demolition from an economic perspective arises when the value of the land exceeds the current value of the building located on it. In such cases, property owners choose to demolish the building and construct new structures that will be significantly more valuable than the demolished ones. In the event of natural disasters (earthquakes, strong winds, storms, etc.) or military actions in populated urban areas, buildings may be severely damaged or destroyed. In such cases, demolition and removal of structures becomes a top-priority and essential task in order to restore the area to a vital and functional state (Arizanović, 2022).

Demolition is one of the most dangerous construction operations because it often leads to fatalities and serious injuries among workers. However, if the demolition project is well-planned, the risks of injury and death can be minimized (Phil Hughes, Ed Ferrett, 2016).

The main hazards associated with demolition work include:

- Workers falling from height;
- materials falling from height;
- premature collapse of the structure being demolished;
- dust and fumes;
- clogging of dust drainage systems;
- issues arising from spilled fuels;
- manual handling;
- presence of asbestos and other hazardous substances;
- noise and vibrations from heavy machinery and equipment;
- fires and explosions due to the use of flammable and explosive substances;
- pneumatic drills and electric tools;
- dangers from electricity, gas, and water;
- tipping of machines and vehicles.

Before starting demolition work, it is necessary to make preparations and plans for the demolition of the structure. This involves compiling technical documentation, including the layout of the structure being demolished at the given location, information about the construction structures, floor plans of the ground floor, all upper floors, and the roof, data on hazardous materials, etc. The demolition plan should include: the demolition procedure, the movement route of the machinery, precautionary measures (such as fencing off the site, training workers, covering walkways, closing traffic and pedestrian paths, installing temporary support structures, installing catch platforms, etc.), structural stability at each demolition phase, and the plan for management and removal of demolition construction waste.

INVESTIGATION AND INSPECTION OF THE BUILDING BEFORE DEMOLITION

The owner of the buildings slated for demolition must provide the demolition contractor with access to conduct an investigation and inspection of the site and the structure prior to demolition. Before any work begins, a complete site investigation must be carried out by civil engineers to identify hazards and associated risks that could affect demolition workers as well as nearby residents or passers-by. According to the

Rulebook on the procedure for adopting the demolition program and its contents, the competent construction inspection authorities are responsible for preparing a program that includes a plan for removing the building or parts of the building, an operational plan, and a cost estimate for the demolition ("Official Gazette of the Republic of Serbia", No. 27/2015).

Site investigation for the structure to be demolished includes:

- the structural composition of the buildings to be demolished (including materials used, roofing, decay, the presence of cantilevered structures, and any general weaknesses), as well as structural details of neighbouring buildings;
- the previous use of the structures;
- soil bearing capacity, including the presence of groundwater;
- the need for possible temporary supports for both the building being demolished and the adjacent buildings;
- the potential for falling materials and people;
- the location of any machinery;
- the presence of asbestos, lead, or other hazardous or radioactive substances and any related health risks;
- environmental protection (dust, water pollution, and noise);
- the safety of passers-by and nearby residents;
- manual handling methods;
- the location of utility infrastructure (water, electricity, gas, sewage, power grid, etc.);
- the location of any underground basements, storage tanks, chimneys, balconies, or bunkers – especially if flammable or explosive substances were previously stored;
- access routes to the site;
- removal of construction waste from the demolition;
- the proximity of neighbouring buildings;
- the location of any public walkways near the building being demolished;
- the proposed demolition method.

Demolition works must be carried out in accordance with the standards prescribed by the Law on Occupational Safety and Health ("Official Gazette of the Republic of Serbia", No. 35/2023).

When drafting the demolition plan, temporary access roads, office space, fuel storage, and facilities for machinery maintenance on-site need to be considered.

The plans must include a procedure for the safe disposal of any hazardous or harmful substances found during the demolition process, in a manner that complies with the legally prescribed requirements.

BUILDING DEMOLITION

Building demolition is carried out by a team of experts specialized in the use of explosives in construction. The method used for this type of work depends on:

- the condition of the structure (whether the entire building is to be demolished at once, demolished in phases or sections, or only specific parts are to be removed);
- the characteristics of the site (whether there are infrastructural facilities and utility networks that must not be damaged during demolition, or if there are none present on the site).

Demolition also depends on:

- the surrounding environment that may be affected by demolition activities. There is a significant difference between demolishing in an urban setting (within a populated area) versus rural conditions (away from residential and public structures);
- the intended goal of the demolition. For example, whether the material from the demolished building is to be recycled and reused, or whether it will be treated as construction waste, etc.

Demolition methods are chosen based on: project and contractual conditions, site location, equipment availability, and environmental tolerance. The following demolition methods are commonly applied:

- Gradual (manual or mechanical) demolition;
- Controlled demolition through intentional collapse using explosives.

Gradual demolition is carried out using manual and mechanical tools. This type of demolition includes: manual demolition, demolition by impact (such as a wrecking ball on a cable excavator, though this method is now rarely used), demolition by cutting (often combined with various types of cranes), and crushing demolition (crawler excavators equipped with specialized tools).

Manual demolition is a preliminary method used to gradually reduce the height of small structures (mostly houses). Tools used include electric or pneumatic hammers. Broken parts of the structure are dropped through a chute into a vehicle positioned next to the building, which then transports the waste away from the site. In addition, mechanical demolition (using an excavator or bulldozer) is employed, where the machine's working tools participate in a continuous demolition process, dismantling the building section by section. This method is also used for high-rise structures where machine access is not possible. These include tall, slender constructions (such as chimney stacks) and buildings higher than 20 stories. Mechanical demolition cannot be applied to these structures due to limited access or the reach of the machine's working arms.

Demolition by impact was once considered one of the most effective demolition methods (in addition to the use of explosives). Today, this method is mostly used for partially collapsed buildings that have deteriorated and begun collapsing on their own over time due to various external influences. Standard hydraulic excavators can be used for demolishing high-rise buildings where the use of explosives is not required. Using a so-called 'pusher arm' and a toothed attachment (plate, hook), the excavator applies horizontal force to bring down the walls, while cutting tools (hydraulic shears) are used to sever reinforcement

bars. Today, this method is no longer used globally due to insufficient control over swinging and inadequate safety.

Crushing demolition is currently the most widespread demolition method in the world. This method involves the use of a crawler excavator and hydraulic tools (arm) for crushing concrete and cutting steel. A pneumatic or vibrating hammer can also be attached as a working tool, which demolishes concrete and brick through its mechanical action.



Figure 1. *Gradual building demolition*

In a controlled intentional collapse, explosives are used to demolish the structure. During the explosion, large amounts of gaseous products are released, causing a sudden increase in pressure and temperature, with the explosive energy being converted into mechanical work. This technique should only be used by trained and competent persons. Demolition must be conducted with technical safety measures in place and only after careful selection of the type of explosive and calculation of the quantity, location, and arrangement of the explosive to be used, in order to minimize damage caused by the accompanying effects of the demolition (Phil Hughes, Ed Ferrett, 2016).

When explosives are used for demolition, it is necessary to establish an exclusion zone at a specified distance around the structure being demolished. All personnel, except the person detonating the explosive, must be outside the exclusion zone at the time of the explosion. This is the most dangerous demolition method, and everyone must be at a safe distance during the collapse. The exclusion zone includes the area of the structure's footprint, the projected fall area where most of the structure is intended to collapse, the expected debris area beyond the projected fall area, and a buffer zone between the debris area and the boundary of the exclusion zone.

The size of the exclusion zone is not only related to the height of the structure – it must also take into account other factors such as the impact of ground vibrations. The main factors influencing the design of the exclusion zone include the mechanism of the planned collapse, the materials used in the building's structure, the structural condition of the building, the site's topography, the proximity of surrounding structures, harmful effects of ground vibrations or accompanying shockwaves, noise, dust, etc.



Figure 2. *Building demolition using explosives*

BUILDING DEMOLITION HAZARDS

Premature structural collapse is one of the main causes of serious injuries arising from demolition work. A common reason for such incidents is the lack of effective planning before the start of demolition. Premature collapse usually begins with the structural failure of floors and is often caused by machines operating on floors that are not certified as safe and/or are not properly supported where necessary. It can also result from poor site supervision and a lack of instructions, training, and information for the workforce. This sometimes leads to workers or teams being unaware of the additional hazards created during the progression of the demolition works. A fully competent and trained workforce, fully familiar with the hazards associated with a particular site, is a prerequisite for successful completion of demolition. Worker safety on demolition sites can be compromised due to the following factors:

- Falls: falling through fragile and weak roofing materials, falling through openings or gaps (e.g. skylights, HVAC and plumbing openings), falling from open edges (e.g. staircases, platforms, scaffolding, and roof edges), falling from elevated work platforms (e.g. scissor lifts), equipment failure (e.g. lifting platforms), falling while accessing roofs or other elevated surfaces, falling down elevator shafts, floor collapses (e.g. concrete slabs and wooden planks), ground collapse above basements or pits, tripping over debris on the ground, etc.
- Hazards from impact, entrapment, or being struck by an object due to: falling debris (e.g. through installation and elevator shafts), accidental or uncontrolled structural collapse, use of machines and equipment (e.g. cranes lifting loads), failure of structural elements (e.g. steel support structures).
- Noise from machinery during demolition. Sources of noise and vibration on demolition sites typically include compressors, pneumatic tools, loaders, excavators, and explosives.
- Inhalation hazards from dust generated during demolition work.
- Presence of hazardous substances and their release during the demolition. Most hazardous substances pose a risk to demolition workers through inhalation, skin contact, or absorption through the skin. Some of the most common hazardous

substances that appear during demolition include:
  - Lead – most dangerous when airborne as vapor or dust (e.g. cutting steel structures coated with lead-based paint or dismantling tanks containing leaded gasoline, etc.).
  - Asbestos – should be removed wherever possible before any other demolition work begins. Asbestos may be found in sprayed coatings, thermal and acoustic insulation materials, fire-resistant walls/partitions, asbestos-cement panels, or flooring materials. Asbestos dust is particularly hazardous.
  - PCBs (polychlorinated biphenyls) – toxic substances found in electrical transformers, capacitors, and other electrical equipment previously used in industrial or chemical processes (MZŽS, 2023).
- Hazards related to machinery and equipment used on demolition sites are numerous. Only fully qualified personnel should operate machinery and equipment on such sites. Some of the hazards associated with machinery and equipment on demolition sites include machine failure due to exceeding its safe working load, accidental dropping of materials due to improper load securing, excessive noise and vibration from machines such as loaders and excavators, flying particles from pneumatic tools such as impact hammers, structural failures of steel frameworks, etc.
- On-site fires and explosions may occur due to hot work or the presence of chemical substances.
- Potential for premature building collapse.
- Damage to electrical installations.

CONCLUSION

Preventive safety measures must be implemented during demolition work on construction sites. These include designating traffic routes, walkways, and crossings for employees and work equipment, as well as establishing conditions for handling various materials. It is important to maintain work equipment and installations in proper working condition and to conduct both preventive and periodic inspections and testing of the equipment and electrical and lightning protection installations. All of this is aimed at ensuring safe and healthy working conditions on the construction site. Areas and locations for storing various materials, especially hazardous substances, must be planned and designated, and the conditions for removing used hazardous substances must be clearly defined.

Demolition of buildings is carried out using either the method of gradual demolition or controlled collapse with the use of explosives. The choice of demolition method depends on the project and contract conditions, the location, the availability of equipment, and the tolerance of the surrounding environment.

If explosives are used for demolition, it is necessary to establish an exclusion zone at a specified distance from and around the structure being demolished.

Before demolition begins, it is essential to obtain the plans of all infrastructure networks that supply the site, such as gas, electricity, sewage, and water.

For the disposal of demolition waste, a Demolition Waste Management Plan must be prepared in accordance with the Regulation on the manner and procedure for managing construction and demolition waste. Contracts must be signed with authorized operators for the transportation and further treatment of the waste.

It is in the public interest to recycle construction debris resulting from demolition, thereby reducing the need for raw materials from natural sources. The recycling of demolition waste can be divided into two phases. The first phase involves the sorting and storage of useful materials generated during demolition, such as glass, plastic, and bitumen. The second phase involves the processing of materials after demolition, which includes crushing, shredding, and cutting, as well as separating secondary raw materials, such as metal, plastics, and glass.

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REFERENCES

Arizanović Dragan, Dejan Beljaković, Predrag Petronijević,(2022). Tehnologija građevinskih radova – grubi građevinski radovi, Građevinski fakultet Beograd.

Arizanović Dragan (2022). Građevinski projekti – organizacija i realizacija, Građevinski fakultet Beograd.

Ministarstvo zaštite životne sredine (MZŽS) (2023). Analiza stanja otpada od građenja i rušenja i reciklažnog potencijala u građevinskom sektoru u Republici Srbiji, Axante.

Pravilnik o postupku donošenja i sadržini programa uklanjanja objekatas ("Sl. Glasnik RS", br. 27/2015).

Phil Hughes, Ed Ferrett, (2016). Introduction to Health and Safety in Construction, Taylor & Francis Group.

Phil Hughes, Ed Ferrett,(2007). Introduction to Health and Safety in Construction, Elsevier Ltd.

Richard J. Diven, Mark Shaurette (2010). Demolition: Practices, Technology, and Management, Purdue University Press.

Seonho Lee, Heeeun Chang, Jechan Lee (2024). Construction and demolition waste management and its impacts on the environment and human health: Moving forward sustainability enhancement, Sustainable Cities and Society, Volume 115, 2024, 105855, ISSN 2210-6707, https://doi.org/10.1016/j.scs.2024.105855.

Uredba o bezbednosti i zdravlju na radu na privremenim ili pokretnim gradilištima ("Sl. glasnik RS", br. 14/2009, 95/2010, 98/2018, 35/2023 - dr. zakon i 76/2024).

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REVIEW PAPER

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RISK MANAGEMENT IN EMERGENCIES: REDUCING VULNERABILITY OF PEOPLE AND ASSETS

Abstract: *Businesses function within a dynamic context, frequently facing negative events and challenges. Modern business processes highlight the need for managing emergency events under conditions of uncertainty. Uncertainty is directly related to risk. Risk management within the field of crisis management is primarily focused on identifying risks and implementing measures for their treatment. Different risk theorists offer various approaches to defining risk and the phases of risk management. The risk management process encompasses a wide range of activities carried out in specific phases, requiring the exploration of opportunities for developing and implementing a systematic approach. Different business systems have different technological processes, but the risk management process is based on the same foundation. Maintaining the quality of the system is directly dependent on the organization of risk management activities related to emergency events. The objective of this process is to reduce the vulnerability of people and material assets through the implementation of preventive and reactive measures.*

Keywords: risk management, risk, risk management, organizational systems

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INTRODUCTION

The modern era has made the causes of adverse events increasingly complex and their consequences more destructive. In order to prevent such events or mitigate their consequences, prevention must be integrated into all phases of the event's development. It is a fact that various safety systems exist within business systems, such as occupational health and safety systems, fire protection systems, physical security, and others. Each of these systems plays its own role in the collective mosaic of corporate security. The key factor for successfully implementing security functions—both individually and collectively—is the knowledge of all individuals involved in the management process. This knowledge is not limited to security topics but also includes all managerial elements.

Since organizational security is a crucial function that encompasses or permeates all aspects of organizational management, it is essential to identify all factors that influence the occurrence and development of events with negative impacts. A modern tool that allows systematic monitoring of such events, assessing the likelihood of their occurrence, and taking preventive measures is risk assessment. Risk assessment directly depends on the level of knowledge of the individuals involved in a process, as well as their understanding of the process itself and external factors.

All risks have a direct or indirect impact on key business processes, which are primarily conditioned by the core dimensions of the organization. They manifest through complexity, formalization, and centralization, and are especially pronounced in organizations where centralization is the dominant element. Risk is always relevant, variable, and dynamic, which makes risk management a pervasive and process-based activity.

RISK AND EMERGENCY EVENTS

Risk is inherent in all business processes. In its broadest and most general conceptual definition, risk is described as the possibility of suffering harm or loss, or as a "factor, object, element, or course involving uncertainty and danger." However, the concept of risk not only evolves over time but also varies depending on the activity in which it is being analyzed, and as such, it is defined and assessed differently. Two main meanings of risk can be distinguished:

1. The possibility that an action or activity will result in damage or loss to materials or persons.
2. The term "risk" is used when outcomes are uncertain (Beck, 1999).

The existence of risk involves uncertainty, which is linked to a lack of information or knowledge, or to the assumption of other, even positive, outcomes. Existing definitions of risk characterize it as the potential for an undesirable event to occur, resulting in various types of negative consequences. The term *possibility* holds a

central place, as it implies uncertainty about the outcome of an event, making the presence of risk directly tied to uncertainty. Since complete certainty is rarely achievable, risk and uncertainty are considered integral parts of most business processes. Uncertainty arises when the future is unknown, and there are no actual (objective or subjective) probabilities associated with alternative outcomes. Risk occurs when specific numerical data about the probabilities are associated with alternative outcomes.

Events with negative impacts are the focus of modern business processes. A changing environment generates a range of events, with or without negative consequences. Monitoring environmental changes is one of the primary challenges of contemporary business processes, particularly in terms of obtaining the information necessary for managing those changes. Events are consequences of a set of environmental circumstances. An event is defined as a circumstance that occurs without the involvement of the organization's will, but which objectively causes the emergence, cessation, or alteration of a state. Events are often referred to as acts of force majeure. Based on this definition, several characteristics can be identified (Kekovic and Kesetovic, 2007; Cvetkovic, 2006):

- An event may consist of one or more occurrences and may have multiple causes;
- An event may consist of something that did not happen;
- An event may sometimes be classified as an "incident" or an "accident";
- An event without consequences may also be considered an event that was "barely avoided," "almost occurred," or was a "near miss."

These characteristics point to the existence of uncertainty and the need to act at the boundaries of our understanding of circumstances. The magnitude and frequency of a set of circumstances are determined by a combination of different environmental factors, which also represent sources of risk (Cvetkovic, 2006). These factors do not influence outcomes in a uniform manner in terms of time, space, and intensity; thus, their significance varies. All factors that can cause a negative event can be classified into four groups: the human factor, the technical-technological factor, the natural factor, and the social factor.

Based on the above, it can be concluded that any event that actually or hypothetically implies negative consequences represents an emergency event. Reducing the impact, preventing, or avoiding a negative event is the focus of the emergency event prevention process (Vauglan, 1997). The "emergency" nature of an event refers to an unplanned occurrence, an unexpected action, or a deviation from normal operations. Organizational management monitors environmental changes, analyzes them, and identifies those that are actually or potentially hazardous to the organization. Identification itself depends on the level of understanding of the characteristics of phenomena that occur or may occur. The subsequent hazard analysis phase will produce poor results if the identification process is based on inadequate information (Molak, 2007).

THE PROCESS-ORIENTED NATURE OF RISK MANAGEMENT

The dynamic environment in which business processes operate generates changes that often produce negative effects on the system. Business requirements and objectives are defined in a way that their fulfillment justifies the system's existence. The desired state of the system is defined through the established quality, which represents the degree to which a set of inherent characteristics meets the requirements. These requirements are defined as needs or expectations that are either implicit or mandatory, and they are materialized through business goals. Responsibility for achieving these objectives lies with the manager, and consequently, so does the responsibility for the quality of the system's functioning.

A prerequisite for the successful implementation and sustainability of the risk management process is its integration into the general process of business management and full support from the management. Risk management must be integrated at all levels of business process management and across all specific areas of organizational operations. A process-oriented approach to risk management enables the proper processing of all risk-related information generated within a given time unit and its use in the decision-making process.

In a decentralized concept, the degree of decentralization depends on the level of responsibility distribution in risk management. In such structures, risk assessment teams exist within each area, particularly characteristic of production-oriented organizations. These teams usually consist of representatives from the following functions and departments: marketing, production, technology, procurement, quality control, and sales. If needed, the team is expanded to include members from other departments such as logistics, after-sales, legal, etc. These teams are both the assessors and the bearers of responsibility for risk. Within these teams, a team leader must be defined, who also serves as a member of the main risk management team.

The application and implementation of the risk management process in business processes require the full commitment of management to the process. It is also essential for all actors involved in the technological and work processes to participate in risk management. Of particular importance are individuals from the governing structures who manage risks within their areas. Overall risk is managed by top management.

To ensure the optimal implementation and realization of the risk management process, the process should:

- Define, align with higher-level management, and approve a risk management policy;

- Inform all stakeholders about the decision to apply risk management and what is expected of them;
- Define indicators for the successful achievement of risk management system objectives;
- Ensure that the objectives of risk management are complementary to the organizational goals;
- Ensure compliance with legal regulations; and
- Provide the necessary resources for the realization of the risk management process.

Uncertainty exists in all business process activities. The top manager, as the decision-maker, bears full responsibility for the quality and execution of the decision and assumes the associated risk. When there is a lack of information necessary for decision-making, this implies a need to gather the missing data. The time between recognizing the lack of information and obtaining it contributes to increased uncertainty and insecurity. The obtained information may contribute to reducing uncertainty, but it does not necessarily eliminate it.

SYSTEMIC APPROACH TO RISK MANAGEMENT

The risk management system consists of two elements: the object of management and the subject of management. The object of management is the risk, observed in the context of the hazards being analyzed. The subject of management is a specially trained and appropriately authorized decision-maker—either an individual or a team—who, through the application of various tools and methods, performs the risk management function.

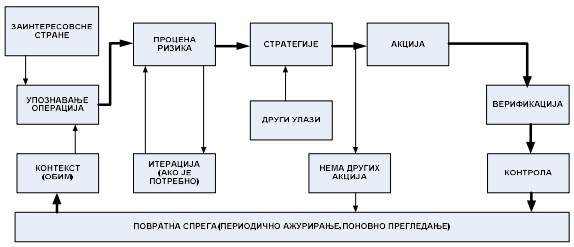


Figure 1. *Phases of Risk Management (Source: Savic, Stankovic, 2018)*

A systemic approach enables the observation of all internal and external connections between the actors within the risk management system, their integration with organizational processes, and the degree of contribution to achieving organizational goals. Organizational mechanisms within risk management systems must be capable of recognizing new problems, creating and implementing new solutions (decisions), ensuring maximum concentration and availability of resources, consolidating existing capacities, and mobilizing forces—all with the aim of mitigating the consequences of a risk event in the shortest possible time.

Within the structure of the risk management system, two mutually exclusive principles are implemented: the principle of individual management (unity of authority and responsibility) and the principle of the distribution of authority and responsibility.

Table 1. Characteristics of Risk Management According to Different Definitions

Source	Elements of Definitions	Common Characteristics
Vauglan E.J.	Maintaining system quality even when risk events occur	Risk management is a part of organizational processes. Risk management is an integral part of the quality system It supports decision-making. It includes risk identification, measurement, analysis, and monitoring.
AS/NZS	Balancing gains and losses	
Sage A.	Controlling areas and events that are potential triggers of unwanted changes	
RMPS	Comprehensive decision-support process integrated through quality	
ISO 31000	Structured process of risk identification, measurement, treatment, and monitoring	

Although every risk management strategy depends on the nature of the system it addresses, the processes described are continuous and logically connected, forming a unified process of the systemic approach to risk management. These processes include: risk planning, risk assessment, and the implementation of risk mitigation measures.

Risk planning as a function of systemic prevention

Every management process begins with planning, which can be defined as the process of setting future goals, making assumptions about the environment in which these goals should be achieved, and choosing a course of action, resources, and methods for achieving those goals. Planning involves analyzing the environment and the organization's capabilities in a changing context, assessing total potential, strengths and weaknesses, alternative development paths, and more. Planning here does not refer strictly to formal short-term and long-term plans, but rather to the organization's long-term strategic orientation. This includes diagnosing the security environment, determining courses of action, setting goals to be achieved, selecting the strategy for achieving those goals, and making managerial decisions through all phases.

Since all other management functions are aligned in the planning process with the selected goals and objectives, the responsibility of the managers performing this function becomes clear. Planning is an integral part of

management at all levels, but its scope differs depending on the level of managerial authority.

Planning is the fundamental starting function of management. It is a process that includes task and goal selection, defining actions to achieve them, and making decisions—i.e., choosing between alternative future courses of action. Plans ensure a rational approach to achieving previously selected goals.

Risk planning is the initial phase of risk management and consists of a set of actions implemented throughout the entire risk management process, as defined by the risk management plan. It includes: defining the problem context and project scope, and familiarization with operations. All stakeholders should be involved in risk planning.

The core elements of a risk management plan are:

- A summary of the system: vision, mission, objectives and system purpose, required standards, and development strategy;
- The approach to risk: methods for risk assessment, risk determination, scales for risk ranking;
- The organization of the risk management process through its phases;
- Responsibility for risk management.

The risk management plan serves as the foundation and guideline for the risk management team.

Risk planning as a function of systemic prevention

The efficiency and effectiveness of the risk management process can only be maximized through continuous improvement. Organizational systems must develop the capacity for risk management. The fundamental assumption for this capacity is the existence of a risk management system, that the decision-maker understands and accepts the need for risk management, that all actors in the process are aware of their obligations within risk management, and that there are qualified personnel competent in implementing and supervising the process. Risk management holds critical importance for the functioning of organizational systems, and therefore, the implementation of ISO 31000 is necessary in the risk management process.

According to this standard, the key components for improving the risk management process are:

1. Continuous development of the risk management system. All elements of the risk management system must be subject to ongoing development. By setting clear performance indicators, organizations can measure the effectiveness of both the organization and individuals responsible for risk management. System reviews should be conducted annually, or more frequently if necessary, to incorporate new goals and adjust existing ones. The assessment of the properties of the risk management system is an integral part of evaluating the effectiveness of organizational systems.
2. Clearly defined and fully accepted accountability for risks, risk control, and implementation of the risk treatment plan
   This means that a risk management policy defines the direction and principles for applying the risk management process in the organization, and internal regulations and procedures define the risk management system. The core of the risk management system lies in human resources—trained and capable of implementing, developing, and supervising the risk management process. With the necessary capacity and resources, management actions can control and improve the process, monitor risks, and communicate effectively about risks—internally with management and externally with stakeholders. Organizational systems use internal regulations to place all risk management actors in a dependent position to ensure compliance with obligations defined by the organization's decision-makers.
3. Inclusion of risk in every decision-making process within the organization
   Regardless of the level of importance, every decision must take into account the risks and apply risk management to an appropriate level. This means that decisions, as driving mechanisms in organizational systems, should be based on conclusions derived from risk management system analysis. These decisions, correlated with the management system of the organization and the products of the risk management process, allow for comprehensive consideration of all aspects of potentially risky events.
4. Permanent communication about risk as part of the organizational system management
5. Establishing the risk management process as a central management process
   This ensures the evaluation of its direct impact on planned objectives.

By continuously respecting these improvement components, the conditions are created for effective and efficient implementation of the risk management system at all levels of business process management.

CONCLUSION

Everyday business operations, in their entirety, take place under certain conditions of uncertainty. The measure of this uncertainty is risk. This observation highlights the importance of risk management in minimizing the impact and consequences of specific undesirable situations. Risk management is a process of actively making decisions to avoid problems—or at least to influence their consequences and likelihood—before they occur. The decision-making process takes place in risk-laden situations and under uncertainty, which essentially presents a challenge for those in managerial roles.

Risk management directly improves the decision-making process, especially for high-risk decisions, by enabling managers to understand the environment (both

internal and external), recognize risks, protect themselves and the organization, and thereby achieve their objectives. In this context, the article seeks to address possible approaches to managing specific risks based on a systemic foundation, contributing to risk management as a vital management function. Anticipating events that may unfold uncontrollably is becoming a daily activity, and risk management is becoming an equal process alongside design, production, service delivery, etc. On the other hand, risk management should ensure the continuous operation of the system. Documentation generated through the risk management process enables the accreditation and authorization of the risk management process itself.

What is common to all forms of risk management is its defined role as a decision-making tool, integrating continuous assessment of what might go wrong (risks), determining which risks are most significant, and developing and applying strategies to address them. Based on the above—especially in the context of risk analysis and management—the key elements of risk management can be identified as: identification, analysis, planning, research, control, and communication. These elements are integrated and interconnected, forming a logical sequence in the risk management process.

Risk management is a fundamental tool for the prevention of emergency events. A reduced number of negative events implies fewer consequences for the business system, which in turn leads to an increase in system quality. By establishing such a process, continuous improvement in the quality of the business system is ensured.

REFERENCE

Bek, U. (2001), Rizično društvo, Filip Višnjić, Beograd

Beck U. (1999), World risk society, Cambridge, Polity Press

Vauglan, E.,J.(1997) Risk management, John Willie & Sons, New York

Kekovic, Z., Kesetovic, Z. (2007) Hrestomatija-prevencija krize, Fakultet bezbednosti, Beograd

Cvetkovic, D. (2006), Upravljanje rizicima, clanak, Festival kvaliteta, Kragujevac

Molak B, (2007), Sta je upravljanje krizama, clanak, Zagreb
Standard ISO 31000:2018

ISO TC 223/SC, Internacionalni standard za društvenu sigurnost

Cupic, M., Tumala, V.M. (1997), Savremeno odlucivanje, metoda i primena, FON, Beograd, 1997.

Jankovic, K., Komazec, N. (2019), Uticaj edukacije u oblasti procene rizika na prevenciju vanrednih dogadjaja, Međunarodna konferencija Rizik i bezbednosni inzenjering, Kopaonik

Savic, S., Stankovic, M. (2012). Teorija sistema i rizika. Beograd: Akademska misao

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COMPARATIVE ANALYSIS OF CARBON FOOTPRINT CALCULATION METHODS

Abstract: *Carbon footprint is one of the key indicators of the environmental impact of human activities, particularly in the context of global warming and climate change. Accurate calculation of this indicator is essential for making sustainable environmental and economic decisions. This paper analyzes various methods for calculating the carbon footprint, including life cycle analysis, economic–ecological models, as well as emission measurement and empirical approaches. Through comparative analysis, the advantages and limitations of these methods are presented, along with their applicability across different sectors, from industry and transportation to individual consumption. The aim of this study is to provide a systematic review of existing methods and recommendations for selecting the most reliable and practical tools for carbon footprint assessment, contributing to the development of strategies to reduce negative environmental impacts.*

Keywords: carbon footprint, calculation methods, life cycle analysis, sustainable development, greenhouse gas emissions

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INTRODUCTION

The carbon footprint is one of the key indicators of the environmental impact of human activities, particularly in the context of global warming and climate change. It is defined as the total amount of greenhouse gas (GHG) emissions, expressed in carbon dioxide equivalents (CO_2e), generated throughout the entire life cycle of a product, service, activity, or organization (Wiedmann & Minx, 2008). In response to the growing need for sustainable development and green transition, accurate calculation of the carbon footprint has become essential for informed strategic decision-making across sectors such as industry, energy, transportation, urban planning, and consumption.

In practice, multiple methodological approaches are available for carbon footprint assessment, ranging from Life Cycle Assessment (LCA), through economic input–output models, to direct measurement and empirical estimations. Each of these approaches entails specific advantages and limitations regarding accuracy, data availability, system boundaries, and implementation costs (Pandey et al., 2011; Sun et al., 2024; Toffel & Sice, 2011). Therefore, the selection of an appropriate method requires careful consideration of the assessment context and objectives.

The aim of this paper is to provide a systematic overview of existing carbon footprint calculation methods, compare their performance, and examine their applicability across different sectors. Through comparative analysis, the study offers guidance for selecting the most reliable and practical tools for quantifying GHG emissions, thereby contributing to more effective planning and implementation of climate change mitigation strategies.

METHODS

This study employs a qualitative methodological approach based on a comprehensive review of relevant scientific and professional literature with the aim of systematizing and comparing methods used for carbon footprint assessment. Key methodologies applied across different sectors, ranging from industry and transportation to individual consumption, are analyzed, with particular attention given to their applicability, strengths, and limitations.

The research begins with a descriptive analysis of the theoretical foundations of each methodological framework, including:

- Life Cycle Assessment (LCA);
- Economic–ecological input–output models;
- Direct emission measurements and empirical approaches.

Subsequently, a comparative analysis of the identified methods is conducted according to the following criteria:

- Accuracy – the extent to which the method provides reliable and valid results in quantifying GHG emissions;

- Complexity – the level of technical expertise and methodological sophistication required for application;
- Cost-effectiveness – estimation of required resources, time, and financial input for implementation;
- Data availability – ease of obtaining necessary input data across different contexts;
- Sectoral applicability – the method's flexibility to adapt to various industrial and consumer environments;
- Standardization and international recognition – the existence of normative frameworks (e.g. ISO 14067, GHG Protocol) that support the method.

The analysis is based on secondary sources, including peer-reviewed articles, international standards, and reports from institutions such as the IPCC, UNEP, ISO, and the GHG Protocol. Additionally, findings from previous case studies illustrating the real-world application of different methods are considered.

The objective of this methodological approach is to provide an objective and well-argued evaluation of existing methods, with the aim of formulating recommendations for selecting the most suitable approach depending on the specific sector and the goals of the carbon footprint assessment.

RESULTS AND DISCUSSION

Carbon footprint assessment can be performed using various methodological approaches, which differ in terms of complexity, accuracy, data requirements, and practical applicability. This section presents and analyzes three of the most commonly used methods: Life Cycle Assessment (LCA), economic–ecological models, and empirical approaches, including direct emission measurements.

Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is a systematic approach that enables the quantification of the total environmental impact of a product, process, or service – from the extraction of raw materials, through production, distribution, and use, to the end of life (e.g. disposal or recycling). When LCA is specifically focused on greenhouse gas emissions, it is employed as a method for calculating the carbon footprint. This approach is standardized by the ISO 14040 and ISO 14044 standards.

Advantages:

- Provides a comprehensive perspective on emissions across all stages of the life cycle;
- Based on standardized methodology, which facilitates comparability of results across different analyses;
- Reveals hidden emissions that are often overlooked in more simplified assessments.

Disadvantages:

- Requires detailed and extensive datasets, which may hinder application in certain sectors;
- Can be complex and time-consuming, especially for smaller organizations lacking technical resources;
- Often relies on assumptions and average values, which may affect the accuracy of the results.

Economic–ecological models

Input–output analysis and equilibrium models quantify greenhouse gas emissions by analyzing interdependencies between economic sectors using input–output tables. Economic–ecological models, such as Leontief models, enable the systemic evaluation of emissions resulting from both production and consumption activities.

Application in macroeconomic and sectoral analysis:

- Suitable for national and sector–level carbon footprint assessments;
- Allow for the estimation of indirect emissions stemming from supply chains;
- Employed for policy impact analysis and low-carbon development scenarios.

Advantages:

- Provide insights into the broader structure of emissions within the economic system;
- Well-integrated with economic modelling and national statistical data.

Disadvantages:

- Lower accuracy compared to micro-level LCA studies;
- Based on aggregated data, which can obscure specific sources of emissions;
- Difficult to apply to individual products or organizations due to limited resolution.

Empirical approaches and direct emission measurements

These approaches involve the use of actual, measurable data related to the consumption of energy, fuel, raw materials, and other resources within specific processes. Direct emission measurements (e.g. from smokestacks, vehicles, or industrial systems) offer a high degree of accuracy in quantifying carbon footprints.

Limitations related to data availability and accuracy:

- Potential deviations due to non-representative sampling or inaccurate measurement instruments;
- Lack of real-time or complete data across all stages of the process;
- Often limited to specific operational phases, rather than encompassing the full life cycle.

Advantages:

- Provide a high level of precision and specificity in emission data;
- Suitable for evaluating the efficiency of particular technologies and processes;
- Simpler to implement in small and medium-sized enterprises (SMEs).

Disadvantages:

- Do not account for the entire value chain or upstream/downstream impacts;

- Dependent on the availability and quality of monitoring instruments;
- Lack a universal methodology – each case must be assessed individually.

Comparative analysis of methods

Based on the previously defined criteria – accuracy, complexity, cost-effectiveness, data availability, sectoral applicability, and standardization – a comparative analysis was conducted of the three dominant approaches used in carbon footprint assessment. The aim of this analysis is to identify the most appropriate method depending on the purpose of the assessment and the sector of application. The results of the analysis are also presented in Table 1.

Table 1. *Comparative Analysis of Carbon Footprint Assessment Methods*

Criterion	LCA	Economic–Ecological Models	Empirical Approaches
Accuracy	High (full life cycle coverage)	Moderate (macro-level, indirect emissions)	High (real measurements)
Complexity	High (requires expert knowledge and software)	Moderate (requires economic/statistical expertise)	Low to moderate (simpler implementation)
Cost-effectiveness	Moderate to low (resource- and time-intensive)	High (uses existing statistical data)	High (especially for SMEs)
Data availability	Requires detailed and structured datasets	Good availability through national accounts	May be limited or fragmented
Sectoral applicability	Applicable across product and process levels	Best suited for national and sectoral analysis	Good for site-specific and operational analysis
Standardization	Yes (ISO 14040, ISO 14044)	Partial (depends on national frameworks)	No standardized universal protocol

Depending on the objectives of the analysis and the available resources, the following recommendations are proposed:

- For strategies based on product life cycle analysis, the most suitable approach is LCA.
- For the development of sectoral policies and economic scenarios, the use of input–output models is recommended.
- For monitoring specific activities, processes, and operations in real time, empirical approaches are the most effective.

Given the limitations of individual methods, there is a growing tendency to recommend the combination of multiple methodologies to achieve a better balance between accuracy, comprehensiveness, and practical applicability. For example, results from direct measurements can be used as input data in LCA, while input–output models can complement LCA by adding systemic-level insights.

For instance, in the study by Rüzgar et al. (2017), the carbon footprint of a single cotton T-shirt was found to be 8.46 kg CO_2-eq. Since a significant share of these emissions (37.4%) occurs during the use phase, it becomes clear how crucial user behaviour is. The study highlights the environmental impact of electricity and water consumption during usage (e.g. washing, ironing, etc.). Furthermore, the end-of-life disposal method is a relevant factor in impact assessment. Approximately 48% recycling led to a 12.1% reduction in greenhouse gas emissions. Therefore, the use and disposal phases play a substantial role in the overall environmental burden.

On the other hand, the study by Islam et al. (2024) presents detailed emission measurements across production stages and provides comparative values. The analysis revealed significant environmental impacts in various categories during the manufacturing of cotton polo shirts. The global warming potential (GWP) associated with the production of 1,000 shirts was 1,345.97 kg CO_2-eq. The highest contributor to GWP was the dyeing process (38.36%), followed by cotton fibre production (29.32%) and yarn manufacturing (18.92%). Additional data showed the following GWP values for the production of 1,000 kg of respective materials: cotton cultivation – 1,084.41 kg CO_2-eq, yarn manufacturing – 783.67 kg CO_2-eq, grey fabric production – 145.88 kg CO_2-eq, dyeing and finishing – 1,723.88 kg CO_2-eq, and final garment assembly – 314.94 kg CO_2-eq.

Based on these findings, it can be concluded that the production phase alone generates significantly lower emissions compared to the entire life cycle, especially when consumer behaviour is taken into account. For this reason, a comprehensive analysis that combines multiple methodological approaches is essential when calculating the carbon footprint.

Sectoral application of methods

In the context of Serbia, carbon footprint calculation methodologies are not yet widely applied in industry, although significant progress has been made through the development of national greenhouse gas (GHG) inventories in accordance with the Decree on the types of data, authorities and organizations and other natural and legal persons that submit data for the preparation of the national greenhouse gas inventory (Government of the Republic of Serbia, 2023).

Carbon footprint assessment is not universally applicable – different sectors require tailored approaches depending on process complexity, data availability, and the goals of the analysis. This section outlines the specific characteristics of methodological application across the industry, transport, and

individual consumption sectors.

In the industrial sector, Life Cycle Assessment is the most widely used methodology due to the need for accurate tracking of emissions throughout all phases of the production process – from raw materials to processing and end-of-life. Case studies by Moazzem et al. (2021) and Islam et al. (2024) conducted LCA analyses for cotton T-shirt production, identifying key high-emission phases, such as cotton cultivation and chemical processing in the textile industry. Despite its high accuracy, the main challenge for LCA application in industry lies in the lack of comprehensive databases, especially in developing countries.

The transport sector is characterized by high operational emissions from fossil fuel combustion. As such, empirical approaches and direct emission measurements dominate this sector. Measurement of fuel consumption, mileage, and tailpipe emissions enables efficient real-time monitoring. Additionally, economic–ecological models facilitate aggregated analyses of policy effects, such as subsidies for electric vehicles or changes in logistics flows. A case study by Dakhil et al. (2024) analyzed GHG emissions from road transport. The authors emphasize both the environmental and the economic advantages of modern battery technologies, while also pointing out challenges related to affordability, infrastructure, and accessibility in countries of the Global South.

For individuals and households, empirical and calculator-based approaches are the most common, using data on electricity consumption, heating, transportation, food, and purchases. Online carbon footprint calculators often rely on average emission factors across consumption categories. For example, Carbon Footprint Ltd. and WWF offer tools that allow users to estimate their personal carbon footprint and identify improvement areas (e.g. reducing meat consumption or using public transportation). The main challenge in this sector lies in the low level of awareness and variability of consumer behaviour, which often causes significant deviation between calculated and actual emissions.

Recommendations and guidelines for method selection

Effective carbon footprint calculation requires the careful selection of methodology, in accordance with sector-specific characteristics, the goals of the analysis, and the available resources of the user. While no universally applicable method exists, several key factors have been identified that determine the most appropriate methodological approach (Table 2).

Table 2. *Recommended Tools and Methods by User Category*

User	Recommended Tools/Methods	Purpose of Application	Resource Requirements
Public authorities	Economic–ecological models (input–output), LCA, national GHG inventories, scenario simulations	Development of climate and energy policies; preparation of national plans and commitments under international treaties	High – requires expert staff, access to databases, software, and institutional coordination
Private sector	LCA, GHG Protocol, direct emission measurement, ISO 14064, software such as SimaPro and GaBi	Sustainability reporting; cost and emission reduction; strategic planning and regulatory compliance	Medium to high – requires software, employee training, expert analysis, and consultants
Citizens	WWF calculator, Carbon Footprint Ltd. calculator, personal CO_2 footprint apps, educational tools	Self-assessment, education, motivation for behavioural change; contribution to Sustainable Development Goals (SDGs)	Low – simple online tools; no expert knowledge required
Research institutions	Combined approaches: LCA + empirical measurements + simulation models; scenario modelling tools	Development of new methodologies, policy evaluation, advanced modelling and impact prediction	High – requires equipment, software, research teams, and access to empirical data
Educational institutions	WWF calculator, scenario simulations, simplified LCA tools, project-based learning	Youth education on climate change; integration of sustainability into curricula and activities	Low to medium – use of available educational tools and materials

Table 2 illustrates the recommended tools and methods for carbon footprint calculation, tailored to different user categories. The analysis of carbon emissions across various stages of a product's life cycle shows that the greatest contribution to greenhouse gas emissions does not occur solely during the production phase, but that a significant portion may also arise during the use phase and at the end of the product's life.

Although industrial processes, particularly energy-intensive stages such as processing, finishing, and packaging, are often identified as dominant emission sources, findings indicate that user behaviour (e.g. frequency of use, energy efficiency, choice of disposal method) can have an equally significant or even greater impact on the overall carbon footprint of a product.

This highlights the importance of adopting a holistic approach in environmental impact assessment, in which methodologies such as Life Cycle Assessment and

empirical monitoring of user behaviour should be used in a complementary manner. Furthermore, decarbonization strategies should not focus solely on production optimization, but must also incorporate consumer education, promotion of energy-efficient use, and the development of circular economy systems.

Key factors influencing method selection:

- Data availability and quality – Methods such as Life Cycle Assessment require detailed and accurate input data on materials, energy use, and emissions across the entire life cycle. In contexts where such data are not accessible, empirical methods and calculator-based tools offer a more feasible alternative.
- Analytical objectives – For purposes of strategic planning, policy development, and macroeconomic modelling, the application of economic–ecological input–output models is recommended. Conversely, if the goal is to identify hotspots within the production chain, LCA emerges as the most precise approach.
- Institutional and technical capacities – The implementation of complex methodologies requires adequate technical infrastructure, software tools, and trained personnel. Organizations with limited resources often opt for simplified calculators or direct empirical measurements.

CONCLUSION

This paper provided a systematic overview of the most relevant methods for calculating the carbon footprint, analyzing their principles, advantages, limitations, and sector-specific applicability. The comparative analysis confirmed that no single method is universally applicable, and that the selection depends on the objectives of the analysis, data availability, and institutional capacity. The key findings indicate that Life Cycle Assessment is the most reliable approach when it is necessary to cover all stages of a product's or service's life cycle. However, it also requires a high level of precision, time, and material resources. In contrast, economic–ecological models, such as input–output frameworks, allow for emission analysis at the macro level and are commonly used in the development of national strategies and sectoral policies. Empirical approaches and carbon footprint calculators are primarily applied in public education and rapid operational assessments, although they are more limited in terms of analytical comprehensiveness.

Particularly important is the insight that the use and end-of-life phases, often neglected in simplified assessments, can contribute as much as, or even more than, the production phase to the overall carbon footprint. This underscores the need for an integrated and holistic approach when assessing the climate impact of products and services.

In the future, the development of effective climate change mitigation policies must be grounded in accurate, transparent, and scientifically validated methods of emission quantification. It is essential to strengthen the development and implementation of open-access databases, digital tools for automated analysis, and the institutional and human capacities needed across all societal sectors – from government and industry to academia and individual citizens.

There is considerable potential in combining methodologies, for example, using empirical measurements to validate LCA results, or incorporating input–output models into macro-level decarbonization scenarios. Only a multidisciplinary and layered approach can enable the generation of accurate, relevant, and operationally useful data, which will serve as a foundation for the transition to a low-carbon and sustainable future.

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REFERENCES

Carbon Footprint Ltd. (n.d.). *Carbon footprint calculators*. Retrieved from https://www.carbonfootprint.com

Dakhil, A., & Zürpel, H. (2024). *Advancing Bangladesh's Transport Sector: Light Electric Vehicles and the Optimal Subsidy for Switching to Lithium-Ion Batteries*. Goethe University Frankfurt. https://dx.doi.org/10.2139/ssrn.4915645

Government of the Republic of Serbia. (2023). *Regulation on the types of data, authorities and organizations, and other legal and natural persons required to submit data for the preparation of the national greenhouse gas inventory* (Official Gazette of the Republic of Serbia, No. 43/2023).

International Organization for Standardization. (2006). *ISO 14040:* Environmental management – Life cycle assessment – Principles and framework.

International Organization for Standardization. (2006). *ISO 14044:* Environmental management – Life cycle assessment – Requirements and guidelines.

International Organization for Standardization. (2018). *ISO 14067:* Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification.

Islam, S., Hasan, A. K. M. M., Bhuiyan, M. A. R., & Bhat, G. (2024). Evaluation of environmental impacts of cotton polo shirt production in Bangladesh using life cycle assessment. *Science of the Total Environment*, 926, 172097. https://doi.org/10.1016/j.scitotenv.2024.172097

Moazzem, S., Wang, L., Daver, F., & Crossin, E. (2021). Environmental impact of discarded apparel landfilling and recycling. *Resources, Conservation and Recycling*, 166, 105338. https://doi.org/10.1016/j.resconrec.2020.105338

Pandey, D., Agrawal, M., & Pandey, J. S. (2011). Carbon footprint: current methods of estimation. *Environmental Monitoring and Assessment,* 178(1), 135–160. https://doi.org/10.1007/s10661-010-1678-y

Qi, S., Chen, S., Sun, L., Qiao, C., Li, X., & Wang, L. (2024). Calculation and evaluation of cotton lint carbon footprint based on different cotton straw treatment methods: A case study of Northwest China. *Journal of Cleaner Production*, 484, 144374. https://doi.org/10.1016/j.jclepro.2024.144374

Rüzgar, A., Taşkın, E. G., Güney, S., & Cambaz, N. (2017, October 26-28). *Life cycle assessment of a cotton T-shirt*. In XIVth International Izmir Textile and Apparel Symposium. BUTEKOM Bursa Technology Coordination and R&D Center, Bursa, Turkey.

Toffel, M., Sice, S. & Carter, K. (2011). *Carbon Footprints: Methods and Calculations*. Harvard Business School Background Note 611-075.

Wiedmann, T., & Minx, J. (2008). A definition of carbon footprint. In: C. C. Pertsova (Ed.), *Ecological Economics Research Trends*, pp. 1–11. Nova Science Publishers.

World Resources Institute & World Business Council for Sustainable Development. (2004). *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard*.

World Wide Fund for Nature. (n.d.). *WWF Footprint Calculator*. Retrieved from https://footprint.wwf.org.uk.

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RISK ASSESSMENT FOR WASTE COLLECTION WORKERS

Abstract: *This paper analyses the risk assessment process for waste collection workers, including activities such as container handling, waste collection, and operation on municipal vehicles. These workers are exposed to mechanical hazards, fall risks, physical, chemical, and biological hazards, as well as physical and ergonomic strain. The risk assessment is conducted in accordance with the Regulation on Risk Assessment, applying a risk matrix to evaluate the likelihood and severity of potential incidents. The process involves data collection, hazard identification, and the definition of protective measures. Particular emphasis is placed on preventing injuries during container handling, reducing exposure to harmful substances, and improving ergonomic conditions. The most common risks include mechanical injuries related to container manipulation, exposure to biological agents, and physical strain during waste unloading. Significant risks also arise from falls, noise and vibration exposure, and traffic related hazards during municipal vehicle operation. To mitigate these risks, the paper proposes technical safety improvements and enhanced worker training. The implementation of these measures can significantly improve occupational safety and reduce injury rates in the waste management sector.*

Keywords: risk assessment, risk matrix, mechanical hazards, physical hazards, biological hazards, strains

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INTRODUCTION

Waste collection is performed daily as part of the organized municipal services system. Although the waste itself is non-hazardous, the tasks involved in its collection include a number of situations that may pose a risk to workers' health and safety (Black et al., 2012). In their daily activities, workers handle municipal waste stored in bins and containers, operate lifting mechanisms, move through traffic and exposed environments, and frequently work outdoors under variable weather conditions. Such working conditions expose them to mechanical, physical, chemical, and biological hazards, as well as physical and ergonomic strain.

These factors increase the overall physical burden on workers and can affect their attention, concentration, and overall safety during operations (Ewis et al., 2013). Given the specificity of tasks and the dynamic nature of field work, it is essential to systematically assess the present hazards, harmful agents, and workload, as well as the level of exposure. This paper presents an example of risk assessment for waste collection workers operating in the city of Sisak and the municipalities of Lekenik, Martinska Ves, and Sunja in the Republic of Croatia. The risk assessment was conducted using a risk matrix method, which evaluates the combination of the probability of an unwanted event and the severity of its consequences. The results provide a basis for recommending specific actions to enhance workplace safety and health.

EXPERIMENTAL

Risk assessment is one of the fundamental components of the occupational health and safety system. Its purpose is to identify potential hazards, and strains in a timely manner, analyse working conditions, and determine measures that can eliminate or reduce risks to an acceptable level. In accordance with the Regulation on Risk Assessment, it is a documented process that includes the analysis of hazards and strains associated with the workplace, work environment, and specific tasks. The procedure involves identifying sources of hazards and strains, assessing workers' exposure, evaluating risk levels, and defining appropriate protective measures (Narodne novine, 112/14, 129/19; Štajner et al., 2021).

The risk assessment process includes the following key steps:

1. Identifying all potential sources of hazards and strains,
2. Analysing existing occupational safety measures,
3. Assessing the residual risk that remains despite implemented measures,
4. Ranking risks based on their likelihood and the severity of consequences,
5. Proposing additional corrective measures to eliminate or reduce hazards and strains

In practice, the risk matrix method is frequently used. It combines two fundamental factors: the probability of an undesirable event occurring and the severity of its consequences. The resulting risk is classified as low, medium, or high. This approach allows for the prioritization of risks in the workplace and the effective proposal of protective measures. It is essential to highlight that risk assessment is an ongoing process, not a one-time task. It must be regularly updated and adapted to real changes in work organization and technological processes. Moreover, it must be understandable to workers and based on actual working conditions (ILO, 2019). This study analyses the risk assessment process related to municipal waste collection in the city of Sisak and the municipalities of Lekenik, Martinska Ves, and Sunja in the Republic of Croatia. The goal of the analysis is to identify the key hazards and work-related strains that workers face, and to propose protective measures that contribute to safer field operations.

WASTE COLLECTION

Municipal waste collection workers operate exclusively outdoors (Figure 1), typically along public roads. Their work tasks involve moving smaller waste bins (with capacities of 120, 240, or 360 litres) from their designated locations to the collection vehicle. In the case of larger containers, such as those with a capacity of 1100 or even 5000 litres, they are moved to the vehicle by being pushed on wheels.



Figure 1. *Waste collection on a public roadway*

A regular part of the work process includes the use of handheld scanners to identify bins. This step verifies the service user's status and records the emptying of the container for monthly billing purposes. Following that, the waste is loaded into the municipal truck using an automated system located on the vehicle's hydraulic superstructure. This system enables emptying the bins without direct contact with the waste, although the worker must still operate the mechanism, monitor the process, and ensure that all actions are carried out safely. Once the vehicle is full, workers drive to the Goričica non-hazardous waste landfill near the city of Sisak. Depending on the waste type, the load is either deposited at a storage area next to the sorting facility (for paper, plastic, glass, and metal) or on the landfill surface (for mixed waste). Throughout the process, workers use specialized municipal vehicles equipped with hydraulic waste compaction systems. Standard work equipment also includes basic tools such as a shovel and broom, used for cleaning up spilled or scattered waste.

IDENTIFICATION OF RISKS IN WASTE COLLECTION OPERATIONS

Workers involved in waste collection are exposed to a range of hazards, including mechanical hazards and fall risks, as well as physical, chemical, and biological hazards, in addition to statodynamic and psychophysiological strains.

Mechanical hazards

Waste collection workers are routinely exposed to a variety of mechanical hazards. These risks arise from physical contact with waste bins, containers, lifting mechanisms, and municipal vehicles. One of the most common risks involves crushing and entrapment injuries during the operation of lifting mechanisms on waste collection vehicles. In cases of technical malfunction, faulty supports, or improper placement of bins or containers into the lifting mechanism, there is a risk of sudden movements or the bin/container unexpectedly falling. Such events pose a serious threat to workers nearby, particularly if they are positioned directly underneath or behind the container during lifting, emptying, or lowering.

To ensure safety during these processes, workers must stand to the side of the lifting mechanism (Figure 2), at a safe distance from its arms. Standing too close, especially directly behind the container, exposes them to the risk of impact or entrapment, which can result in serious injuries. In the rush of daily operations, workers may sometimes overlook safe distancing, particularly when actions are automated. For this reason, it is important to regularly remind them of proper body positioning and safe movement around the vehicle during work.



Figure 2. *Proper positioning of workers during bin lifting*

During manual handling of large-volume containers, such as those with capacities of 770, 1,100, or 5,000 litres, there is a risk of foot injuries caused by container wheels. This risk is especially pronounced when containers are pulled downhill, where the loss of control over the load can result in uncontrolled rolling. During the loading process itself, there is a risk of spinal and wrist injuries from lifting and manoeuvring containers. Improper handling of heavier containers without assistance from another worker can easily lead to musculoskeletal injuries. A particularly serious source of mechanical injuries is the presence of sharp or pointed objects inside the containers. Items such as broken glass, metal sheets, wires, and similar materials present a high risk of cuts and abrasions. These injuries are more likely when bins are emptied manually or when workers fail to wear gloves and other personal protective equipment.

Vehicles operating within the work area also pose a significant hazard. Traffic from other road users near waste collection points can compromise worker safety, especially if collection takes places on both sides of the road−practice that is strictly forbidden. In such scenarios, workers are at risk of being hit by moving vehicles or are forced to react very quickly, which increases the likelihood of an accident. Risks are also associated with riding on the rear platforms of collection vehicles during transport. Such transport is only permitted while the vehicle is moving forward and actively collecting waste. However, jumping onto moving platforms or riding over uneven terrain can lead to falls, impacts, serious fractures, or even fatalities (Beroš, 2020).

These risks are further intensified in conditions of reduced visibility, on slippery surfaces, and during sudden turns. Particularly dangerous is driving at a speed not adjusted to road conditions, which greatly increases the risk of traffic accidents. An additional serious risk is posed by manual loading of waste into the vehicle. During such loading, workers may come into contact with the waste compaction mechanism. Inserting hands into the loading area, holding waste in place, or attempting to sort through its contents is strictly prohibited, as it may result in severe injuries or even amputations if the mechanism is accidentally activated.

During waste collection, workers frequently use digital tools such as handheld scanners. These systems are based on RFID technology and are used to identify containers, record locations, and track emptying frequency. This helps optimize collection routes and improve the overall efficiency of the waste management system. However, using handheld scanners in field conditions can introduce additional mechanical risks. While scanning, workers often hold the device in one hand while handling the bin with the other. This reduces body stability and makes it more difficult to control the container. The risk increases further on uneven terrain, in poor weather conditions, or when vehicles are present nearby. When working with large containers that require two-person handling, holding a scanner can interfere with proper grip and coordination. It is therefore recommended that workers use belt or shoulder- mounted scanner holders to keep both hands free for safe and stable container manipulation.

Fall hazards

One of the most common causes of injuries during waste collection are falls. Waste collection is performed outdoors, frequently in unfavorable weather conditions, which increases the risk of slipping on wet surfaces or tripping over curbs. Additionally, falls may occur from the rear platform of the collection vehicle or while handling bins on uneven ground (Beroš, 2020). Winter conditions, when the ground is covered with snow or ice, are particularly hazardous. In such cases, a fall may result in serious injuries such as fractures or sprains. Another contributing factor is loss of balance during pushing or pulling heavy bins. For this reason, large containers should always be handled by two workers cooperating as a team.

Physical hazards

While riding on the platform of the waste collection vehicle, workers are exposed to noise and vibration, both classified as physical hazards. Vibrations affect the hands, legs, and back, and prolonged exposure can lead to occupational diseases such as hand arm vibration syndrome (Poplašen, 2013). In addition to physical strain, work is often carried out in extreme weather conditions, including both high and low temperatures, which place additional stress on the body. Such conditions may result in exhaustion, dehydration, heatstroke, or frostbite (Abidin, 2025). Municipal vehicles and their lifting mechanisms generate noise during operation. Moreover, additional noise is produced by road traffic, resulting in average sound levels that often exceed 85 dB. Prolonged exposure to such noise can lead to hearing loss, increased irritability, fatigue, and reduced concentration (Klančnik, 2013).

Chemical hazards

Chemical hazards also represent a significant risk during waste collection. Workers may be exposed to various harmful substances improperly disposed of in waste bins, such as solvents, acids, cleaning agents, and similar materials. The highest risk arises from leaks of hazardous liquids from improperly sealed bottles or damaged packaging. Inhalation of such substances may cause dizziness and irritation of the eyes and respiratory system (Šarić, 2002). If exposure is frequent or prolonged, more serious health effects may occur (Ewis et al., 2013). During the emptying of containers with loose material, workers may also come into contact with various types of dust. Inhalation of dust particles can lead to respiratory irritation and allergic reactions.

Biological hazards

Exposure to biological hazards is one of the main risks in municipal waste collection. This includes contact with bacteria, viruses, fungi, and parasites that may be present in discarded waste (Madsen et al., 2020). During the opening and emptying of containers, especially in the summer months, aerosols and dust containing pathogenic microorganisms may be released. Potential consequences include skin and respiratory infections, and in more serious cases, diseases such as hepatitis A or leptospirosis. Biological hazards are particularly dangerous when they come into contact with broken or scratched skin or when personal protective equipment (gloves, masks, goggles) is not properly used. In addition to the previously described hazards, particular attention must be paid to biological materials disposed of without prior sterilization, including used diapers, animal faeces, and animal carcasses. These materials can be a source of infectious diseases, especially when they come into contact with the skin or respiratory system. High temperatures further promote microbial growth, increasing the risk of skin infections (dermatitis), eye infections (conjunctivitis), and respiratory tract infections (bronchitis) (Madsen et al., 2025). A particular concern is the presence of thermophilic actinomycetes and fungi, which spread from containers in the form of spores. Long-term exposure to these agents is associated with occupational diseases such as hypersensitivity pneumonitis (Štrkalj, 2024).

Statodynamic strains

Waste collection involves continuous statodynamic strains on the body. Workers perform repetitive tasks daily, such as pushing and pulling waste containers. Other repetitive tasks include lifting and moving container lids and climbing up and down from the vehicle platform, which places considerable stress on the spine, shoulders, and knees. Handling large containers requires two workers, and lack of coordination or improper posture may result in muscle strain or lower back pain. Workers often operate on uneven or slippery road surfaces and repeated movements and prolonged walking further burden the musculoskeletal system.

Accordingly, the physical strain experienced by waste collection workers is not limited to the weight of the objects being handled and transported, but also includes the frequency of repetitive movements, working conditions, and body posture.

Psychophysiological strains

Waste collection workers are also subject to psychophysiological strains due to the specific demands of their work. The work rhythm is continuous and requires precision and focus. Additionally, workers are constantly visible to the public, which can lead to chronic fatigue, decreased motivation, and emotional exhaustion factors that negatively impact attention, concentration, and overall workplace safety. Situations where other road users contribute to psychological burden are not uncommon, particularly when waste collection vehicles block traffic during collection activities. These situations may increase stress levels, potentially reducing workers' focus and increasing the likelihood of errors. Furthermore, prolonged exposure to stress can lead to burnout syndrome (Hooper et al., 2008).

RISK ASSESSMENT DURING WASTE COLLECTION

Risk assessment is based on the analysis of the frequency of specific hazards and their potential health consequences for workers. Risk assessment for identified factors (hazards and strains) was conducted using a risk matrix, which links the likelihood of occurrence with the severity of consequences. Table 1 presents the results of the assessment along with specific examples for each individual factor.

Mechanical hazards represent the most prevalent category of risk. They include the potential for crushing, impacts, entrapment, cuts, and contact with moving parts of the vehicle. Workers are exposed to these risks daily while handling bins and containers, operating lifting mechanisms, and moving within traffic environments. This conclusion is supported by data from the company *Gospodarenje otpadom Sisak*, presented in Figure 3, which shows recorded injuries among waste collection workers from 2022 to 2024. During this period, four superficial injuries, two open wounds, and one case each of fracture, contusion, and dislocation were reported. All incidents were directly related to mechanical hazards. Based on these findings, it can be concluded that mechanical hazards pose a high risk due to the combination of high probability and potentially severe consequences.

Falls have been identified as the second most prominent risk category. Their occurrence is most often associated with weather conditions and the nature of field locations, especially during the winter months. Although the severity of consequences varies, reported cases include sprains and fractures. Due to their frequency and potential severity, falls are classified as a high risk category.

Table 1. *Risk assessment for waste collection operations using the risk matrix*

Type	Example	Likelihood	Consequence	Risk level
Mechanical hazards	Crushing injuries during container loading, impacts from moving parts of the municipal vehicle	Very likely	Extremely harmful	High risk
Fall hazards	Falls while climbing onto or off the municipal vehicle platform; slipping on wet or uneven surfaces	Likely	Extremely harmful	High risk
Physical hazards	Exposure to noise, vibration, and extreme temperatures during work	Very likely	Moderately harmful	Medium risk
Chemical hazards	Inhalation of vapours from improperly disposed hazardous substances in waste	Unlikely	Extremely harmful	Medium risk
Biological hazards	Contact with decomposing organic waste, microbial growth in warm weather	Likely	Extremely harmful	High risk
Statodynamic strain	Repetitive lifting of bins, bending while handling containers	Very likely	Moderately harmful	Medium risk
Psychophysiological strain	Stress from fast-paced work, traffic exposure, conflicts with residents	Very likely	Moderately harmful	Medium risk

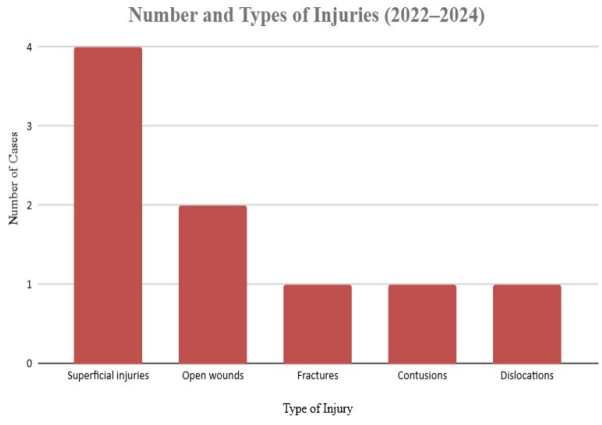


Figure 3. *Number and types of injuries during waste collection operations (2022–2024)*

Physical hazards are assessed as a constant source of risk. These include noise, vibration, and extreme temperatures. While they may not result in immediate injuries, they can cause long-term health effects, particularly with regard to the respiratory system (WHO, 2014). Due to their everyday presence and cumulative effect, this category is classified as medium risk.

Chemical hazards are found to be less frequent but potentially serious. Exposure typically occurs due to the improper disposal of hazardous substances in waste, leading to leaks or vapours. Although the probability of occurrence is lower, the potential severity of consequences requires caution (Ewis et al., 2013). For this reason, chemical hazards are also classified as medium risk.

Biological hazards become more significant during warmer months. High temperatures support the growth of microorganisms, while the contents of waste bins often include materials with a high biological component. Prolonged exposure increases the risk of infections and allergic reactions (Štrkalj, 2024). Accordingly, this group has been assessed as high risk.

Statodynamic strains arise from repetitive movements and improper body posture. This type of strain acts daily and has a cumulative effect. The consequences include pain in the back, shoulders, and lower limbs (Kompelj et al., 2021). Due to its frequency and long-term impact, this category is classified as medium risk.

Psychophysiological strains result from dynamic working conditions. In addition to constant exposure to traffic and the pressure of a fast work pace, psychological stress caused by interactions with other road users is also present (Ruxton, 2016). Long-term effects include reduced concentration and fatigue, which is why this category is also considered medium risk.

A comprehensive analysis indicates that the workplace of waste collection workers is associated with multiple types of risk. Mechanical hazards and falls stand out due to their high frequency and the severity of their consequences, while other groups require continuous monitoring and the application of protective measures. Priority actions include technical maintenance, consistent use of personal protective equipment, and regular worker training.

The results of the conducted risk assessment indicate that mechanical hazards and fall risks are the most frequent and may lead to serious health consequences for workers. These two categories have therefore been rated as high risk. Physical, chemical, and biological hazards occur with lower frequency or involve less severe outcomes but remain present in daily work and are assessed as medium risk. Statodynamic and psychophysiological strains, although often overlooked, are also significant factors contributing to long-term strain on the body. Due to their daily presence, they are also defined as medium risk.

RISK REDUCTION MEASURES

Based on the identified hazards and strains, as well as the assessed risk levels, a set of measures has been proposed to help create a safer and healthier working environment for waste collection workers.

First and foremost, it is essential to regularly maintain municipal vehicles and their lifting mechanisms, including daily visual inspections before starting work. Special attention should be given to the use of cut-resistant protective gloves, sturdy footwear with steel toe caps, and high visibility clothing such as reflective shirts or vests.

To reduce the risk of traffic related accidents, workers are required to wear high visibility garments that incorporate fluorescent colours (most commonly orange) and reflective strips. Figure 4 shows a worker wearing a high-visibility shirt with integrated reflective strips. This type of shirt represents an improvement over the standard combination of a regular shirt and a separate reflective vest. Since the reflective elements are sewn directly into the shirt, the garment is more comfortable, more practical, and allows greater freedom of movement, which facilitates everyday use of personal protective equipment.



Figure 4. *Worker wearing a high visibility shirt with reflective strips*

Workers should follow internal work instructions, which define proper techniques for lifting and handling containers. These instructions also provide guidelines for hazard recognition and correct procedures in case of an incident. Riding on the rear platform of the municipal vehicle should be limited to the shortest possible distances and carried out only under safe conditions. When handling larger containers, tasks should be organized in pairs to reduce physical strain and the risk of injury. In extreme temperatures, work schedules should be adjusted, and exposure to heat or cold should be minimized as much as possible. Visual and audible signals on the vehicle must be functional and effective in order to reduce traffic-related risks.

Work task rotation is also recommended to avoid prolonged exposure to repetitive movements and statodynamic strains. In addition to technical and organizational measures, it is important to regularly conduct worker training on proper procedures and occupational safety measures. During training, it is helpful to present real examples of common injuries, so that workers clearly understand the potential consequences of ignoring safety protocols. This approach encourages more cautious behaviour and helps integrate safety into daily work routines.

Finally, it is essential to ensure that safety instructions are accessible and understandable and that regular internal monitoring is conducted to ensure the consistent application of protective measures in daily operations.

CONCLUSION

Workers engaged in municipal waste collection are exposed daily to numerous hazards and strains that may adversely affect their health and safety. Mechanical hazards, fall risks, statodynamic and psychophysiological strains, as well as physical, chemical, and biological hazards, together constitute a complex risk that requires a systematic and responsible approach. The conducted risk assessment enabled the identification of the most prevalent hazards and their categorization according to severity and frequency. Mechanical hazards and fall risks emerged as the most significant due to their high occurrence and serious consequences. Although other hazard categories were assessed as medium risk, their daily presence requires constant attention and continuous improvement of safety measures. The findings of this analysis can serve as a basis for developing specific measures aimed at improving occupational safety.

Technical maintenance of equipment, use of personal protective equipment, worker training, and organizational adjustments are key components of effective prevention. It is important to emphasize that a significant number of injuries could be avoided at the very beginning if workers followed the prescribed safety instructions and took the potential consequences seriously. Workplace injuries often result in long-term effects that may permanently impact quality of life and working capacity, further emphasizing the importance of preventive action.

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REFERENCES

Abidin, A. U., Munawaroh, A. L., Rosinta, A. & Sulistiyani, A. T. (2025). Heat stress in landfill environments: Evaluating worker exposure and occupational risks. *Case Studies in Chemical and Environmental Engineering*, 11, 101097. https://doi.org/10.1016/j.cscee.2025.101097

Beroš, G.(2020). Ozljeda radnika zbog pada s komunalnog vozila. *Sigurnost*, 62(3), 295-300.

Bleck, D., Wettberg, W. (2012). Waste collection in developing countries – Tackling occupational safety and health hazards at their source. *Waste Management*, 31(11), 2009-2017. https://doi.org/10.1016/j.wasman.2012.03.025

Ewis, A. A., El-Gilany, A. H., & Awad, M. E. (2013). Health hazards of solid waste collectors. *International Journal of Occupational Medicine and Environmental Health, 26*(5), 684–691. https://doi.org/10.2478/s13382-013-0144-7

International Labour Organization. (2019). *Safety and health at the heart of the future of work: Building on 100 years of experience*. https://www.ilo.org/global/topics/safety-and-health-at-work

Klančnik, M. (2013). Utjecaj buke na zdravlje i radnu sposobnost. *Javno zdravstvo*, 7/2.

Kompelj, L., Markovinović, D., & Gašparić, I. (2021). Ergonomics in waste management sector: Physical load and musculoskeletal risks. *Safety Engineering,* 11(1), 42–49.

Madsen, A. M., Frederiksen, M. W., Jacobsen, M. H. &Tendal, K. (2020). Towards a risk evaluation of workers' exposure to handborne and airborne microbial species as exemplified with waste collection workers. *Environmental Research*. 183, 109177. https://doi.org/10.1016/j.envres.2020.109177

Madsen, A. M., Raulf, M., Duquenne, P., Graff, P., Cyprowski, M., Beswick, A., Laitinen, S., Rasmussen, P. U., Hinker, M., Kolk, A., Górny, R. L., Oppliger, A. & Crook, B. (2021). Review of biological risks associated with the collection of municipal wastes. *Science of The Total Environment*, 791, 148287. https://doi.org/10.1016/j.scitotenv.2021.148287

Narodne novine. (2014). *Pravilnik o izradi procjene rizika*. Narodne novine br. 112/14., 129/19.

Poplašen D. (2013). *Vibracije koje se prenose na šake i ruke*. Sigurnost 55 (4), 389 – 391

Ruxton, C. (2016). Tea: Hydration and other health benefits. *Primary Health Care, 26*(8), 34–42. https://doi.org/10.7748/phc.2016.e1162

Šarić, M., E. Žuškin, E. (2002). *Medicina rad i okoliša*. Medicinska naklada, Zagreb.

Štajner,B., Štajner, M., Štajner, G. (20121). *Procjena rizika u kontakt-centrima u kontekstu Covid-19*. Sigurnost. 63(3), 303-310.

Štrkalj, A. (2024). *Kemijske i biološke štetnosti*. Metalurški fakultet Sveučilište u Zagrebu.

World Health Organization. (2014). *Comprehensive implementation plan on maternal, infant and young child nutrition*. https://apps.who.int/iris/bitstream/handle/10665/113048/WHO_NMH_NHD_14.1_eng.pdf?ua=1

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REVIEW PAPER

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ANALYSIS OF MEASURES TO MITIGATE THE IMPACT OF UNDERGROUND COAL MINING ON THE ENVIRONMENT

Abstract: *Underground coal mines pose numerous risks of accidents and environmental hazards. The dangers to soil, surface water and groundwater are particularly noteworthy. For this reason, various measures must be taken to monitor, control and mitigate the environmental impact of mining activities. These measures ensure compliance with regulations, protect natural resources and promote sustainable mining practices. The paper discusses ten groups of key measures: air quality measures, water management measures, waste management measures, land reclamation and remediation measures, noise and vibration control measures, energy efficiency and carbon management measures, environmental monitoring and compliance measures, community and stakeholder engagement measures, health and safety measures, and innovative technologies and best practices. The AHP method was used for analysis. The ranking process was performed by workers and managers of different underground coal mines in Serbia using the group decision method. The findings reveal a clear differentiation among individual mitigation measures. Furthermore, the results underscore the significance of the analytical process in facilitating informed decision-making for both management and workers, enabling the identification of the most critical measures to minimize the environmental impact of underground coal mining.*

Keywords: Mine environment; Measures for mitigation; AHP; Underground coal mine

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INTRODUCTION

Coal is widely regarded as the dirtiest of all fossil fuels. Underground coal mining is the first step in the dirty life cycle of coal, which has many harmful effects on the environment. These include landscape degradation, deforestation, and the release of toxic minerals and heavy metals into soil and water. The environmental repercussions of coal mining persist long after coal extraction has ceased. Furthermore, the environmental problems of underground coal mining also include mine accidents, subsidence and the disposal of mining waste. For instance, poor mining practices can trigger coal fires that may burn for decades, releasing fine ash and smoke laden with greenhouse gases and toxic chemicals. Additionally, mining operations emit methane gas—a greenhouse gas 20 times more potent than carbon dioxide.

To mitigate these adverse effects, it is crucial to identify and address potential environmental impacts at both current and abandoned mining sites. Key measures include assessing geophysical disturbances, implementing technologies to prevent the uncontrolled release of heavy metals into the environment, treating water pollution, and controlling air emissions.

Modern underground mining operations must integrate comprehensive environmental mitigation strategies from the outset. These include pollution control measures, continuous monitoring of mining activities, and systematic land rehabilitation efforts. The overarching goal of underground coal mining should be to minimize its environmental footprint, particularly concerning local communities, ecosystems, and the long-term viability of land use.

Implementing effective environmental engineering solutions in underground coal mines is essential for mitigating ecological damage, ensuring regulatory compliance, and fostering sustainable mining practices. By integrating technological, operational, and managerial strategies, the mining industry can reduce its environmental impact while continuing to meet global energy demands.

This paper aims to conduct a multi-criteria analysis of measures designed to mitigate the environmental impacts of mining activities. Additionally, essential mitigation strategies that significantly reduce the negative consequences of coal mining will be examined. These measures are crucial for regulatory compliance, the protection of natural resources, and the promotion of sustainable mining practices.

LITERATURE REVIEW

A range of measures have been developed and implemented to monitor, control, and mitigate the environmental impact of mining. The analysis of underground coal mining's effects on the environment is a subject of extensive research across multiple scientific disciplines, each approaching the issue from different perspectives. The body of literature on this topic is vast.

Underground coal mining releases significant quantities of toxic gases, including carbon monoxide (CO), hydrogen sulfide (H_2S), sulfur dioxide (SO_2), nitric oxide (NO), nitrogen dioxide (NO_2), total suspended particulates (TSP), smoke, and dust. These emissions negatively affect both the working environment (Shihang et al., 2023) and the surrounding ecosystem (Pandey et al., 2014). The aforementioned authors have proposed various mitigation strategies to reduce the environmental impact of these pollutants.

The relationship between coal mining and water resources, as well as its effects on water quality and availability, has been extensively discussed in the literature (Hasii & Gasii, 2024; Masood & Hudson-Edwards, 2020). These studies also explore measures to minimize and prevent the contamination of both groundwater and surface water.

Straupnik (2022) conducted an extensive examination of various waste types generated in coal mining operations, including overburden, host rock, tailings, petroleum products, waste oil, and dust. He highlighted that overburden contains sulphur and coal, along with trace amounts of non-ferrous and rare metals, as well as negligible concentrations of radionuclides such as thorium and uranium.

Lawrence (2003) and Gupta et al. (2006) emphasized that underground coal mining has the most severe environmental impact, particularly due to land subsidence resulting from the collapse of excavated areas.

Furthermore, mining activities can generate considerable noise and vibration, primarily due to underground blasting, the transportation of ore and overburden by trucks within the mining site, stockpiling, screening, and ore crushing. Additional sources of noise include truck and rail traffic associated with the delivery of consumables to the mine and the transportation of extracted materials for further processing (Mocek, 2023). Sensogut (2007) conducted a comprehensive study on noise pollution in mining operations, exploring various mitigation strategies to minimize its environmental impact.

Underground coal mining is a highly energy-intensive process, requiring substantial electrical power for plant operations. Consequently, energy audits are essential to identify and implement energy-saving measures (Kumar et al., 2021).

Coal mining is a significant contributor to carbon emissions. To address this issue, Li et al. (2022) propose a method for quantifying carbon emissions from coal mining as a critical step toward their reduction. Initially, a carbon emission threshold for fully mechanized coal mining is established. Subsequently, a carbon emission accounting model (B-R model) is developed to quantify the total emissions. Zhou et al. (2020) propose gas extraction and utilization and gas utilization as an effective mitigation measure.

Despite advancements in technology, underground coal mining continues to exert a substantial environmental impact. Dramlić et al. (2024) examine this impact, emphasizing the crucial role of environmental monitoring as a key component of environmental protection. Their study aims to analyze the interactions between underground mining and the environment, provide a comprehensive assessment of its environmental footprint, and highlight the importance of monitoring specific environmental parameters.

Sustainability in the mining industry is a critical concern due to its far-reaching social, economic, and environmental implications. Matikainen (2020) explores sustainability through the lens of stakeholder engagement, underscoring its necessity for addressing sustainability challenges. Effective engagement with key stakeholders—including local communities, employees, and governmental bodies—is imperative for developing sustainable mining practices.

The health and safety of underground coal mine workers remain a pressing global issue, given the recurring fatalities and disasters in the industry. Mahdevari (2014) introduces a fuzzy TOPSIS-based methodology for assessing occupational health risks, facilitating the implementation of control measures and informed decision-making. This model primarily serves to identify potential hazards and implement appropriate mitigation strategies to minimize or eliminate risks before accidents occur.

The coal mining industry has undergone continuous evolution, punctuated by several revolutionary advancements that have significantly transformed extraction methods, equipment, and overall productivity. In recent years, technological progress has increasingly emphasized the integration of communication systems, automation, and data science to enhance miner health and safety while optimizing operational efficiency (Bhattacharyya, 2023). Furthermore, the growing emphasis on environmental, social, and governance (ESG) considerations has introduced new dimensions of sustainability, simultaneously presenting complex challenges for the global mining sector. Consequently, the industry has been compelled to modernize, developing economically viable mining techniques that minimize environmental impact.

Koul (2024) investigates the application of robotics in underground coal mining to improve operational efficiency and safety through technological advancements. The deployment of high-tech robotic equipment has demonstrated substantial productivity gains while mitigating occupational health risks for

workers. In highlighting these innovations, the study underscores the necessity of continuous advancements in robotics to maximize resource extraction and safeguard worker well-being, positioning robotic systems as a transformative force in the coal mining industry.

DATA AND METHODOLOGY

Research is being conducted in various underground coal mines across Serbia, which currently operates nine such mines with an annual production of up to 400,000 tons. The existing environmental monitoring practices in Serbia's underground coal mines lack systematic and comprehensive procedures (Dramlić et al., 2024). Consequently, further research is necessary to identify the most significant environmental impacts of underground coal mining and to determine appropriate mitigation measures.

This study identifies key measures for mitigating environmental impacts and ranks them based on research findings, expert consultations with coal mining professionals, and a literature review.

Environmental conditions in Serbian underground coal mines vary significantly, and while various mitigation measures are implemented, they are often fragmented and focus on specific impacts rather than providing a comprehensive approach. To develop a holistic set of mitigation strategies, this study engaged numerous mining experts and industry managers, ensuring a robust foundation for generating high-quality results.

AHP method

The Analytic Hierarchy Process (AHP) is a quantitative methodology designed to structure, analyze, and solve complex decision-making problems within a multidimensional hierarchical framework (Saaty, 1980). This hierarchical structure is composed of objectives, criteria, and alternatives.

AHP employs a pairwise comparison matrix to assess the relative importance of each criterion and to evaluate alternatives concerning each criterion. These comparisons are conducted using a numerical scale ranging from 1 to 9 (Table 1.), facilitating a systematic and consistent assessment of priorities.

Table 1. *Pair-wise comparison scale for the AHP method*

Verbal Judgement	Numerical Rating
Equally preferred	1
Moderately preferred	3
Strongly preferred	5
Very strongly preferred	7
Extremely preferred	9
2, 4, 6 and 8 are intermediate values	

Based on a comparison of decision elements, the application of an appropriate evaluation method leads to the final ranking of alternatives.

In this study, only the first step is employed to rank the criteria—identifying the most important working environment parameters—by calculating the relative strength of each criterion.

The research method

The original research methodology was developed to analyze and rank the measures for mitigating the impact of underground coal mining on the environment. The methodology consists of the following four steps: (1) literature review, data collection, (2) determination of the most important measures to mitigate the impact of underground coal mining on the environment, (3) AHP calculations, and (4) results and discussion (Figure 1.).

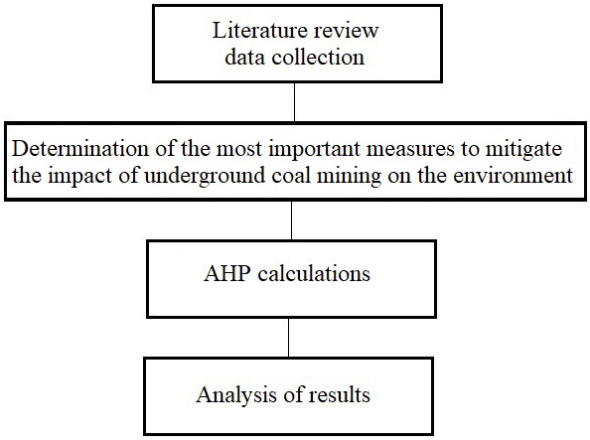


Figure 1. *Schematic overview of the research method*

The study commenced with a comprehensive literature review to identify the most critical measures for mitigating the impact of the underground coal mining on the environmental impact of. Given the vast body of existing research, an extensive review was conducted to encompass all relevant mitigation measures. Additionally, structured interviews were conducted with mining experts and industry managers to collect high-quality data and gain insights into practical decision-making processes. Based on the findings, a final list of key mitigation measures was established.

Subsequently, the identified measures were ranked using the Analytic Hierarchy Process (AHP) to assess their relative influence on mitigation. Upon obtaining the ranking results, the most significant measures were analyzed to provide a solid foundation for future mining practices and environmental protection efforts, thereby enhancing the understanding of priorities in this domain.

RESULTS AND DISCUSSION

Literature review and data collection

As previously mentioned, the research commenced with an extensive literature review and in-depth interviews with mining experts and managers in Serbia. This phase was the most time-intensive and laid the groundwork for the subsequent research stages. Based on the collected data, a structured questionnaire was

developed to systematically identify and prioritize key mitigation measures derived from the responses.

Determination of the most important measures to mitigate the impact of underground coal mining on the environment

In this phase, the identified mitigation measures are classified according to their inherent characteristics and effectiveness. This categorization is based on an extensive literature review and expert consultations with mining professionals and industry managers to establish a consensus on each mitigation measure. Following this approach, ten key measures for mitigating the environmental impact of underground coal mining have been defined, namely:

- ***Air quality measures (M1)*** – *Ventilation systems:* install and maintain advanced ventilation systems to effectively dilute and eliminate hazardous gases such as methane (CH_4) and carbon monoxide (CO); *Dust suppression:* implement water spray systems, foam applications, and dust collection mechanisms to mitigate coal dust emissions; *Methane capture:* deploy degasification technologies to extract methane from coal seams and utilize it for energy production; and *Real-time monitoring:* integrate air quality sensors to continuously track gas concentrations and particulate matter levels.
- ***Water management measures (M2)*** – *Mine water treatment:* treat acid mine drainage through neutralization or passive remediation techniques; *Water recycling:* establish water recycling and reuse systems within mining operations to minimize freshwater consumption; *Containment systems:* construct engineered barriers and liners to prevent the infiltration of contaminated water into groundwater and surface water bodies; and *Rainwater harvesting:* implement rainwater collection and storage systems to supplement water supply for mining activities.
- ***Waste management measures (M3)*** – *Backfilling:* utilize coal gangue and other waste materials to backfill mined-out areas, thereby mitigating surface subsidence and minimizing waste accumulation; *Tailings management:* store tailings in engineered containment facilities equipped with liners and leachate collection systems to prevent environmental contamination; and *Waste utilization:* repurpose mining waste for construction materials and land reclamation initiatives.
- ***Land reclamation and remediation measures (M4)*** – *Subsidence monitoring:* employ GPS and satellite-based monitoring systems to assess and mitigate land subsidence; *Revegetation:* restore vegetation cover by planting native species to enhance ecological recovery and prevent soil erosion; *Soil stabilization:* apply soil stabilization techniques such as terracing and mulching to improve land resilience in reclaimed areas; and *Land use planning:* rehabilitate post-mining landscapes for agricultural, forestry, or recreational purposes.
- ***Noise and vibration control measures (M5)*** – *Noise barriers:* install physical barriers or enclosures around high-noise equipment to mitigate sound propagation; *Blasting techniques:* utilize controlled blasting methods to minimize vibrations and noise pollution; and *Equipment maintenance:* implement routine maintenance programs to reduce machinery noise levels and prevent excessive vibrations.
- ***Energy efficiency and carbon management measures (M6)*** – *Energy audits:* conduct comprehensive energy audits to identify and implement energy efficiency measures; *Renewable energy:* deploy solar panels, wind turbines, and other renewable energy solutions to power mining operations; and C*arbon capture and storage:* implement CO_2 capture and sequestration technologies for underground storage or industrial reuse.
- ***Environmental monitoring and compliance measures (M7)*** – *Real-time sensors:* utilize sensor networks to monitor air, water, and soil quality continuously; *Environmental impact assessments:* conduct before initiating mining activities to evaluate and mitigate potential environmental risks; and *Regulatory reporting:* maintain comprehensive environmental records and submit regulatory reports to demonstrate compliance with legal frameworks.
- ***Community and stakeholder engagement measures (M8)*** – *Public consultation:* foster community engagement through transparent communication and stakeholder dialogue; *Compensation and benefits:* ensure equitable compensation and socio-economic benefits for communities affected by mining operations; and *Education and training:* provide environmental awareness programs and safety training for workers and local communities.
- ***Health and safety measures (M9)*** – *Personal protective equipment (PPE):* supply workers with appropriate PPE to safeguard against occupational hazards; *Health monitoring:* conduct periodic medical screenings to detect and prevent occupational diseases; and *Emergency preparedness:* develop and implement emergency response protocols and plans for incidents such as gas leaks or water contamination.
- ***Innovative technologies and best practices (M10)*** – *Automation and robotics:* integrate automated machinery and robotic systems to enhance safety and reduce environmental impact; *Green mining technologies:* adopt environmentally sustainable technologies such as bioleaching and in-situ coal gasification; and *Data analytics:* utilize data-driven insights and machine learning techniques to optimize environmental management and anticipate potential risks.

AHP calculations

The AHP calculations were performed using the group decision-making approach, involving experts and managers from mining companies in Serbia. The Aggregation of Individual Judgments (AIJ) method was employed to facilitate group consensus-based decision-making. Figure 2. presents the hierarchical structure of the AHP model. Mitigation measures were systematically evaluated and ranked until consensus was reached for each assessment, utilizing the scale outlined in Table 1. The 10×10 comparison matrix is presented in Figure 3. The AHP computations were conducted using AHP-OS online software (https://bpmsg.com/ahp/), and the results derived from the comparison matrix are depicted in Figure 4.

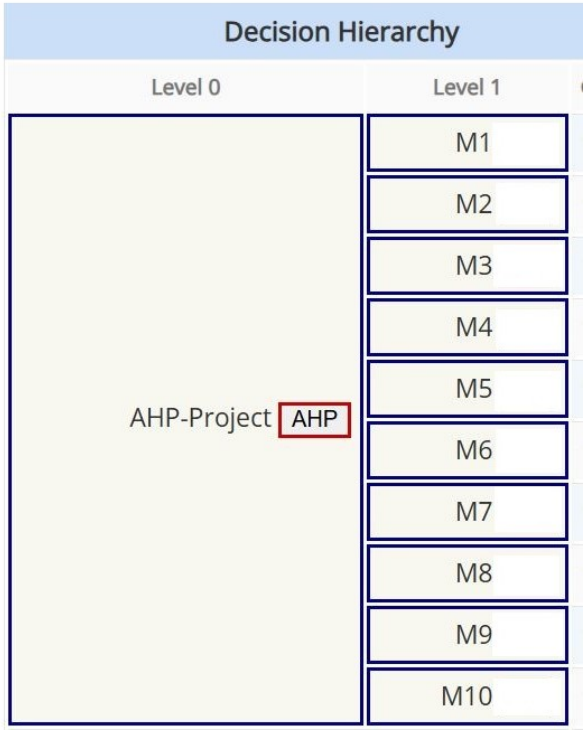


Figure 2. *Hierarchical structure of the AHP problem*

	1	2	3	4	5	6	7	8	9	10
1	1	0.17	0.25	0.14	3.00	0.25	0.33	0.25	0.14	0.20
2	6.00	1	3.00	0.33	4.00	2.00	1.00	1.00	0.25	0.33
3	4.00	0.33	1	0.33	2.00	0.25	0.20	0.25	0.17	0.20
4	7.00	3.00	3.00	1	4.00	2.00	1.00	0.50	0.25	0.33
5	0.33	0.25	0.50	0.25	1	0.25	0.20	0.25	0.17	0.20
6	4.00	0.50	4.00	0.50	4.00	1	0.50	0.33	0.25	3.00
7	3.00	1.00	5.00	1.00	5.00	2.00	1	1.00	0.33	0.50
8	4.00	1.00	4.00	2.00	4.00	3.00	1.00	1	0.50	0.50
9	7.00	4.00	6.00	4.00	6.00	4.00	3.00	2.00	1	1.00
10	5.00	3.00	5.00	3.00	5.00	0.33	2.00	2.00	1.00	1

Figure 3. *Criteria comparison matrix*

Cat		Priority	Rank
1	M1	2.5%	9
2	M2	8.9%	7
3	M3	3.5%	8
4	M4	10.8%	4
5	M5	2.2%	10
6	M6	10.3%	5
7	M7	10.1%	6
8	M8	12.0%	3
9	M9	23.4%	1
10	M10	16.5%	2

Figure 4. *Results obtained by AHP calculations*

Results and discussion

The obtained results clearly identify the measures that exert the most significant influence on mitigating the impact of underground coal mining on the environment. Based on their respective weighting coefficients, the measures can be classified into three distinct categories according to their relative impact on the mitigation process. The first category encompasses measures with weighting coefficients exceeding 0,2 (20%), represented solely by M9 – health and safety measures. The second category includes measures with weighting coefficients ranging between 0,1 and 0,2. These are: M10 – innovative technologies and best practices, M8 – community and stakeholder engagement measures, M4 – land reclamation and remediation measures, M6 – energy efficiency and carbon management measures, and M7 – environmental monitoring and compliance measures. Conversely, the third category comprises measures with weighting coefficients below 0,1, reflecting a relatively lower influence. This group includes M2 – water management measures, M3 – waste management measures, M1 – air quality measures, and M5 – noise and vibration control measures.

In the first, the most influential category of measures is M9 with a weighting coefficient of 0.234 (23,4%). According to mining experts, health and safety measures represent the highest priority. These measures, aimed at preserving the health and lives of workers, are considered the most critical due to the inherently challenging, demanding, and hazardous nature of underground mining operations.

The second major category of measures is considered less influential than the first. Within this category, innovative technologies and best practices (M10) have the highest weighting coefficient. The continuous enhancement of existing methods and the adoption of advanced, more innovative technologies have the potential to substantially mitigate the adverse

environmental impacts of underground coal mining. However, the primary drawback of these measures lies in the substantial initial investment they typically require. Ranked second in this category are the measures classified as M8, which pertain to community and stakeholder engagement. These include public consultations, the provision of compensation and benefits, and the implementation of education and training programs. Actively involving both local and broader communities in addressing environmental issues associated with mining operations is essential. This includes facilitating participation in decision-making processes, providing restitution for damages, and acknowledging community concerns and warnings. Such an inclusive approach can significantly diminish the environmental footprint of mining activities. The third-ranking measures in this group are those classified under M4, which relate to land reclamation and remediation. These are designed to mitigate the degradation of land caused by underground mining operations. Experts in the field emphasize their importance, as they encompass actions such as terrain subsidence monitoring, revegetation, soil stabilization, and strategic land-use planning. Following this are measures associated with energy efficiency and carbon management (M6). These are crucial in optimizing energy and gas use while aiming to reduce greenhouse gas emissions, given that mines are substantial sources of such emissions. Finally, M7 pertains to environmental monitoring and compliance measures. These are critical for ongoing surveillance of both the mining site and its surrounding environment. They include monitoring pollution parameters and establishing alert systems to notify stakeholders of incidents that could negatively impact either the mine or the environment.

The third category of measures has the least direct impact on mitigating the environmental consequences of coal mining. Nevertheless, the measures within this category are essential and must be implemented continuously. These measures are generally simpler to apply and demand fewer resources compared to those in the first two categories. Consequently, mining professionals have assigned them a lower priority, as they believe they can yield tangible results within a relatively short timeframe. Within this category, M2 – water management measures exert the most significant influence. Underground coal mines disrupt both groundwater and surface water systems. Therefore, the implementation of measures aimed at water protection, purification, and the provision of sufficient quantities for the uninterrupted operation of mining activities is of critical importance. Ranked second are M3 – waste management measures. Underground coal mining operations generate substantial volumes of waste. The primary objective of these measures is to reduce the amount of generated waste and to enable its further processing and potential utilization in other industrial sectors. In the penultimate position are M1 – air quality control measures. These measures involve air purification, methane capture, dust suppression, and similar activities. Although such practices are applied in Serbian mines to varying degrees, their limited and inconsistent implementation has led to their lower ranking. M5 – noise and vibration control measures occupy the lowest position. Underground coal mining inevitably produces noise due to the operation of main ventilation systems, blasting activities, and other processes. Additionally, while vibration exposure exists, it is generally less pronounced than in other industrial sectors. As a result, these measures are considered less critical and have been ranked accordingly.

Finally, several key challenges in the implementation of environmental protection measures in underground coal mining operations have been identified. Among the most prominent are the high costs associated with advanced technologies and infrastructure, the difficulty of reconciling production targets with environmental protection goals, and the need to address legacy environmental issues and abandoned mine sites. Coal mines in Serbia predominantly rely on outdated technologies and methods of exploitation. The most pressing issue is the lack of financial resources necessary for the modernization of operations, particularly for the procurement of advanced equipment and technologies. Moreover, in practice, production objectives are often prioritized over environmental concerns. In addition, unresolved environmental problems inherited from previous decades continue to pose a serious threat to the environment and remain unaddressed.

CONCLUSION

The implementation of comprehensive environmental engineering interventions in underground coal mining operations constitutes a critical component in mitigating adverse ecological impacts, ensuring rigorous compliance with environmental legislation, and fostering the development of sustainable mining frameworks. Through the deployment of advanced technological innovations, the optimization of operational protocols, and the application of integrated environmental management systems, the coal mining sector can significantly curtail its environmental footprint while sustaining its strategic role in meeting global energy demands.

The Analytic Hierarchy Process (AHP) was employed to evaluate and prioritize the most important measures for mitigating the environmental impacts of underground coal mining. Ten key groups of mitigation measures were assessed and ranked: M1 (air quality measures), M2 (water management measures), M3 (waste management measures), M4 (land reclamation and remediation measures), M5 (noise and vibration control measures), M6 (energy efficiency and carbon management measures), M7 (environmental monitoring and compliance measures), M8 (community and stakeholder engagement measures), M9 (health and safety measures), and M10 (innovative technologies and best practices).

Based on the ranking results, these mitigation measures were categorized into three distinct priority categories. The first and most critical category includes M9 (health and safety measures). The second category, of moderate importance, comprises M10 (innovative technologies and best practices), M8 (community and stakeholder engagement measures), M4 (land reclamation and remediation measures), M6 (energy efficiency and carbon management measures), and M7 (environmental monitoring and compliance measures). The third category, representing measures of comparatively lower priority, includes M2 (water management measures), M3 (waste management measures), M1 (air quality measures), and M5 (noise and vibration control measures).

The prioritization of these key groups of measures provides valuable insights for mining professionals and decision-makers in selecting the most effective strategies for minimizing the environmental footprint of underground coal mining operations.

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REFERENCES

Bhattacharyya, S., Fan, L., Azam, S., & Liu, S. (2023). Advances in coal mining technology and sustainable mining techniques. In D. Osborne (Ed.), *The coal handbook: Volume 1* (2nd ed., pp. 263–321). Woodhead Publishing. https://doi.org/10.1016/B978-0-12-824328-2.00011-X

Dramlić, D., Ristić, V., Zlatanović, D., Ivaz, J., & Đukanović, D. (2024). Development of a conceptual model for environmental monitoring in underground coal mining. *Tehnički vjesnik, 31*(4), 1270–1276. https://doi.org/10.17559/TV-20240503001516

Hasii, O., & Gasii, G. (2024). Coal mining and water resources: Impacts, challenges, and strategies for sustainable environmental management. *IOP Conference Series: Earth and Environmental Science, 1348*(1), 012017. https://doi.org/10.1088/1755-1315/1348/1/012017

Koul, P. (2024). Robotics in underground coal mining: Enhancing efficiency and safety through technological innovation. *Podzemni Radovi, 1*(45), 1–26. https://doi.org/10.5937/podrad2445001K

Kumar, M., Maity, T., & Kirar, M. K. (2021). Energy-use assessment and energy-saving potential analysis in an underground coal mine: A case study. In *2021 IEEE Kansas Power and Energy Conference (KPEC)* (pp. 1–7). IEEE. https://doi.org/10.1109/KPEC51835.2021.9446232

Li, B., Shi, Y., Hao, J., Ma, C., Pang, C., & Yang, H. (2022). Research on a carbon emission calculation model and method for an underground fully mechanized mining process. *Energies, 15*(8), 2871. https://doi.org/10.3390/en15082871

Li, S., Chen, X., Peng, G., Han, M., Guo, Q., Hou, J., & Gao, B. (2023). Research on the evaluation of air quality in underground coal mines based on a generalized contrastive weighted comprehensive scale index method. *Atmosphere, 14*(6), 1021. https://doi.org/10.3390/atmos14061021

Mahdevari, S., Shahriar, K., & Esfahanipour, A. (2014). Human health and safety risks management in underground coal mines using fuzzy TOPSIS. *Science of The Total Environment, 488–489*, 85–99. https://doi.org/10.1016/j.scitotenv.2014.04.076

Masood, N., Hudson-Edwards, K., & Farooqi, A. (2020). True cost of coal: Coal mining industry and its associated environmental impacts on water resource development. *Journal of Sustainable Mining, 19*(3), 135–149. https://doi.org/10.46873/2300-3960.1012

Matikainen, L. M. (2020). *Enhancing sustainability in the mining industry through stakeholder engagement* (Master's thesis). Tampere University, Master's Programme in Business Studies, Management and Organizations.

Mocek, P. (2023). Environmental impact of noise from mining operations. *Scientific Journals of the Maritime University of Szczecin, 73*(145), 15–28. https://doi.org/10.17402/551

Pandey, B., Agrawal, M., & Singh, S. (2014). Assessment of air pollution around coal mining area: Emphasizing on spatial distributions, seasonal variations and heavy metals, using cluster and principal component analysis. *Atmospheric Pollution Research, 5*(1), 79–86. https://doi.org/10.5094/APR.2014.010

Saaty, T. L. (1980). *The analytical hierarchy process*. McGraw-Hill.

Sensogut, C. (2007). Occupational noise in mines and its control – A case study. *Polish Journal of Environmental Studies, 16*(6), 939–942.

Straupnik, I. A. (2022). An overview of the environmental impact of coal industry waste. *IOP Conference Series: Earth and Environmental Science, 1070*(1), 012004. https://doi.org/10.1088/1755-1315/1070/1/012004

Zhou, A., Hu, J., & Wang, K. (2020). Carbon emission assessment and control measures for coal mining in China. *Environmental Earth Sciences, 79*, 461. https://doi.org/10.1007/s12665-020-09189-8

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INDOOR AND OUTDOOR AIR QUALITY: ANALYSIS OF SUSPENDED PARTICLES IN RESIDENTIAL SPACES IN BOR, SERBIA

Abstract: *This study examines the levels of suspended particles (PM_{10} and $PM_{2.5}$) in residential settings in Bor, Serbia, alongside simultaneous outdoor measurements of PM. The project lasts 2 years and involves 30 apartments per year, selected based on criteria such as window type, connection to central heating, non-smoking status, distance from major pollution sources, and prevailing wind direction. Results from the winter measurement campaign (heating season) in 15 apartments, presented here, show that indoor PM concentrations vary significantly depending on ventilation habits, window type, and proximity to pollution sources. Measurements were conducted over 45 days during the heating season, and residents maintained activity diaries to document household activities. The average PM_{10} concentration in apartments was 18.2 μg/m³, while the average $PM_{2.5}$ concentration was 12.0 μg/m³. The average indoor/outdoor concentration ratio was 0.58 for PM_{10} and 0.68 for $PM_{2.5}$. The final results of this project will support the development of recommendations aimed at reducing indoor air pollution in urban homes across Serbia.*

Keywords: air quality, monitoring, suspended particles, measurement

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INTRODUCTION

Air pollution, particularly involving particulate matter (PM), has emerged as a significant environmental and public health concern globally. Fine particles such as PM_{10} (particles with diameters ≤ 10 μm) and $PM_{2.5}$ (particles with diameters ≤ 2.5 μm) are especially hazardous due to their ability to penetrate deep into the respiratory system, leading to various health issues. These particles have been linked to increased risks of cardiovascular and respiratory diseases, lung cancer, and premature mortality, especially in vulnerable populations such as children, the elderly, and individuals with pre-existing conditions (Gladović et al., 2023).

While outdoor air pollution has been extensively monitored, indoor air quality (IAQ) has only recently gained the attention it deserves. Given that people spend up to 90% of their time indoors, indoor exposure to PM represents a substantial public health risk. Indoor PM concentrations are influenced not only by outdoor air infiltration but also by indoor sources such as heating, cooking, and smoking. In urban and industrial areas, studies have shown that indoor PM levels can often rival or exceed those measured outdoors (Radović et al., 2024).

The city of Bor in eastern Serbia is one of the country's most prominent industrial centers, primarily due to its large-scale copper mining and smelting operations. This industrial activity has long been associated with poor air quality. Studies from recent years have confirmed that Bor frequently exceeds national and European Union air quality standards, particularly for outdoor SO_2 and PM_{10} concentrations and content of As, Pb, and Cd in PM_{10} samples (Serbula et al., 2013; Tasić et al., 2010; Tasić et al., 2012; Tasić et al., 2017), while some studies have investigated PM levels in public buildings or outdoor urban areas, there is a lack of systematic data on PM concentrations in residential settings in Bor.

To address the existing knowledge gap concerning indoor air quality in Bor, a scientific research initiative was launched in January 2025. This project, funded by the Center for the Promotion of Science (CPN), involves a collaborative effort between the Mining and Metallurgy Institute Bor (MMI Bor) and the civil society organization "Građanska čitaonica Evropa." The primary objective is to quantify the concentrations of PM (PM_{10} and $PM_{2.5}$) within residential environments and assess the extent to which indoor air quality is influenced by Bor's well-documented ambient air pollution.

The project is scheduled to span a two-year period and will involve air quality measurements in 30 residential units per year, selected from the broader central area of Bor. Based on responses to a preliminary citizen survey, 60 apartments will be chosen - 30 equipped with wooden window frames and 30 with PVC or aluminium joinery.

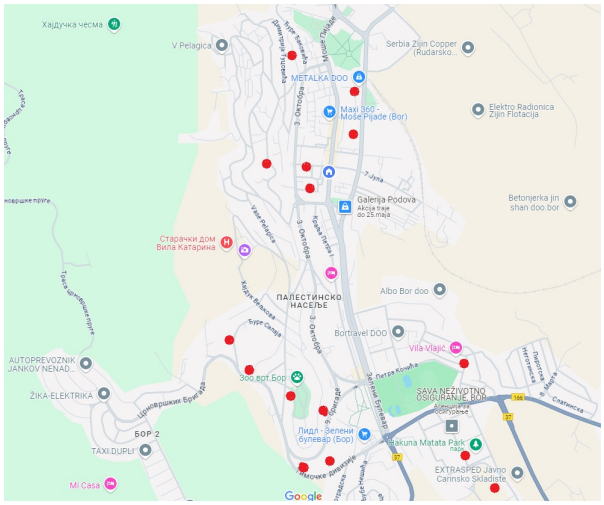


Figure 1. *Location of the first 15 selected apartments in the city of Bor*

Inclusion criteria include connection to the central heating system and occupancy by non-smoking residents. In each apartment, measurements will be conducted over two 40–50 day periods: one during the heating season and the other during the non-heating season.

Residents will be actively engaged in the study through participation in the measurement process within their homes. They will be asked to maintain a detailed activity diary during the monitoring periods, which will be instrumental in evaluating their exposure to particulate matter and understanding the influence of routine household activities on indoor PM concentrations.

The research team will analyze both the measured PM levels and the self-reported activity data to identify correlations and potential causal relationships.

Through seasonal sampling and comprehensive data analysis, the study aims to elucidate patterns and interrelations between indoor and ambient PM levels. It also seeks to enhance public awareness regarding the health implications of indoor air pollution. By integrating scientific expertise and civic participation, the initiative promotes a collaborative model for environmental monitoring and public health research. The empirical data generated will contribute to the broader scientific understanding of indoor air pollution in industrial urban contexts and support the formulation of evidence-based mitigation strategies.

Ultimately, the findings will inform both policymakers and residents, offering insights into how to improve living conditions and reduce health risks associated with prolonged exposure to particulate matter indoors.

METHODOLOGY

This paper presents the results of measurements of PM concentrations (PM_{10} and $PM_{2.5}$) conducted in 15 residential apartments in the city of Bor, during the period from March 1 to April 17, 2025. Figure 1 shows the locations of the 15 selected apartments on the map of the city of Bor. Among the 15 selected apartments, eight featured PVC window frames, whereas the remaining seven had wooden frames.



Figure 2. *PM monitor installed in the apartment*

PM measurements in indoor air

In each apartment, an automatic PM monitor (Božilov et al., 2022) was installed to continuously measure PM_{10} and $PM_{2.5}$ concentrations, along with indoor temperature and relative humidity (Figure 2).

The PM monitors recorded one-minute average values for all observed parameters, while hourly averages were used for the analyses presented in this paper. Prior to deployment in real-world settings, all PM monitors were tested under laboratory conditions at the MMI Bor to verify measurement accuracy. During the calibration process, the results from each device were compared with those obtained using the reference gravimetric method for determining PM concentrations (Ramachandran et al., 2003), in order to identify potential deviations and apply necessary corrections.

PM measurements in ambient air

The automatic monitoring station (AMS) Bor-Town Park measurements were used to compare the average hourly values of PM concentrations measured in apartments with PM concentrations in ambient air. At this measuring point, PM concentrations are measured with an automatic Grimm EDM 180 analyzer, and 1-hour average values of outdoor PM concentration can be downloaded from the official website of the Serbian Environmental Protection Agency (SEPA): https://sepa.gov.rs/

RESULTS AND DISCUSSION

The average values of the measurement results are presented in Table 1. During the measurement campaign conducted in the heating season, no exceedances of the daily limit value for PM_{10} (50 µg/m³) or $PM_{2.5}$ (25 µg/m³) were observed in any of the monitored apartments. The average ambient concentrations of PM_{10} and $PM_{2.5}$ during the measurements campaign were 31.3 µg/m³ and 17.6 µg/m³, respectively. The average ambient concentration ratio of $PM_{2.5}$ and PM_{10} during the campaign was 0.56.

Table 1. *Average values of PM concentrations and PM indoor/outdoor (I/O) ratios during the heating season*

No.	PM_{10} (µg/m³)	$PM_{2.5}$ (µg/m³)	PM_{10} I/O	$PM_{2.5}$ I/O
N30	25.0	14.1	0.80	0.80
N42	23.2	12.0	0.74	0.68
N49	20.8	17.0	0.66	0.97
N2	20.1	11.1	0.64	0.63
N45	19.1	13.5	0.61	0.77
N31	18.3	12.4	0.58	0.71
N43	18.2	12.9	0.58	0.73
N46	17.6	11.9	0.56	0.67
N40	16.6	12.1	0.53	0.79
N34	16.5	12.5	0.53	0.71
N44	16.2	11.1	0.52	0.63
N47	16.3	9.8	0.52	0.56
RZ	16.1	11.3	0.51	0.64
N35	16.0	9.4	0.51	0.53
N41	12.9	9.1	0.41	0.52
average	**18.2**	**12.0**	**0.58**	**0.69**
min	12.9	9.1	0.41	0.52
max	25.0	17.0	0.80	0.97
stdev	3.1	2.0	0.10	0.11

The measurement results summarized in Table 1 suggest that indoor sources of suspended particles were either negligible or absent in the studied apartments. Similar PM concentration levels were reported in the study (Tasić et al., 2015) during the heating season, where measurements were conducted in the offices of MMI Bor. The average concentrations of PM_{10} and $PM_{2.5}$ in the offices during the measurement campaign were 20.3 µg/m³ and 10.9 µg/m³, respectively.

Another study of PM_{10} concentrations conducted in four apartments in Bor (Tasić et al., 2013) reported similar PM_{10} levels during the heating season. The average indoor and ambient concentrations of PM_{10} during the measurement campaign were 26.13 µg/m³ and 52.6 µg/m³, respectively. The average PM_{10} I/O ratio was 0.55. These findings are consistent with the results reported by Pekey et al. (2010) for Kocaeli (Turkey) during the cold season, where the PM_{10} I/O concentration ratio was 0.56, and by Diapouli et al. (2008) for a typical residence in the center of Athens, where the PM_{10} I/O ratio was approximately 0.61.

Table 2 presents the Pearson correlation coefficients (r) between indoor and outdoor (I/O) PM concentrations during the heating season. The average correlation coefficient for I/O PM_{10} concentrations is 0.33, while the average *r* value for I/O $PM_{2.5}$ concentrations is 0.51. These results indicate a higher infiltration of $PM_{2.5}$ from the outdoor environment into the apartments.

Table 2. *Pearson correlation coefficients (r)between I/O PM concentrations during the heating season*

No.	PM_{10} I/O corr. coef.	$PM_{2.5}$ I/O corr. coef.
N30	0.45	0.60
N42	0.22	0.42
N49	0.27	0.31
N2	0.32	0.53
N45	0.22	0.46
N31	0.40	0.61
N43	0.36	0.64
N46	0.40	0.68
N40	0.35	0.55
N34	0.45	0.60
N44	0.45	0.55
N47	0.20	0.52
RZ	0.25	0.36
N35	0.27	0.34
N41	0.40	0.48
average	**0.33**	**0.51**
min	0.20	0.31
max	0.45	0.68
stdev	0.09	0.11

Figure 2 shows the PM concentrations measured during the heating season in one of the selected apartments in Bor. The apartment is occupied by two retirees who follow their regular daily routines. Episodes of elevated PM concentrations in this apartment occur during cooking and while cleaning the apartment (vacuuming and dusting). This apartment is located less than 500 meters from the AMS Bor Town Park, from which hourly average ambient PM concentrations and meteorological data were obtained. Additionally, the apartment is situated next to a busy street where heavy-duty vehicle traffic is allowed. Despite these factors, the average I/O ratios for PM_{10} and $PM_{2.5}$ during the measurement campaign were 0.58 and 0.71, respectively. Although the apartment is over 50 years old, it has relatively well-preserved wooden window frames, which likely contributed to the observed Pearson correlation coefficients between I/O PM concentrations during the campaign: 0.40 for PM_{10} and 0.61 for $PM_{2.5}$.

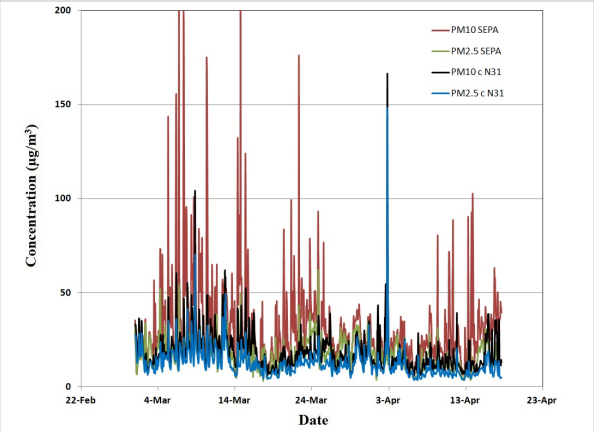


Figure 2. *An example of PM concentrations in one of the apartments in Bor during the heating season*

CONCLUSION

In conclusion, the findings suggest that indoor PM concentrations in the analyzed apartments in Bor during the heating season were largely influenced by the infiltration of outdoor particles, as well as by the occupants' cooking and cleaning activities. The average I/O ratios of 0.58 for PM_{10} and 0.68 for $PM_{2.5}$, along with higher correlation coefficients for $PM_{2.5}$ ($r = 0.51$) compared to PM_{10} ($r = 0.33$), indicate a more efficient penetration of finer particles into indoor environments.

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REFERENCES

Božilov, A., Tasić, V., Živković, N., Lazović, I., Blagojević, M., Mišić, N., & Topalović, D. (2022). Performance assessment of NOVA SDS011 low-cost PM sensor in various microenvironments. *Enviromental Monitoring and Assessment*, 194, 595 https://doi.org/10.1007/s10661-022-10290-7

Gladović, A., Petrović, B., Vukelić, D., Buha Djordjević, A., Ćurčić, M., Đukić-Ćosić, D., Šoštarić, A., Antonijević, B., & Bulat, Z. (2023). Carcinogenic and human health risk assessment of children's and adults' exposure to toxic metal(oid)s from air PM_{10} in critical sites of the Republic of Serbia. *Environmental Science and Pollution Research*, *30*(22), 61753–61765. https://doi.org/10.1007/s11356-023-26375-w

Diapouli, E., Chaloulakou, A., & Spyrellis, N. (2008). Indoor and outdoor PM concentrations at a residential environment, in the Athens area, *Global NEST Journal, 10*, 201-208. https://journal.gnest.org/sites/default/files/Journal%20Papers/201-208_553_Diapouli_10-2.pdf

Pekey, B., Bozkurt, Z.B., Pekay, H., Dogan, G., Zararsiz, A., Efe, N. & Tuncel G. (2010). Indoor/outdoor concentrations and elemental composition of PM_{10}/$PM_{2.5}$ in urban/industrial areas of Kocaeli City, Turkey, *Indoor Air*, *20,* 112-125. https://doi.org/10.1111/j.1600-0668.2009.00628.x

Radović, B., Tasić, V., Kovačević, R., Apostolovski-Trujić, T., Manojlović, D., Cocić, M., & Urošević, T. (2024). Chemical composition of PM_{10} in a classroom near the copper smelter in Bor, Serbia. *Atmosphere, 15*(8), 920. https://doi.org/10.3390/atmos15080920

Ramachandran, G., Adgate, J. L., Pratt, G. C., & Sexton, K. (2003). Characterizing indoor and outdoor 15-minute average $PM_{2.5}$ concentrations in urban neighborhoods. *Aerosol Science and Technology*, 37, 33–45. https://doi.org/10.1080/02786820300889

Serbula, S., Kalinovic, T., Kalinovic, J., & Ilic, A. (2013). Exceedance of air quality standards resulting from pyro-metallurgical reduction of copper: A case study, Bor (Eastern Serbia). *Environmental Earth Sciences, 68*(7), 1989–1998. https://doi.org/10.1007/s12665-012-1886-6

Tasić, V., Kovačević, R., Maluckov, B., Apostolovski-Trujić, T., Cocić, M., Matić, B., & Šteharnik, M. (2017). The content of As and heavy metals in TSP and PM_{10} near copper smelter in Bor, Serbia. *Water, Air, & Soil Pollution, 228*, 230. https://doi.org/10.1007/s11270-017-3393-6

Tasić, V., Kovačević, R., & Maluckov, B. (2013). Preliminary measurements of PM_{10} in apartments in Bor, Serbia. *In Proceedings of the 4th International WeBIOPATR Workshop & Conference Particulate Matter: Research and Management (WeBIOPATR2013)* (pp. 117–120). Belgrade, Serbia. ISBN 978-86-83069-40-8.

Tasić, V., Maluckov, B., Apostolovski-Trujić, T., Kovačević, R., Živković, M., & Lazović, I. (2015). Particulate Matter (PM_{10} and $PM_{2.5}$) Concentrations in Naturally Ventilated Offices in Bor, Serbia, *Facta Universitatis, Series: Working and Living Environmental Protection*, 12(3), 279-288. https://casopisi.junis.ni.ac.rs/index.php/FUWorkLivEnvProt/article/view/899/1054

Tasić, V., Milošević, N., Kovačević, R., Jovašević-Stojanović, M., & Dimitrijević, M. (2012). Indicative levels of PM in the ambient air in the surrounding villages of the copper smelter complex, Bor, Serbia. *Chemical Industry & Chemical Engineering Quarterly, 18*(4), 643–652. https://doi.org/10.2298/CICEQ111228109T

Tasić, V., Milošević, N., Kovačević, R., & Petrović, N. (2010). The analysis of air pollution caused by particle matter emission from the copper smelter complex Bor (Serbia). *Chemical Industry & Chemical Engineering Quarterly, 16*(3), 219–228. https://doi.org/10.2298/CICEQ090909011T

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ANALYSIS OF CO_2 EMISSIONS IN LONGITUDINAL MEDIUM TURNING OF 42CrMo4 STEEL

Abstract: *In the context of sustainable, eco-friendly machining, in addition to standard process performances, through which the suitability of selected parameters is assessed, analysis of the process environmental and sustainable performances is often considered. With this in mind the present study aims at analysing CO_2 emissions per volume of material removed in dry longitudinal single-pass medium turning of low-alloyed steel 42CrMo4 using a coated carbide cutting tool. Full factorial design was applied to arrange the main cutting parameters, i.e. depth of cut, feed rate and cutting speed, at three levels. For each experimental trial CO_2 emissions data were obtained using a tool and cutting data recommendation system of the cutting tool manufacturer (Walter GPS). The analysis of results involved the analysis of main, interaction and quadratic effects, determination of statistically significant effects and development of non-linear model for the prediction of CO_2 emissions per volume of material removed. In addition, the optimized cutting conditions for minimization of CO_2 emissions were determined.*

Keywords: turning, CO_2 emissions, full factorial design, 42CrMo4 steel, prediction

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INTRODUCTION

Sustainable, green and environmentally friendly manufacturing industry is a goal set by many production companies, regulatory authorities and regulations. Actually, it has been a major role player in the Industry 4.0 transformation (Gupta, 2020). The scientific society and manufacturing practice are constantly investigating the possibilities of incorporating circular economy models, improving energy efficiency and minimizing/eliminating any kind of waste to create a more environmentally friendly manufacturing industry (Barać et al., 2024; Stojković et al., 2022). To this end, investigation and application of machining technologies, as one of the most widely used manufacturing processes, in addition to the analysis of important process performances, technological and economic criteria, in recent times also considers different sustainable, green and environmental performances. Related to turning technology, several previous research studies have addressed these important aspects.

Somashekaraiah et al. (2016) formulated a green cutting fluid and compared its performance with the performance of common commercial cutting fluids used in machining. The formulation was found to be cost effective and stable, offering better machining capabilities. The best sustainable practices in machining regarding water consumption and cutting fluid usage were reviewed and analysed by Pervaiz et al. (2018). Kumar et al. (2022) made a review regarding the use of eco-friendly cutting fluids for sustainable machining.

Bousnina and Hamza (2020) performed an experimental investigation on the turning of 304L stainless steel with the aim to optimize cutting parameters to increase energy efficiency and minimize energy consumption. With the use of Taguchi method and ANOVA, Kumar et al. (2021) determined the optimal values of cutting parameters in finish turning of EN 353 alloy for maximization of energy efficiency. The optimization results were compared to those obtained with the use of RSM prediction model developed in terms of depth of cut, feed rate, cutting speed and tool nose radius. Park et al. (2016) performed bi-objective optimization of consumed cutting energy and energy efficiency in turning of hardened workpiece material. Response surface methodology (RSM) was used to model the relationships between parameters and considered process responses. A non-dominated sorting genetic algorithm was applied to determine a set of Pareto solutions, while the TOPSIS method was used to select the best compromise solution. Hassine et al. (2015) developed a multi-objective optimization model for sustainable rough turning operations. The model

considered three objective functions (production time, production cost and energy consumption), five process constraints and two independent variables (cutting speed and feed rate). The authors applied a metaheuristic algorithm, i.e. particle swarm optimization, to determine optimal cutting conditions. Bhanot et al. (2016) presented an overview of models and criteria that can be used for assessing the sustainability of the turning process. In addition, a social sustainability assessment framework was developed. Rajemi et al. (2010) proposed a model for determining economic tool life in order to minimize the energy footprint, i.e. energy cost and environmental footprint.

Ic et al. (2018) applied RSM to optimize process parameters (cutting speed, depth of cut and cutting tool material) in turning of three aluminium alloys to minimize carbon emissions and maximize machining quality. The multi-objective optimization results obtained using goal programming and the desirability function approach were compared. Yin et al. (2019) considered cost and carbon emissions in the turning process using a metric called profit per unit carbon emissions. The authors determined the set of machining parameters to maximize profit per unit carbon emissions using a genetic algorithm for two case studies and discussed the impacts of cutting parameters on carbon emissions. Cakir (2021) proposed a novel approach for carbon emissions minimization in turning. An experimental study in turning of DIN 1.2367 steel material showed that using harder cutting tools, lower feed rates, and higher depths of cut values at optimum cutting speed can result in lower carbon emissions. Jiang et al. (2021) developed a model for calculating carbon emissions in turning by considering energy consumption, resource depletion and waste generation. In addition to experimental validation, the authors analysed the effects of process parameters on carbon emissions.

Fernando et al. (2022) performed a life cycle assessment (LCA) to analyse the environmental performance in turning of AISI P20 under dry and wet cutting conditions. The authors observed that electrical energy was the most significant contributor, while the effect of cutting fluid was negligible. In addition, with the application of grey-based Taguchi method optimized cutting conditions were determined. Mia et al. (2019) performed LCA and multi-objective optimization of eco-friendly cryogenic N_2 assisted turning of Ti-6Al-4V. The authors concluded that there is a clear relation between cooling strategy and environmental aspects that directly affect the machining process.

As could be observed from literature review there is a greater number of empirical modelling and optimization studies related to LCA, carbon emissions, energy efficiency and use of sustainable cutting fluids in turning. This reflects the continual endeavour of researchers to explore sustainable, green and environmentally friendly strategies in the application of turning technology. With this in mind, the present study focuses on the analysis of CO_2 emissions per volume of material removed in medium turning of low-alloyed steel 42CrMo4. Analysis of the results involved determination of statistically significant effects, analysis of parameter effects, development of non-linear prediction model and identification of a stationary point that yields minimal CO_2 emissions per volume of material removed.

EXPERIMENTAL DATA

The start diameter for longitudinal single-pass turning was 60 mm, while the machined length was 50 mm. The workpiece material was low-alloyed steel 42CrMo4. The machine tool was the CNC lathe with the motor power of P_m = 25 kW, the maximum spindle speed of n_{max} = 3000 rpm and the maximum torque of M_{cmax} = 1100 Nm.

Walter was selected as the cutting tool manufacturer. The cutting tool was the Walter PCLNR3225P12 toolholder (cutting edge angle of κ = 95°, rake angle of γ_{oh} = -6°) with a Walter CNMG120408-MP5 WPP20G coated carbide insert for medium machining (cutting edge length of l = 12 mm, nose radius of r_ε = 0.8 mm and rake angle of γ_{oi} = 15°). Cutting parameter ranges and levels were selected considering the availability and capabilities of the tool and the cutting data recommendation system of the cutting tool manufacturer (Walter GPS) and recommended cutting conditions for the insert.

The experimental trials were conducted in accordance with the full factorial design. The main cutting parameters, i.e. depth of cut, feed rate and cutting speed, were arranged at three levels (Table 1).

Table 1. *Cutting parameter levels used in the experiment*

Parameter	Level 1	Level 2	Level 3
Depth of cut a_p [mm]	0.8	2.4	4
Feed rate f [mm/rev]	0.18	0.29	0.4
Cutting speed v [m/min]	240	269	298

Twenty-seven different combinations of factor levels were tried in the "virtual" experiment and CO_2 emissions per component (gCO_2) produced by machining operation and idle machine run were obtained using the tool and cutting data recommendation system of the cutting tool manufacturer (Walter GPS). For every experimental trial, CO_2 emissions per volume of material removed (gCO_2/cm^3) were calculated by dividing total CO_2 emissions per component by the volume of material removed.

RESULTS AND DISCUSSION

Statistical analysis of main, interaction and quadratic effects

Based on the applied design matrix and by using the obtained values of CO_2 emissions per volume of material removed, main, interaction and quadratic effects were estimated using RSM (Table 2).

Table 2. *Summary of estimated main, interaction and quadratic effects*

Term	Coefficient	T	p
Constant	0.87788	11.835	0.000
a_p	-0.97348	-28.350	0.000
f	-0.47180	-13.740	0.000
v	-0.11121	-3.239	0.005
$a_p \times a_p$	0.64307	10.812	0.000
$f \times f$	0.19139	3.218	0.005
$v \times v$	0.02209	0.371	0.715
$a_p \times f$	0.35401	8.418	0.000
$a_p \times v$	0.09182	2.183	0.043
$f \times v$	0.06282	1.494	0.154
$S = 0.146,$ $R^2 = 0.986, R^2_{adj} = 0.978, R^2_{pred} = 0.963$			

The analysis of the results indicates that all linear effects of cutting parameters are significant. In addition, small p-values of interaction and quadratic effects suggest the presence of curvature in the response surface. Among these, however, the quadratic effect of the cutting speed and the interaction effect of the feed rate and cutting speed are not statistically significant. Coefficient of determination (R^2) shows that 98.6% of the total variability of CO_2 emissions per volume of material removed is explained by main, interaction and quadratic effects. In addition, based on the predicted coefficient of determination (R^2_{pred}), one can expect that this model would be able to explain 96.3% of the variability in predicting new cutting regimes, with arbitrarily chosen values of depth of cut, feed rate and cutting speed.

ANOVA

In order to validate the appropriateness and predictive capability of the quadratic model, ANOVA was performed, as given in Table 3. ANOVA of the quadratic model indicates that all model terms (linear, interaction and quadratic) are significant as indicated by the Fischer's F-test and zero probability values (p-values = 0.000).

Table 3. *Analysis of variance for the CO_2 emissions per volume of material removed data*

Source of variation	Sum of squares	Degree of freedom	Mean square	F	p
Second order model	25.6435	9	2.8493	134.25	0.000
linear	21.2871	3	7.0957	334.32	0.000
interaction	1.6524	3	0.5508	25.95	0.000
quadratic	2.704	3	0.9013	42.47	0.000
Residual error	0.3608	17	0.02122		
Total	26.0043	26			

Non-linear prediction model

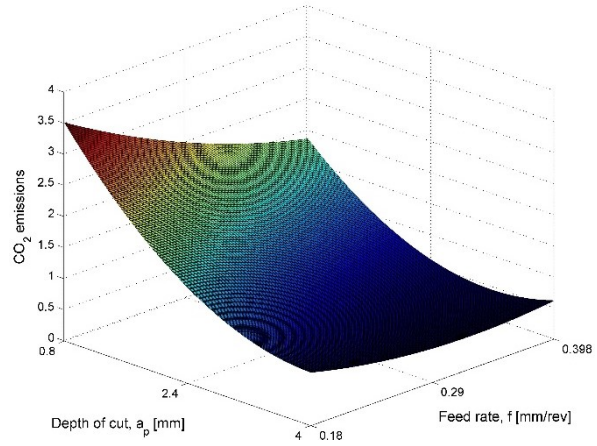
Based on previous analyses, the response variable, i.e. CO_2 emissions per volume of material removed, was modelled with the full quadratic model in order to take into account main, interaction and quadratic effects of the depth of cut, feed rate and cutting speed. The coded form of the CO_2 emissions per volume of material removed data prediction model is as follows:

$$CO_2\ emissions = 0.8778 - 0.9735x_1 - 0.4718x_2 - 0.1112x_3 + 0.6431x_1^2 + 0.1914x_2^2 + 0.0221x_3^2 + 0.354x_1x_1 + 0.0918x_1x_3 + 0.0628x_2x_3\ , \quad (1)$$

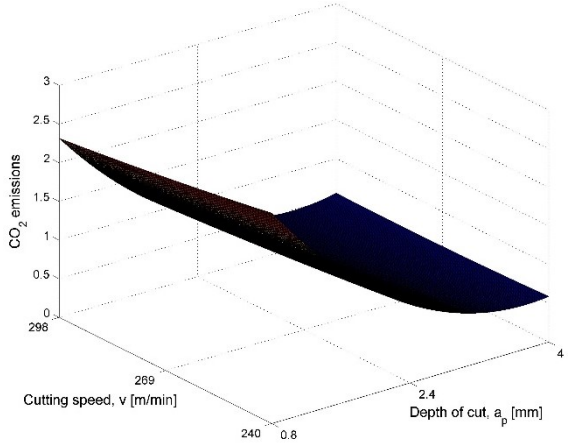
where the coded variables x_1, x_2 and x_3 represent depth of cut (a_p), feed rate (f) and cutting speed (v), respectively.

Analysis of parameter effects

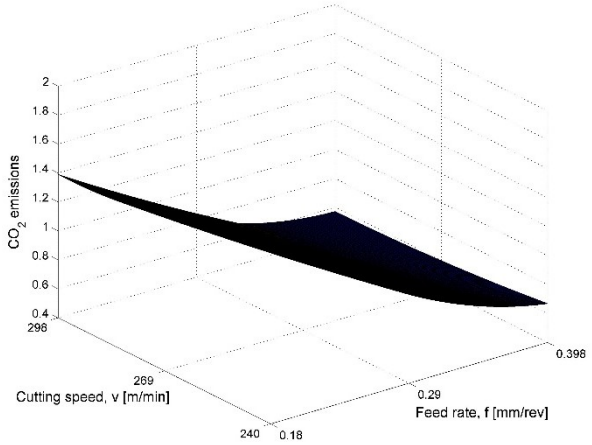
The derived RSM model was further visualized by developing surface plots (Figure 1), allowing the detailed analysis of the main and two-way interaction effects of cutting parameters on the CO_2 emissions per volume of material removed.



a) v = 269 m/min



b) f = 0.29 mm/rev



c) a_p = 2.4 mm

Figure 1. *Response surface plots presenting the dependence of CO_2 emissions per volume of material removed with respect to two-factorial interactions*

As shown in Figure 1, increasing the value of any cutting parameter leads to a decrease in CO_2 emissions per volume of material removed. However, the depth of cut has the most significant effect, followed by the feed rate and the cutting speed. The clearly visible patterns of developed surface plots suggest a nonlinear nature of the effects of the depth of cut and feed rate, which is in accordance with the previously performed analysis that showed statistically significant quadratic effects of the depth of cut and feed rate. In the case of cutting speed, the observed dependence is approximately linear.

The existence of interaction effects and qualitative change in the parameter effects can be observed in Figure 1a). Namely, for small depths of cuts, an increase in feed rate non-linearly significantly decreases CO_2 emissions per volume of material removed. For intermediate and high values of the depth of cut, an increase in feed rate also decreases CO_2 emissions per volume of material removed, wherein that decrease is much smaller in a quantitative sense, and it is realized according to a pattern with much less curvature. Moreover, there is a qualitative change in the effect of the feed rate at the highest depth of cut. As could be observed, for the highest depth of cut, an increase in feed rate up to 0.33 mm/rev decreases CO_2 emissions per volume of material removed. However, further increase in feed rate values results in a slight increase in CO_2 emissions per volume of material removed. Finally, it should be noted that, taking into account the previously observed statistical significance of two-factorial interaction effects, related specifically to the effect of the depth of cut, this does not mean that there are no other significant qualitative changes within the covered experimental hyper-space regarding two-factorial interaction effects for other parameter values that are kept constant.

Process optimization

Since the CO_2 emissions per volume of material removed is accurately modelled by the second-order model, it is necessary to determine the optimum settings. Optimization of control parameters in machining is necessary to achieve appropriate efficiency and quality (Kawecka, 2024). In the present study, the optimum setting corresponds to the combination of cutting parameter values that result in minimal CO_2 emissions per volume of material removed. Because of higher dimensionality and possible interaction effects, it is not convenient to locate optimum settings using surface or contour plots, but it is necessary to apply more efficient procedures to determine, if it exists, an optimum point, i.e. a stationary point. The stationary point, representing maximum or minimum response or a saddle point, can be found using matrix algebra. The most straightforward way to determine the nature of the stationary point is the construction of contour plots, or a more formal, or canonical, analysis (Montgomery, 2017).

The stationary point in terms of the natural values of variables was obtained as: depth of cut a_p = 3.27 mm, feed rate f = 0.361 mm/rev and cutting speed v = 282 m/min. Based on these values and using variable transformations, one can estimate the minimum response, i.e., CO_2 emissions per volume of material removed at the stationary point, with the value of 0.433 gCO_2/cm^3. The nature of the response surface can be verified from Figure 2.

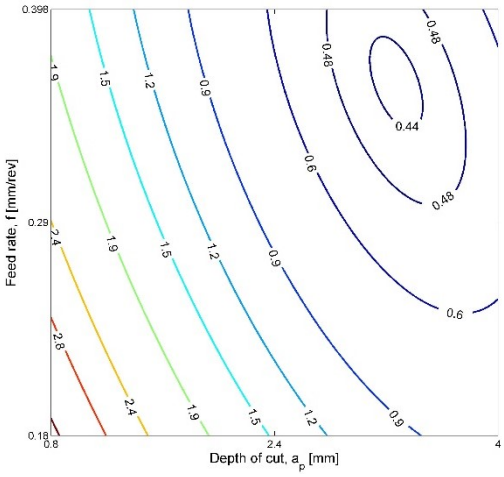


Figure 2. *Contour plot showing the stationary point*

From Figure 2, it could be verified that within the region of exploration, the stationary point is a minimum. Finally, it should be noted that the identified optimum has a response value, i.e. CO_2 emissions per volume of material removed, lower than any of the design points used in the experimental design for model development.

CONCLUSION

The present study dealt with the analysis of CO_2 emissions per volume of material removed in dry longitudinal medium turning of low-alloyed steel 42CrMo4. Based on the conducted analyses and obtained results, the following conclusions can be drawn:

- For the covered experimental hyper-space, CO_2 emissions per volume of material removed are mostly affected by the depth of cut, followed by feed rate and cutting speed.
- All main effects of the depth of cut, feed rate and cutting speed were found to be statistically significant, along with depth of cut interaction effects, as well as quadratic effects of the depth of cut and feed rate.
- Generally, there exists an indirect relationship between CO_2 emissions per volume of material removed and cutting parameters, i.e. increasing either depth of cut, feed rate or cutting speed results in a decrease in CO_2 emissions per volume of material removed.
- By identification of the stationary point, the optimized cutting conditions for minimization of CO_2 emissions were determined as: depth of cut a_p = 3.27 mm, feed rate f = 0.361 mm/rev and cutting speed v = 282 m/min. It may be argued that for a given cutting speed, there exists a particular combination of depth of cut and feed rate that yields minimal CO_2 emissions per volume of material removed.

The RSM model developed in the present study can be used in the formulation of the turning optimization problem while considering other important performances related to quality and cost, as well as process constraints related to technological limitations of machine tools.

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REFERENCES

Barać, M., Vitković, N., Stanković, Z., Rajić, M., & Turudija, R. (2024). Description and Utilization of an Educational Platform for Clean Production in Mechanical Engineering. *Spectrum of Mechanical Engineering and Operational Research*, 1(1), 145-158. https://doi.org/10.31181/smeor11202413

Bhanot, N., Rao, P.V., & Deshmukh, S.G. (2016). An Assessment of Sustainability for Turning Process in an Automobile Firm. *Procedia CIRP*, 48, 538-543. https://doi.org/10.1016/j.procir.2016.03.024

Bousnina, K., & Hamza, A. (2020). Reducing the energy consumed and increasing energy efficiency in the turning process. *International Journal of Modern Manufacturing Technologies*, 12(2), 23-28.

Cakir, A.K (2021). A new approach to minimize carbon emission rate in turning processes. International Journal of Low-Carbon Technologies, 16(4), 1444-1452. https://doi.org/10.1093/ijlct/ctab058

Fernando, R., Gamage, J., & Karunathilake, H. (2022). Sustainable machining: environmental performance analysis of turning. *International Journal of Sustainable Engineering*, 15(1), 15-34. https://doi.org/10.1080/19397038.2021.1995524

Gupta, K. (2020). A Review on Green Machining Techniques. *Procedia Manufacturing*, 51, 1730-1736. https://doi.org/10.1016/j.promfg.2020.10.241

Hassine, H., Barkallah, M., Bellacicco, A., Louati, J., Riviere, A., & Haddar, M. (2015). Multi Objective Optimization for Sustainable Manufacturing, Application in Turning. *International Journal of Simulation Modelling*, 14(1), 98-109. https://doi.org/10.2507/IJSIMM14(1)9.292

Ic, Y.T., Saraloğlu Güler, E., Cabbaroğlu, C., Dilan Yüksel, E., & Maide Sağlam, H. (2018). Optimisation of cutting parameters for minimizing carbon emission and maximising cutting quality in turning process. *International Journal of Production Research*, 56(11), 4035-4055. https://doi.org/10.1080/00207543.2018.1442949

Jiang, Z., Gao, D., Lu, Y., Kong, L., & Shang, Z. (2021). Quantitative Analysis of Carbon Emissions in Precision Turning Processes and Industrial Case Study. *International Journal of Precision Engineering and Manufacturing-Green Technology*, 8(1), 205-216. https://doi.org/10.1007/s40684-019-00155-9

Kawecka, E., Perec, A., & Radomska-Zalas, A. (2024). Use of the Simple Multicriteria Decision-Making (MCDM) Method for Optimization of the High-Alloy Steel Cutting Process by the Abrasive Water Jet. *Spectrum of Mechanical Engineering and Operational Research*, 1(1), 111-120. https://doi.org/10.31181/smeor11202411

Kumar, P., Jain, A.K., Chaurasiya, P.K., Tiwari, D., Gopalan, A., Arockia Dhanraj, J., Solomon, J.M., Sivakumar, A., Velmurugan, K., & Fefeh Rushman, J. (2022). Sustainable Machining Using Eco-Friendly Cutting Fluids: A Review. *Advances in Materials Science and Engineering*, 2022, Article ID: 5284471, 16 pages. https://doi.org/10.1155/2022/5284471

Kumar, R., Bilga, P.S., & Singh, S. (2021). An Investigation of Energy Efficiency in Finish Turning of EN 353 Alloy Steel. *Procedia CIRP*, 98, 654-659. https://doi.org/10.1016/j.procir.2021.01.170

Mia, M., Gupta, M.K., Lozano, J.A., Carou, D., Pimenov, D.Y., Królczyk, G., Khan, A.M., & Dhar, N.R. (2019). Multi-objective optimization and life cycle assessment of eco-

friendly cryogenic N2 assisted turning of Ti-6Al-4V. *Journal of Cleaner Production*, 210, 121-133. https://doi.org/10.1016/j.jclepro.2018.10.334

Montgomery, D.C. (2017). *Design and Analysis of Experiments (9th ed.)*. John Wiley & Sons.

Park, H.S., Nguyen, T.T., & Dang, X.P. (2016). Multi-Objective Optimization of Turning Process of Hardened Material for Energy Efficiency. *International Journal of Precision Engineering and Manufacturing*, 17(12), 1623-1631. https://doi.org/10.1007/s12541-016-0188-4

Pervaiz, S., Kannan, S., & Kishawy, H.A. (2018). An extensive review of the water consumption and cutting fluid based sustainability concerns in the metal cutting sector. *Journal of Cleaner Production*, 197, Part 1, 134-153. https://doi.org/10.1016/j.jclepro.2018.06.190

Rajemi, M.F., Mativenga, P.T., & Aramcharoen, A. (2010). Sustainable machining: selection of optimum turning conditions based on minimum energy considerations. *Journal of Cleaner Production*, 18(10-11), 1059-1065. https://doi.org/10.1016/j.jclepro.2010.01.025

Somashekaraiah, R., Suvin, P.S., Gnanadhas, D.P., Kailas, S.V., & Chakravortty, D. (2016). Eco-Friendly, Non-Toxic Cutting Fluid for Sustainable Manufacturing and Machining Processes. *Tribology Online*, 11(5), 556-567. https://doi.org/10.2474/trol.11.556

Stojković, M., Madić, M., Trifunović, M., & Turudija, R. (2022). Determining the Optimal Cutting Parameters for Required Productivity for the Case of Rough External Turning of AISI 1045 Steel with Minimal Energy Consumption. *Metals*, 12(11), Article ID: 1793, 23 pages. https://doi.org/10.3390/met12111793

Walter (2025). *Walter GPS*. https://www.walter-tools.com/en-gb/gps

Yin, R., Ke, J., Mendis, G., & Sutherland, J.W. (2019). A cutting parameter-based model for cost and carbon emission optimisation in a NC turning process. *International Journal of Computer Integrated Manufacturing*, 32(10), 919-935. https://doi.org/10.1080/0951192X.2019.1667026

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NOISE AND SILICA DUST AS KEY RISK FACTORS DURING EARTHWORKS AT CONSTRUCTION SITES

Abstract: *Construction sites involve different activities and operations, each contributing to various forms of pollution that elevate mortality rates and give rise to different occupational diseases. Earthworks include operations such as excavation, digging, and demolition, which generate high noise and silica dust. This research focuses on two key risk factors of every construction site – noise and silica. The aim of this research has a twofold effect: (1) to show measured levels of noise during earthworks with both a sound level meter (SLM) and a personal dosimeter, to establish how noise impacts the possibility of communication through communication devices, and to determine the negative impact of noise on human health with a recommendation of preventive measures; (2) to show that silica dust is a causative agent of serious respiratory diseases – such as silicosis, autoimmune disorders, infections, and other lung diseases – during the earthwork construction phase, using measured quantities from various studies, and to propose preventive measures that should be implemented. To lower the risk of noise and silica dust, it is necessary to represent their risk on a global level, with the intention to reduce worker exposure and prevent diseases like occupational hearing loss and silicosis through different research and innovation models.*

Keywords: noise, dust, construction site, occupational hearing loss, silicosis

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INTRODUCTION

Every unpleasant and unwanted sound is defined as a noise – a significant pollutant (Samardžić, 2021; Anees et al., 2017) that can lead to hearing loss, high blood pressure, and other related symptoms (irritability, stress, anxiety, insomnia, reduced cognitive abilities, etc.) (Jain et al., 2016). Construction sites are a source of noise, where different construction machinery, tools, and operations can lead to high levels of noise (Mučenski, 2018) exceeding the permissible noise level – above 85 dB (Ministarstvo za rad, zapošljavanje, boračka i socijalna pitanja, 2019). Workers who manipulate construction machinery for earthworks, such as excavators, bulldozers, and loaders are exposed to high noise levels (usually between 97-107 dB, according to OSHA (2012)) and there is a possibility of hearing loss (Kantová, 2017; Movahed and Ravanshadnia, 2022). The noise level mostly depends on the type and complexity of the task (Movahed and Ravanshadnia, 2022). To ensure better management of noise on construction sites, measurement of noise levels generated by different machinery is a fundamental step in identifying potential sources of excessive noise, alongside a comprehensive analysis of noise sources, machinery, processes, and human activity and the application of adequate preventive measures.

In addition to noise exposure, exposure to chemical hazards such as dust at construction sites poses an everyday problem that has a negative impact on workers' health. The air present on construction sites and in the production of building materials contains high levels of these harmful chemical substances (OSHA, 2012). Construction sites represent one of the primary sources of air pollution, where dust is mostly of natural origin, e.g. silicate dust, wood dust, and low-toxicity dust generated from materials such as gypsum, limestone, marble, and dolomite (Mučenski, 2018). The problem occurs when free crystalline silica appears in the air of a construction site, because once inhaled, it causes various diseases, of which silicosis is the most common (Keramydas et al., 2020). Excavation, drilling, rock processing, tunnelling, demolition of buildings, and cutting of brick, concrete, and granite tiles are activities with the highest exposure to dust, where silica dust is present (HSE UK, 2020). Exposure to silica dust is a growing worldwide problem responsible for the largest cases of silicosis across Asia, Africa, and South America (Hoy et al., 2022). In addition, more than 5.5 million workers are exposed to silica dust in the European Union, 1.7 million in the USA, and 350,000 in Canada (Wiebert et al., 2023; Sauvé et al., 2013), which significantly increases the risk of mortality (Requena-Mullor et al., 2021). Through the

implementation of suitable preventive measures, such as measuring the exposure to silica dust, using water sprays and ventilation of containment structures, and using personal protective equipment (PPE), it is possible to minimize the negative effect of silica dust on the human body (OSHA, 2012).

To lower the risk of noise and silica dust, it is necessary to represent their risk on a global level, to reduce worker exposure, and prevent diseases like occupational hearing loss and silicosis, through different research and innovation models.

The aim of this research has a twofold effect: (1) to show the noise levels recorded during earthworks using a sound level meter (SLM) and a personal dosimeter, and additionally to establish the detrimental effects of noise on human health, to determine how noise interferes with communication through communication devices, and to suggest preventive measures; (2) to demonstrate that exposure to silica dust during the earthwork construction phase contributes to serious respiratory conditions – including silicosis, autoimmune disorders, infections, and other lung diseases – based on data from multiple studies, and to recommend appropriate preventive measures.

OCCUPATIONAL NOISE IN EARTHWORKS

Noise measurement results and preventive measures in earthworks

Through revising documentation on occupational environmental assessments, noise measurements are mostly conducted in industrial settings, and such insight indicates the existence of a gap in noise measurement assessments within the construction sector. Therefore, since construction sites are recognized as the source of noise (Mučenski, 2018), there is a need to implement the measurement of noise on construction sites with both an SLM and a personal dosimeter.

With the intention to assess noise exposure of excavator operators who performed earthworks, with both newer and old excavators, previous research (Kužet et al., 2024a, Kužet et al., 2024b) was designed to capture real working conditions and actual noise exposure. By applying combined measurements, both with an SLM and a personal noise dosimeter, a holistic assessment was obtained. Measurements conducted by the SLM were taken for 15 minutes, depending on the process and fieldwork conditions, but long enough to capture all the changes in the observed operational process. Personal dosimeter measurements were taken over the entire duration of the shift (8-hour shift) to measure the operators' exposure at their exact location and for their particular behaviour.

Results of measured equivalent continuous noise level – L_{eq} (Kužet et al., 2024a) showed that:

- noise level during the operation of loading soil material into the truck was between L_{Aeq} = 69.9-75.3 dB;
- noise level during the excavation operation was between L_{Aeq} = 65.8-85.4 dB; and
- noise level in idle operation was between L_{Aeq} = 70.9-81.3 dB.

Based on the results, the measured noise levels ranged between 65.8 to 85.4 dB. Although the peak value was marginally higher than 85 dB, this does not necessarily mean that the allowable daily noise exposure limit of 85 dB was exceeded (Ministarstvo za rad, 2019). Also, 65.8 dB during the same operation was measured on the newer model of excavator and explained as a good example of regular maintenance, service, and design of the machine. Regardless of the fact that the measured values were mostly below the exposure noise level, further analysis of noise measurements showed that there was difficulty to communicate through communication devices. In 81.25% of the cases, communication was difficult, and in the remaining 18.75%, the possibility of communication using communication devices was unsatisfactory because it exceeded L_{Aeq} = 75 dB. This finding is consistent with data from the European Community, where it was determined that one in five workers in Europe has to raise their voice for more than half of the working time to be heard by other workers, while 7% of workers suffer from health problems caused by noise.

Personal dosimeter measurements (Kužet et al., 2024b) showed that throughout the 8-hour work shift, there were values exceeding 85 dB and 90 dB and that measured values of noise varied between L_{Aeq} = 85 and 95 dB, with the highest value for L_{Aeq} of 94.7 dB, which is 9.7 dB higher than the exposure noise level of 85 dB. Also, a very high value of C-weighted Peak Sound Level (L_{Cpeak}) was recorded during the measurement, indicating the existence of high-value periodic or impulsive noise that requires hearing protection at work. In the end, the dose value suggests that during 20% of the workday, the operator of the excavator is exposed to disturbing noise. Figure 1 shows recorded levels of noise when the operator was simultaneously excavating and loading soil material, where the average LA_{eq} value was 89.2 dB, and L_{Cpeak} was 143.1 dB.

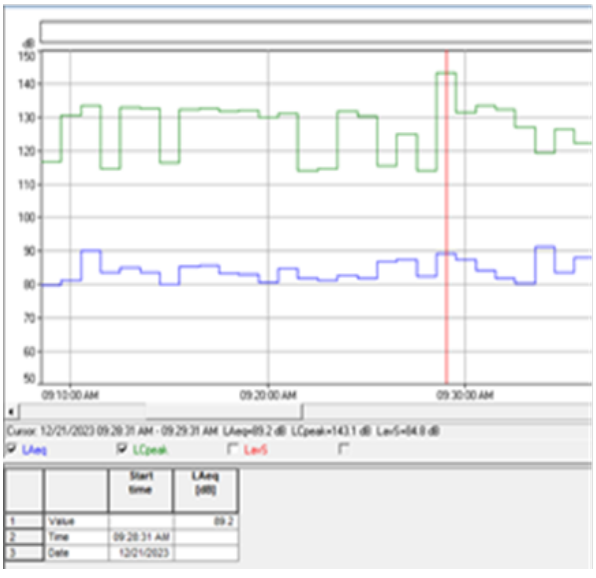


Figure 1. *Partial personal dosimeter readings for an eight-hour working shift (source: Kužet 2024b)*

The results of the overall measurements show that if the excavator operator was exposed to noise greater than 80 dB at certain moments during the measurement, it means that exposure to high noise levels during working hours is guaranteed and that appropriate protection measures must be taken. According to the Rulebook on preventive measures for safe and healthy work during noise exposure (Ministarstvo za rad, 2019), when daily noise exposure level for an 8-hour working shift exceeds the upper exposure action value of 83 dB, the worker must wear personal protective equipment or employers must pause work and organize working hours differently. To improve the current protection system, which includes: work breaks, organization of working hours, employee training, use of personal protective equipment, and regular maintenance of heavy construction machines (OSHA, 2012; European Agency for Safety and Health at Work, 2004), it is necessary to introduce mandatory noise measurements at construction sites.

When measuring, preference should be given to the use of a personal dosimeter, due to the collection of precise data on the actual exposure of workers to noise. In this way, it would ensure not only the monitoring of workers' exposure to high noise levels during working hours and a better definition of preventive measures and work organization, but it would also make it possible to prevent related diseases and illnesses from exposure to high noise levels in time, during which the prevention of hearing loss would be of key importance.

Negative effects of noise on human health

Exposure to loud noise causes different morphological and physiological alterations in the human body. In the auditory system, it lowers the levels of necessary enzymes in the cochlear fluid and causes structural damage to the stereocilia, which are fine hair-like structures responsible for the transmission of sound. Besides that, noise exposure also causes hypertension and mental health disturbances. Moreover, Xue (2018) states that genetic factors account for more than half of hearing impairments present since birth or early childhood.

The impact of noise on the human body is manifested in two ways – acute and chronic traumas. Acute trauma happens when the operator is exposed to a very high noise level for a very short time, and can cause mechanical damage to the eardrum and auditory ossicles. Chronic trauma happens when the operator is exposed to a high noise level, but exposure is prolonged and can cause damage to sensory cell sensors. Both acute and chronic trauma can lead to deafness, hearing loss, progressive hearing loss, and total hearing loss. Damage and loss of hearing are most often caused by damage to cells, nerves, and the entire structure inside the ear (OSHA, 2012).

A perfect example of the negative impact of noise on human health is the paralysis of fine hairs inside the inner ear due to excessive noise, which can cause immediate hearing loss, and prolonged exposure to this level of noise can destroy them. Figure 2 shows what happens during prolonged exposure to high noise levels – in the inner ear of the spiral curve of the cochlea, there is a complete loss of hairs and their accompanying nerve fibres, which results in irreversible damage of hair cells (Sripaiboonkij et al., 2013).

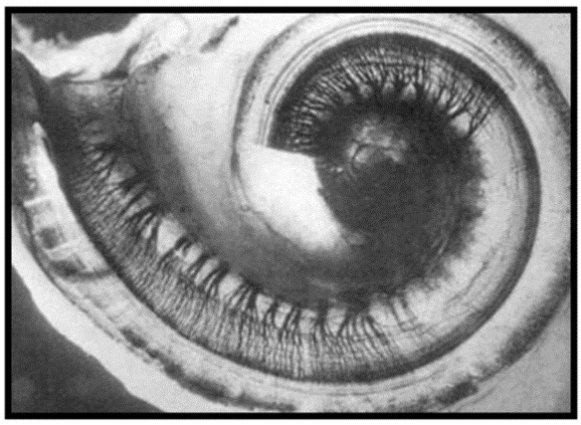


Figure 2. *Cochlear damage (source: https://nap.nationalacademies.org/read/18593/chapter/26#295)*

The most common damage that occurs due to noise exposure is tinnitus – a ringing in the ears. Tinnitus is not characterized as a disease but as a symptom of something wrong. People who are exposed to high noise levels (e.g. construction workers) may develop tinnitus over time due to damage to the sensory cells in the inner ear (OSHA, 2012).

It has been established that noise is one of the causes of cardiovascular problems; it promotes the risk factors of coronary diseases and disturbs the work of the heart, and the changes are easily observed on the electrocardiogram. Fritschi et al. (2011) concluded that a noise level of 55 dB is enough to cause stress in a person. Upward of that, a noise level of 65 dB causes cardiovascular disorders, a noise level of 70 dB leads to hypertension, a noise level of 70 dB causes heart disorders, and a noise level of 80 dB leads to hearing loss. Diseases of the endocrine, gastrointestinal, peripheral, and central nervous system caused by increased noise can be easily determined by biochemical analysis.

Pahlavan and Arouss (2016) confirmed that the impact of noise on humans is reflected in aggressive behaviour, and exposure can lead to an increase in excitement, which is a trigger for various negative health effects, primarily stress. Stress itself causes immediately visible effects, such as emotional reactions or physiological changes, which significantly affect social and psychological behaviour (Gross, 1998). It has been concluded that the direct link between noise-induced suffering, depression, migraines, and aggression is based on biochemical processes related to hormones and neurotransmitters, due to the release of large amounts of hormones such as adrenaline, cortisol, and noradrenaline, which are associated with depression and aggression (Ramirez, 2006).

Noise has a negative effect on a person's biorhythm – sleep issues, insomnia, waking up during the night, and influence on the Rapid Eye Movement (REM) phase

during sleep. Anees et al. (2017) determined through research that 30 dB is enough to disrupt sleep.

OCCUPATIONAL EXPOSURE TO SILICA DUST

According to OSHA (2012), silica dust is a chemical substance that acts as a pollutant in the construction site air and affects people's health in different ways, whether as a simple irritation or a serious illness. The origin of silica is natural, but it still poses a danger to the respiratory system and human health, which can lead to a serious disease called silicosis (Mučenski, 2018). The highest concentrations of silica dust are mostly found during excavation, drilling, rock processing, tunnelling, demolition of buildings, cutting and processing of concrete, brick, ceramic and granite tiles, etc. (HSE UK, 2020).

Two high-quality sources (Luo et al., 2021; Bello et al., 2019) provide essential data about the measurement approaches and exposure levels that occur when staff perform earthwork duties because directly relevant research on silica dust exposure at construction sites is lacking. Through different monitoring technologies and construction site working conditions, these studies provide important information about workplace hazards in Table 1.

Table 1. *Measurement approaches and exposure levels of silica dust during earthworks*

Study	Measurement Method	Context/Job tasks	Silica Dust Concentration
Luo et al. (2021)	Optical laser – scattering detectors (PC-3B, PH-YC01); 15-min intervals	Earthwork phase – excavator drivers, truck drivers, site commanders	Up to **9.635 mg/m³** (excavator driver); others: 0.2–6.7 mg/m³
Bello et al. (2018)	Gravimetric sampling + FT-IR (NIOSH Method 7602)	Crushing machine tenders processing excavated material	GM: **93.3 µg/m³**; max: **239 µg/m³**; 50% of samples exceeded OSHA PEL of 50 µg/m³

The measured values of silica dust during earthworks depend on operation – the excavator and truck operator experienced the highest average dust concentrations (almost 9.6 mg/m³ at some point of measurement) that exceed the permissible exposure limit (PEL) of silica dust. It was noticed that the level of dust near the excavation site, where the intensity of work was at its highest point, can reach about 130 mg/m³, while workers who were located further from the source tended to encounter lower dust concentrations (Luo et al., 2021). Bello et al. (2018) revealed that 50% of samples collected from the crushing machine during measurements of silica dust exceeded the OSHA PEL of 50 µg/m³, with a geometric mean of respirable crystalline silica (RCS) 93.3 µg/m³, and the highest concentration of 239 µg/m³. (Bello et al., 2019).

While RCS is the fine, inhalable fraction that can penetrate deeply into the lungs and have major health effects, silica dust is the general term for airborne particles from materials containing silica. RCS is contained in silica dust, has no colour and smell, is non-irritating, and does not cause immediate health effects. When small particles of silica dust (less than 5 µm in diameter) are inhaled, they travel to the lower part of the lungs and usually form scars (Requena-Mullor et al., 2021; Xiao and Li, 2023). Since silica dust is a chemical substance that can have a toxic effect on human health, this effect is divided into two categories: acute and chronic. Acute signs happen quickly and after high exposure, whereas chronic signs develop more slowly, over a longer period. Both types of effects can cause different diseases, where the main disease is silicosis. In addition, it is important to highlight that silica dust can also have systemic health effects, where a substance like silica penetrates target organs (such as lungs), accumulates, and exerts its negative effects (OSHA, 2012). Long-term exposure (15 to 20 years) to medium and low concentrations can lead to diseases of the respiratory system, namely bronchitis, silicosis, and cancer. Due to the large amounts of silica dust deposited in the workers' lungs, their immunity weakens and thus they become more susceptible to diseases such as tuberculosis. As a result, workers may exhibit one or more of the following symptoms: shortness of breath during physical exertion, severe coughing, fatigue, loss of appetite, chest pain, and fever. Also, Hoy and Chambers (2020) determined that acute silicosis exhibits significant differences compared to chronic silicosis. Acute silicosis is caused by a very high level of exposure to silica dust over several weeks to 5 years. It is typical for workers who carry out sandblasting, those who work in tunnels, and those who process silica flour. It presents as a progressive condition with nonspecific symptoms, including dyspnoea, cough, fatigue, weight loss, fever, and pleuritic pain. Disease progression can be rapid, and there is a high mortality rate.

Overall, exposed workers might not suffer directly from silicosis, but rather from groups of associated diseases (Kreuzer et al., 2013), such as

- cardiovascular diseases;
- sarcoidosis;
- pulmonary tuberculosis;
- lung infections;
- chronic obstructive disease;
- certain types of tumours;
- lung cancer;
- autoimmune diseases;
- kidney disorders,

whereby it is important to highlight that an increased risk of mortality is observed in workers who smoke cigarettes (Wang et al., 2020). It is important to

emphasize that one of the main causes of mortality and increased mortality of workers exposed to silica dust is the development of Mycobacterium tuberculosis (TB) infection (Barboza et al., 2008). TB rates are extremely high in workers exposed to silica dust in regions with high base rates of TB and HIV. TB infection is associated with an increased risk of progression of silicosis and severity of the disease. The effects of TB are also exacerbated by HIV infection and smoking, which often coexist, especially in developing countries, like South Africa (Rees and Murray, 2007; Leung et al., 2012). Also, Rees and Murray (2007) concluded that exposure to silica dust increases the risk of tuberculosis, even without silicosis, and continues after exposure has stopped.

The cure for silicosis does not exist (Requena-Mullor et al., 2021; OSHA, 2012), and the way to determine if a worker has silicosis is to conduct a complete medical examination, which contains a complete work history, an X-ray of the chest, and a lung function test. The X-ray test is significant for diagnosing chronic silicosis since it can be unnoticed in the early stages and seen on an X-ray after 15-20 years of exposure. The importance of chest X-rays was confirmed by Keramydas et al. (2020).

Keramydas et al. (2020) presented a study where 86 construction workers were exposed to silica dust in underground construction works – underground excavation and tunnelling. They recorded low exposure to silica dust (0.0125 mg/m^3) among workers, but also discovered interesting information that during the lung X-ray examination, 5 employees (7.2%) were diagnosed with a specific finding, and 12 employees (17.4%) had non-specific findings. As a suspicious enlargement of the right hilum was observed in one X-ray finding of the lung, a CT scan of the lung confirmed the presence of a right hilar tumour.

According to laws and regulations, the risk from silica dust must be estimated through risk assessment, risk control, and review of the list of preventive measures. Preventive measures against silica dust can be divided into:

- Engineering – of which water curtains and tool extraction systems are best-known, and
- Administrative – breaks during work, training of employees, limiting the number of people who work with silica dust, ventilation, proper choice of PPE, etc.

If used correctly, with delivering sufficient amounts of water to appropriate places during the entire time the work is being performed, water curtains are a good choice to be used as a preventive measure against silica dust on construction sites (Figure 3). Also, the tool extraction system removes the dust while it is being produced, and it is placed directly on the tool (Figure 4). Considering that water curtains or tool extraction systems are not always applicable, adequate use of respiratory PPE represents a last-resort preventive measure, intended to lower exposure to silica dust (Figure 5).



Figure 3. *Use of water curtains during excavation (source: https://www.instagram.com/p/DF-sMSfS34x/)*

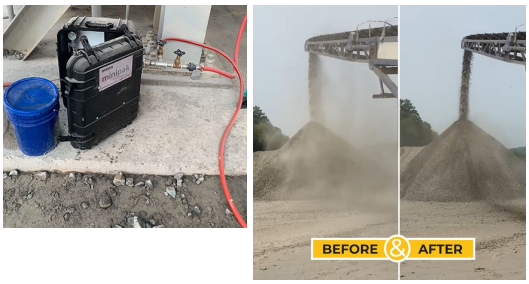


Figure 4. *Using a dust suppression system (left) and results of implementation (right) (source: https://benetechglobal.com/products/minipak-dust-suppression-system/)*

Respiratory PPE must be adequate and comfortable for work, with the assigned protection factor (APF) for the construction industry – 20, which means that the user inhales only 1/20 of the total amount of dust in the air. Respiratory PPE must adhere to the face, be compatible with other PPE, and be worn in the proper way (OSHA, 2012).



Figure 5. *An example of respiratory PPE for construction workers (source: https://i0.wp.com/www.safetysuppliesunlimited.net/wp-content/uploads/2020/02/respirator-safety.png?fit=895%2C545&ssl=1)*

In addition to that, since PPE is one of the easiest ways to protect from silica dust, the situation on construction sites shows a weak system of using PPE. Pérez-Alonso et al. (2014) noticed that in most cases PPE is not provided, or if PPE is provided, workers do not know how to use it properly.

Workplace protocols that decrease silica dust exposure involve task organization and personnel training as administrative safeguards. The organization reduces the number of workers in the area and implements personnel rotation while using barriers to separate workstations, providing general mechanical ventilation, and selecting appropriate dust-free clothing. Training of employees is the most important administrative

measure, which should be focused on understanding silica dust hazards and the proper use of PPE. The effectiveness of these measures must be followed through control of work procedures, measurement of exposure to the silica dust, regular maintenance of equipment, and health surveillance.

Health surveillance of exposed workers is widely recommended and usually includes a periodic health questionnaire, physical examination, lung function measurements, and a chest X-ray. After diagnosis of silica dust-related disease, cessation of further exposure is recommended (Rees and Silica, 2017).

Therefore, the measurements for silica dust on construction sites should be taken into account as a normal part of an examination of working conditions. This fact is supported by Hoy and Chambers (2020). When available, regular measurements of ambient silica levels are essential to ensure compliance with regulatory limits and to make control effective and productive. Respirators should not be the primary means of protection for employees but should be used only after more effective control measures, such as elimination, replacement, and venting.

CONCLUSION

Dual occupational hazards of noise and silica dust exposure during earthworks on construction sites are highlighted in this research, showing that noise levels and silica dust significantly varied. Measured with both an SLM and a personal dosimeter, noise levels were almost always above the exposure noise level of 85 dB. The excavation phase was the loudest, whereby a personal dosimeter measured an equivalent noise level of L_{Aeq} = 94.7 dB, and a very high value of L_{Cpeak} – 143.1 dB, indicating the risk of deafness, difficulty in communication, and stress among the construction workers during earthworks phase. Simultaneously, measured concentrations of RCS during earthworks where maximum levels were above 239 μg/m³ exceeded the permissible limits set by OSHA (50 μg/m³).

The occurrence of these hazards significantly increases the overall risk exposure for construction workers. Noise exposure leads to hearing loss and affects communication between workers, while on the other hand, silica dust precedes irreversible health conditions, such as silicosis, both of which affect workers' safety and health. Therefore, this research showed that regular personal measurements should be taken and be legally binding, not only to precisely determine actual exposure and efficient planning of preventive measures but also to prevent professional diseases, raise awareness among workers, and provide them with proper education and training in order to enhance the safety at work. To lower the risk of noise and silica dust, it is necessary to represent their risk on a global level, to reduce worker exposure, and to prevent diseases like occupational hearing loss and silicosis through different research and innovation models.

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REFERENCES

Anees, M. M., Qasim, M., and Bashir, A. (2017). Physiological and physical impact of noise pollution on environment. *Earth Science Pakistan*, *1*(1), 8–11. https://doi.org/10.26480/esp.01.2017.08.10

Barboza, C. E., Winter, D. H., Seiscento, M., Santos, U. P., and Terra, F. M. (2008). Tuberculosis and silicosis: Epidemiology, diagnosis and chemoprophylaxis. *Jornal Brasileiro de Pneumologia*, *34*(11), 959–966. https://doi.org/10.1590/S1806-37132008001100012

Bello, A., Mugford, C., Murray, A., Shepherd, S., and Woskie, S. R. (2019). Characterization of occupational exposures to respirable silica and dust in demolition, crushing, and chipping activities. *Annals of Work Exposures and Health*, *63*(1), 34–44. https://doi.org/10.1093/annweh/wxy089

European Agency for Safety and Health at Work. (2004). *Management of noise in construction* (Factsheet No. 50). https://osha.europa.eu/en/publications/factsheet-50-management-noiseconstruction

Fritschi, L., Brown, L., Kim, R., Schwela, D., and Kephalopoulos, S. (2011). *Burden of disease from environmental noise—Quantification of healthy life years lost in Europe*. WHO Regional Office for Europe.

Gross, J. J. (1998). Antecedent- and response-focused emotion regulation: Divergent consequences for experience, expression, and physiology. *Journal of Personality and Social Psychology*, *74*, 224–237.

Health and Safety Executive (HSE). (2020). *Construction dust: Construction information sheet No. 36 (Revision 3)*. https://www.hse.gov.uk/pubns/cis36.pdf

Hoy, R. F., and Chambers, D. C. (2020). Silica-related diseases in the modern world. *Allergy*, *75*(11), 2805–2817. https://doi.org/10.1111/all.14202

Hoy, R. F., Jeebhay, M. F., Cavalin, C., Chen, W., Cohen, R. A., Fireman, E., ... and Rosental, P. A. (2022). Current global perspectives on silicosis—Convergence of old and newly emergent hazards. *Respirology*, *27*(6), 387–398. https://doi.org/10.1111/resp.14242

Jain, G., Gupta, V., and Pandey, M. (2016). Case study of construction pollution impact on environment. *International Journal of Emerging Technologies in Engineering Research (IJETER)*, *4*(6).

Kantová, R. (2017). Construction machines as a source of construction noise. *Procedia Engineering*, *190*, 92–99. https://doi.org/10.1016/j.proeng.2017.05.312

Keramydas, D., Bakakos, P., Alchanatis, M., Papalexis, P., Konstantakopoulos, I., Tavernaraki, K., ... and Lazaris, A. C. (2020). Investigation of the health effects on workers exposed to respirable crystalline silica during outdoor and underground construction projects. *Experimental and Therapeutic Medicine*, *20*(2), 882–889. https://doi.org/10.3892/etm.2020.8786

Kreuzer, M., Sogl, M., Brüske, I., Möhner, M., Nowak, D., Schnelzer, M., and Walsh, L. (2013). Silica dust, radon and death from non-malignant respiratory diseases in German uranium miners. *Occupational and Environmental Medicine*, *70*, 869–875.

Kužet, Ž., Samardžić, S., Mučenski, V., and Lakatoš, R. (2024a). Noise exposure assessment for excavator operators. In *The 9th International Conference Civil Engineering – Science and Practice* (pp. 1161–1170). Kolašin, Montenegro.

Kužet, Ž., Samardžić, S., and Mučenski, V. (2024b). Noise measurement with personal dosimeter on construction site and preventive measures. In *2nd International EUROSA Conference* (p. 112).

Leung, C. C., Yu, I. T., and Chen, W. (2012). Silicosis. *The Lancet*, *379*, 2008–2018.

Luo, Q., Huang, L., Xue, X., Chen, Z., Zhou, F., Wei, L., and Hua, J. (2021). Occupational health risk assessment based on dust exposure during earthwork construction. *Journal of Building Engineering*, *44*, 103186. https://doi.org/10.1016/j.jobe.2021.103186

Ministarstvo za rad, zapošljavanje, boračka i socijalna pitanja [Ministarstvo za rad]. (2019). Pravilnik o preventivnim merama za bezbedan i zdrav rad pri izlaganju buci (Rulebook on preventive measures for safe and healthy work during noise exposure), "Službeni glasnik Republike Srbije" br. 96/2011, 78/2015 i 93/2019, Beograd, Srbija, 2011. [online] Available at: https://www.paragraf.rs/propisi/pravilnik_o_preventivnim_merama_za_bezbedan_i_zdrav_rad_pri_izlaganju_buci.html [Accessed: 29 April 2025]. (in Serbian)

Movahed, N., and Ravanshadnia, M. (2022). Noise exposure assessment in construction equipment operators in Tehran, Iran. *Journal of UOEH*, *44*(1), 43–52. https://doi.org/10.7888/juoeh.44.43

Mučenski, Lj. V. (2018). *Teorijske osnove bezbednosti i zdravlja na radu u građevinarstvu* [Theoretical foundations of safety and health at work in construction]. Faculty of Technical Sciences in Novi Sad, University of Novi Sad. ISBN: 978-86-6022-049-5

Occupational Safety and Health Administration (OSHA). (2012). *Health hazards in construction workbook*. https://www.osha.gov/sites/default/files/2019-03/health_hazards_construction_pt2.pptx

Pahlavan, F., and Arouss, M. (2016). Does exposure to noise lead to decreased regulatory abilities, and increased aggression? *Journal of Behavioral and Brain Science*, *6*(1), 53–80.

Pérez-Alonso, A., Córdoba-Doña, J. A., Millares-Lorenzo, J. L., Figueroa-Murillo, E., García-Vadillo, C., and Romero-Morillos, J. (2014). Outbreak of silicosis in Spanish quartz conglomerate workers. *International Journal of Occupational and Environmental Health*, *20*, 26–32. https://doi.org/10.1179/2049396713Y.0000000049

Ramírez, J. M. (2006). Bioquímica de la agresión. *Psicopatología Clínica, Legal y Forense*, *5*, 43–66.

Rees, D. M., & Silica, J. (2017). In Newman Taylor, A. C. P., Blanc, P., and Pickering, A. (Eds.), *Parkes' Occupational Lung Disorders* (4th ed., pp. 187–205). CRC Press.

Rees, D., and Murray, J. (2007). Silica, silicosis and tuberculosis. *International Journal of Tuberculosis and Lung Disease*, *11*(5), 474–484.

Requena-Mullor, M., Alarcón-Rodríguez, R., Parrón-Carreño, T., Martínez-López, J. J., Lozano-Paniagua, D., and Hernández, A. F. (2021). Association between crystalline silica dust exposure and silicosis development in artificial stone workers. *International Journal of Environmental Research and Public Health*, *18*(11), 5625. https://doi.org/10.3390/ijerph18115625

Samardžić, S. (2021). *Odabrana poglavlja iz fizike I* [Selected chapters in physics I]. Faculty of Technical Sciences in Novi Sad, University of Novi Sad. ISBN: 978-86-6022-326-7

Sauvé, J. F., Beaudry, C., Bégin, D., Dion, C., Gérin, M., and Lavoué, J. (2013). Silica exposure during construction activities: Statistical modeling of task-based measurements from the literature. *Annals of Occupational Hygiene*, *57*, 432–443. https://doi.org/10.1093/annhyg/mes089

Sripaiboonkij, P., Chairut, S., and Bundukul, A. (2013). Health effects and standard threshold shift among workers in a noisy working environment. *Health*, *5*, 1247–1253. http://www.scirp.org/journal/PaperInformation.aspx?PaperID=35510

Wang, D., Yang, M., Liu, Y., Ma, J., Shi, T., and Chen, W. (2020). Association of silica dust exposure and cigarette smoking with mortality among mine and pottery workers in China. *JAMA Network Open*, *3*, e202787. 10.1001/jamanetworkopen.2020.2787

Wiebert, P., Andersson, T., Feychting, M., Sjögren, B., Plato, N., & Gustavsson, P. (2023). Occupational exposure to respirable crystalline silica and acute myocardial infarction among men and women in Sweden. *Occupational and Environmental Medicine*, 80(1), 21-26. doi: 10.1136/oemed-2022-108505

Xiao, P., and Li, Y. (2023). Dose response assessment of silica exposure and poisoning of construction workers. *Environmental Pollutants and Bioavailability*, *35*(1), 2190489. https://doi.org/10.1080/26395940.2023.2190489

Xue, L. (2018). The effect of a high-frequency-hearing-threshold weighted value on the diagnosis of occupational-noise-induced deafness. *Journal of Biosciences and Medicines*, *6*(12), 88.

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REVIEW PAPER

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EVALUATING ALTERNATIVE VEHICLE FUELS THROUGH MULTI-CRITERIA DECISION ANALYSIS

Abstract: *In the last century, alongside the development of combustion engines, researchers, engineers, and manufacturers have explored alternative fuel solutions. The results of such experiments and concepts were usually not commercialized due to a lack of awareness of the negative environmental impact of fossil fuels and insufficient technological readiness. Today, due to strict regulations and emission restrictions, the automotive industry is driven to develop and explore vehicles with more efficient engines, lower emissions, and sustainable production methods. This paper applies Multi-Criteria Decision Analysis (MCDA) to rank various propulsion options, such as electricity, hydrogen, biofuels, and synthetic fuels, based on key criteria like energy efficiency, carbon footprint, economic feasibility, technological maturity, infrastructure readiness, etc. The analysis highlights trade-offs between different power systems, emphasizing the role of policy, innovation, and infrastructure in shaping the future of mobility.*

Keywords: sustainable transportation, alternative vehicle fuels, energy efficiency, emission

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INTRODUCTION

Today's world is highly dependent on fossil fuels, and transportation is considered one of the major energy consumers, alongside the residential and industrial sectors. In the European Union, transportation accounts for around 33.1% of total energy consumption, followed by the industrial sector with 23.3% and the residential sector with 38.9% of final energy consumption (International Energy Agency, 2021). Fossil fuels, such as gasoline and diesel, remain the primary energy sources, despite their negative environmental impact. The extraction, refinement, and use of these fuels are responsible for high greenhouse gas emissions (GHG) released into the atmosphere (U.S. Environmental Protection Agency, 2023). In addition to their environmental impact, the depletion of oil reserves, which are the primary energy source for transportation, is also considered a major problem (Doğan & Erol, 2019). This has led to the development of alternative energy sources and fuels for vehicles. It should be noted that such fuels were initially developed alongside internal combustion engines but with different motivations than today, primarily to reduce dependence on oil and the oil industry. Today, environmental concerns are the main driving force for the development of alternative fuels (Towoju, 2021). Despite this, internal combustion engines fueled by fossil fuels still dominate road transportation (Flach et al., 2017). This is influenced by the lower cost of both fuel and vehicles, as well as consumer habits. To reduce greenhouse gas emissions, many countries have introduced supportive measures for purchasing vehicles powered by alternative fuels, particularly electric and hybrid ones, and have implemented various regulations in the transportation sector to reduce emissions (Towoju, 2021). Although alternative fuels can be more efficient, and there is increasing support for replacing internal combustion (IC) engines with electric ones, resistance to this transition still exists. This paper will examine different types of alternative fuels and use a multicriteria analysis to evaluate and rank them based on criteria such as environmental impact, infrastructure requirements, and other relevant factors.

ALTERNATIVE FUELS

This section will explore different types of alternative propulsion options. Some of them have become widely used by now, such as natural gas, biodiesel, and electric vehicles. In addition, this section will examine alcohol-based fuels, which are often blended with gasoline to improve fuel quality, as well as hydrogen, whose technology is still in the development stage. Toyota is actively researching this technology and introduced the first hydrogen-powered car, the Toyota Mirai (Thompson et al., 2018). While electric vehicles are expected to dominate the transport sector, particularly in passenger cars, other alternatives are still needed. Their usage will largely depend on the intended purpose and function of the vehicle (Varga, Sagoian, & Mariasiu, 2019).

Electric vehicles

Although many authors include hybrids and plug-in hybrids under the category of electric vehicles, the authors of this paper consider that these types of vehicles are already commercially available and widely used. Therefore, they will not be considered as alternatives in this paper. Electric vehicles (EVs) convert electrical energy from batteries into mechanical energy using electric motors. These vehicles emit zero greenhouse gases into the atmosphere and are considered a better alternative to IC engine vehicles, especially in urban areas, where noise is also an issue, as electric vehicles are much quieter. In addition, electric motors are significantly more efficient than IC engines, with an energy conversion rate of 80–90%, compared to just 20–30% in internal combustion engines. These types of vehicles are also considered a preferable solution because their operating costs are very low. In most cases, the cost of recharging the battery is much lower than the cost of refueling with diesel or gasoline. However, there are still several issues with electric vehicles. First, they are only truly "green" if the electricity they use comes from renewable sources (Towoju, 2021). Another challenge is the underdeveloped charging infrastructure, along with slow battery charging times. Electric vehicles also have a shorter driving range compared to IC vehicles, and face concerns regarding battery life cycles. Additionally, EVs are generally more expensive than IC or hybrid vehicles, but many countries have introduced policies and incentive programs to support the purchase of electric cars (Enoma et al., 2022).

Natural gas

Natural gas is an attractive fuel because it is domestically available in many countries, has been used in vehicles for many years, and benefits from a well-established infrastructure. It also produces minimal harmful emissions and is considered a “cleaner” fuel compared to traditional fossil fuels. It has been introduced into internal combustion engines to help reduce greenhouse gas emissions (Chen et al., 2018). Vehicles powered by natural gas typically use either compressed natural gas (CNG) or liquefied natural gas (LNG), and it is often applied in bi-fuel systems, such as diesel/CNG or gasoline/CNG, to improve engine performance and reduce emissions. One of the key advantages of natural gas is its lower cost compared to diesel or gasoline, which makes it a very appealing alternative. In addition to being widely available in many countries and regions, natural gas can be sourced from various origins, so it has the potential to be a more sustainable and renewable energy option. These sources include conventional gas wells, coalbed methane, and shale formations. Although natural gas infrastructure is relatively well developed, there are still challenges, particularly the limited number of refueling stations compared to conventional fuels, which makes bi-fuel usage (e.g. gasoline/CNG) more practical and appealing in many regions (Enoma et al., 2022).

Biodiesel

Biodiesel is currently used as a blend with standard diesel to reduce emissions, improve cold starts, and enhance fuel intake. It is blended this way because of its high viscosity and density, which can cause fuel injection problems when used on its own. In standard internal combustion engines, the use of biodiesel, depending on the blend, can reduce greenhouse gas emissions by up to 78% (Nabi et al., 2019). This type of fuel is typically derived from renewable lipid sources and is considered sustainable only when it does not compete with the food industry. There are four generations of biodiesel, each distinguished by the type of feedstock used. The first generation is produced from crops like corn, wheat, and vegetable oils. The second generation uses non-edible plants, waste oils, energy crops, and lignocellulosic biomass. The third and fourth generations are still under development. The third generation focuses on algal biomass, while the fourth involves genetically modified microorganisms (Stančin et al., 2020). Pure biodiesel is rarely used on its own in engines; it is commonly blended with conventional diesel. This is due to several challenges, including the lack of regulatory support, its high viscosity, which can clog fuel filters, and potential compatibility issues that may lead to the degradation of engine components and fuel system parts (U.S. Department of Energy, 2016).

Alcohol derivate fuels

Like biodiesel, alcohol derivate fuels have been successfully used in IC engines in blends with fossil fuels, where shares of alcohol do not exceed 20%. Commercially used is ethanol, but in this paper, methanol and dimethyl ether will be reviewed as well.

Methanol can have various roles as an alternative fuel: it was used and can be used in IC engines in blends, in fuel cells, and as a potential hydrogen carrier. Engines solely for methanol usage are under development. Methanol is a colorless, volatile, and flammable liquid that raises concerns for its storage and safety regulations. It is important to note that while methanol can be produced from a variety of feedstocks, priority should be given to producing it from renewable and sustainable sources (Stančin et al., 2020).

Ethanol is a widely used alternative fuel, typically produced from corn, sugarcane, wheat, and various forms of agricultural and forestry waste. Similar to biodiesel, it is most often blended with fossil fuels to enhance fuel quality, reduce emissions, and improve engine efficiency. The most common blend contains 10% ethanol, while higher blends require engine modifications (Enoma et al., 2022). One major drawback of ethanol is its low energy density, which leads to increased fuel consumption and the need for larger fuel tanks or more frequent refueling. Additionally, incomplete combustion of ethanol can result in the release of harmful gases into the

atmosphere, such as formaldehyde (Stančin et al., 2020).

Dimethyl ether (DME) has been used as a fuel additive and has demonstrated strong performance in spark-ignition engines. It is a non-toxic, non-carcinogenic compound with a low global warming potential and a cetane number comparable to that of diesel, which makes it a promising and environmentally friendly alternative to fossil fuels. However, DME faces similar challenges as ethanol—its low energy density requires larger or reinforced fuel tanks, and its low viscosity can lead to fuel leakage issues which require the development of a new fuel delivery system (U.S. Department of Energy, 2016).

Hydrogen

Hydrogen is a promising alternative fuel that can be used in compressed, liquid, or solid form, each with its limitations. The most efficient and attractive application of hydrogen is in fuel cells, where compressed hydrogen gas is converted into electricity to power electric motors (Brooks et al., 2018). Although hydrogen has a lower energy density than fossil fuels, posing challenges for storage and distribution, it offers a significantly higher energy conversion efficiency, around 60%. When used as a fuel, hydrogen emits only water vapor and heat, without releasing any harmful gases (Enoma et al., 2022). Despite being the most abundant element in the universe, hydrogen is rarely found in its pure elemental form on Earth. It can be produced in several ways, but the most common method relies on fossil fuels, which makes the process less sustainable, though currently cheaper than renewable-based alternatives. Greater emphasis should be placed on producing hydrogen from renewables, such as through electrolysis powered by renewable energy (Stančin et al., 2020). However, hydrogen faces major challenges in terms of storage and infrastructure. Establishing a reliable hydrogen distribution network is expected to require billions of dollars in investment over the coming decades (Acar & Dincer, 2019).

METHODOLOGY

In this paper, Multi-Criteria Decision Analysis (MCDA) was used to evaluate and weigh the given alternatives. This method is usually used when is needed to evaluate alternatives and rank them based on valuation criteria with varying scales or units (Kügemann & Polatidis, 2020). MCDA methods typically rely on two main inputs: the performance of each alternative across several criteria, and the relative importance (weights) assigned to each criterion. A common approach is to combine these inputs into an overall score for each option by aggregating weighted values across the criteria. In many cases, this is done using a hierarchical structure, where the main criteria are divided into sub-criteria. Each alternative is then evaluated on these sub-criteria, and the results are aggregated step-by-step to obtain a final ranking. Several MCDA methods are commonly used for evaluating complex alternatives across multiple criteria, such as Weighted Sum Method (WSM), Weighted Product Model (WPM), Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Multi-Attribute Utility Theory (MAUT), and others (Huang, Keisler, & Linkov, 2011). Among these, the Weighted Sum Method (WSM) is one of the simplest and most intuitive with straightforward calculation and ease of interpretation. It involves assigning a weight to each criterion based on its importance and then multiplying these weights by the chosen performance scores of each alternative. The total score for each alternative is obtained by summing up these weighted values and the preferred option is the one with the highest overall score (Taherdoost, 2023).

This paper applies to the Weighted Sum Method (WSM) due to its simplicity and the authors' belief that all considered alternatives have potential applications; the aim is to rank them in terms of which is likely to become the most widely used and conventional.

SELECTION OF ALTERNATIVES AND CRITERIA

Alternative propulsion options face several challenges in reaching widespread commercial adoption. The main obstacles include underdeveloped infrastructure, higher costs compared to fossil fuels, and reliance on fossil-based production methods. For alternative fuels to be considered competitive and truly sustainable, their production should move away from fossil fuel dependence and adopt more efficient, renewable-based processes. Additionally, to achieve price competitiveness with conventional fuels, government support through subsidies or tax incentives is often necessary (Hordeski, 2013).

To rank alternatives, selected criteria will focus on the next crucial criteria: emission of greenhouse gases (GHG), developed/accessible infrastructure, level of technology readiness (TRL), energy density and cost. Each criterion has been assigned a weight based on its relative importance in the current context shown in Table 1.

Table 1. *Criteria and its*

Criteria	Weight
Greenhouse gas emission (GHG)	0.25
Infrastructure	0.25
Energy density	0.2
Technology readiness (TRL)	0.15
Cost	0.15

Emissions and infrastructure are considered the most critical factors, each receiving the highest weight (0.25), due to their direct impact on sustainability and practical deployment. Energy density is next in importance (0.20), as it influences refueling logistics and overall efficiency. Technology readiness and cost are weighed lower (0.15 each), as these parameters are

more likely to evolve and improve over time with further development and market dynamics. The alternatives: electricity, CNG, biodiesel, alcohol derivate fuels and hydrogen will be first evaluated against these criteria on a scale from 1 (poor) to 5 (excellent) and then multiplied by the weight of each criterion. It should be noted that the ranking is based on findings in the reviewed literature (Stančin et al., 2020; Towoju, 2021), and that the assigned scores also reflect a level of informed subjectivity based on the current development status and projected potential of each technology.

These scores reflect the perceived performance of each fuel in the respective category. For example, EVs received the highest score in GHG emissions due to their zero tailpipe emissions, but scored lower in energy density, highlighting the current limitations of battery technology. CNG and ethanol, with relatively mature infrastructure and technology, scored consistently well across most categories. In contrast, hydrogen and DME were rated lower in infrastructure and cost due to their limited commercial deployment and high production or distribution expenses.

Table 2. *Score of alternatives on each criterion*

Energy/ Fuel type	GHG	Infra-structure	Energy density	TRL	Cost
EV	5	4	2	4	4
CNG	3	4	3	5	5
Biodiesel	3	4	4	4	4
Methanol	3	2	3	4	4
Ethanol	4	4	3	5	3
DME	3	2	4	3	2
Hydrogen	5	2	3	3	2

Table 3 presents these scores normalized to a 0–1 range and then multiplied by the corresponding weights and summed to calculate an overall score for each fuel.

Table 3. *Total score for each alternative fuel*

Energy/ Fuel type	GHG	Infra-structure	Energy density	TRL	Cost	Total
EV	0.25	0.2	0.08	0.12	0.12	0.77
CNG	0.15	0.2	0.12	0.15	0.15	0.77
Biodiesel	0.15	0.2	0.16	0.12	0.12	0.75
Methanol	0.15	0.1	0.12	0.12	0.12	0.61
Ethanol	0.2	0.2	0.12	0.15	0.09	0.76
DME	0.15	0.1	0.16	0.09	0.06	0.56
Hydrogen	0.25	0.1	0.12	0.09	0.06	0.61

Based on the results, the most preferable and mature technologies are electric vehicles and compressed natural gas, followed by ethanol and biodiesel. Methanol, hydrogen and dimethyl ethyl still need further research and development to be widely commercialized.

Another approach to achieving sustainable and efficient transportation is the use of flexible fuel vehicles (FFVs). These vehicles are designed to operate on more than one type of fuel, typically a combination of gasoline and alternative fuels, such as ethanol or methanol. The main advantage of FFVs is their ability to leverage the benefits of multiple fuels, allowing for greater flexibility, improved fuel efficiency, and reduced environmental impact. By combining the best characteristics of different fuels, FFVs offer a practical solution during the transition toward cleaner energy sources in the transport sector (Hordeski, 2013).

CONCLUSION

The future of transportation will not be defined by a single dominant solution, but rather by a combination of various alternative propulsion options and technologies, each suited to different contexts and applications. Among these, although ethanol, biodiesel and CNG are widely spread and used, electric vehicles (EVs) are currently positioned as the most prominent option. This is largely due to the strong policy support provided by many governments and their technological maturity. However, the limitations of EVs, particularly in terms of charging infrastructure and long-distance travel capabilities, highlight the need for continued innovation.

Other alternatives, such as hydrogen, biofuels, and alcohol-derivate fuels, also offer distinct advantages and face specific challenges. Their adoption will depend on advancements in production efficiency, infrastructure development, and cost reduction. Flexible-fuel vehicles and hybrid systems, which allow the use of multiple fuels, represent a particularly promising direction. By combining the strengths of different energy sources, they offer greater adaptability and resilience, as seen in CNG/gasoline and hybrid-electric vehicles.

Ultimately, the success of any alternative depends not only on technical feasibility and policy support but also on consumer behavior. A lack of awareness, motivation, or confidence among buyers can significantly impact the adoption of newer technologies, particularly when conventional vehicles remain more affordable and familiar.

In conclusion, while EVs are likely to dominate in the short term, the future of the automotive industry will be shaped by a range of coexisting technologies. Each alternative fuel pathway will require further development, commercialization efforts, and user education to secure a meaningful role in a sustainable transportation ecosystem.

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REFERENCES

Acar, C., & Dincer, I. (2019). Review and evaluation of hydrogen production options for a better environment. *Journal of Cleaner Production, 218*, 835–849. https://doi.org/10.1016/j.jclepro.2019.02.046

Brooks, K. P., Sprik, S. J., Tamburello, D. A., & Thornton, M. J. (2018). Design tool for estimating chemical hydrogen storage system characteristics for light-duty fuel cell vehicles. *International Journal of Hydrogen Energy, 43*, 8846–8858. https://doi.org/10.1016/j.ijhydene.2018.03.090

Doğan, B., & Erol, D. (2019). The future of fossil and alternative fuels used in automotive industry. *2019 3rd International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)*, 1–8. https://doi.org/10.1109/ISMSIT.2019.8932925

Enoma, N., Inikori, I., Kwasi-Effah, C., Charles, A., Ovuru, P., & Aduwenye, B. (2022). A comprehensive review of alternative fuels for automobiles: Benefits, challenges, and future direction. *Zenodo, 4*, 226–242. https://doi.org/10.5281/zenodo.8018736

Flach, B., Lieberz, S., Rondon, M., Williams, B., & Wilson, C. (2017). *EU-28 Biofuels Annual 2016*. USDA Foreign Agricultural Service.

Hordeski, M. F. (2013). *Alternative fuels: The future of hydrogen* (3rd ed.). River Publishers. https://doi.org/10.1201/9781003151753

Huang, I. B., Keisler, J., & Linkov, I. (2011). Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends. *Science of the Total Environment, 409*(19), 3578–3594. https://doi.org/10.1016/j.scitotenv.2011.06.022

International Energy Agency. (2021). *Statistics report: Key world energy statistics 2021*. Paris, France: IEA. https://www.iea.org/reports/key-world-energy-statistics-2021

Kügemann, M., & Polatidis, H. (2020). Multi-criteria decision analysis of road transportation fuels and vehicles: A systematic review and classification of the literature. *Energies, 13*(1), 157. https://doi.org/10.3390/en13010157

Nabi, M. N., Rasul, M. G., Anwar, M., & Mullins, B. J. (2019). Energy, exergy, performance, emission and combustion characteristics of diesel engine using new series of non-edible biodiesels. *Renewable Energy*. https://doi.org/10.1016/j.renene.2019.03.066

Stančin, H., Mikulcic, H., Wang, X., & Duic, N. (2020). A review on alternative fuels in the future energy system. *Renewable and Sustainable Energy Reviews, 128*, 109927. https://doi.org/10.1016/j.rser.2020.109927

Thompson, S. T., James, B. D., Huya-Kouadio, J. M., Houchins, C., DeSantis, D. A., Ahluwalia, R., et al. (2018). Direct hydrogen fuel cell electric vehicle cost analysis: System and high-volume manufacturing description, validation, and outlook. *Journal of Power Sources, 399*, 304–313. https://doi.org/10.1016/j.jpowsour.2018.07.100

Towoju, O. A. (2021). Fuels for automobiles: The sustainable future. *Journal of Energy Research and Reviews, 7*(3), 8–13.

Towoju, O. A. (2021). Carbon footprint reduction with the adoption of the electricity-powered vehicles. *International Energy Journal, 21*(1A), 101–106.

Taherdoost, H. (2023). Analysis of Simple Additive Weighting Method (SAW) as a Multi-Attribute Decision-Making Technique: A Step-by-Step Guide. *Journal of Management Science & Engineering Research, 6*(1), 21–24. https://doi.org/10.30564/jmser.v6i1.5400

U.S. Department of Energy. (2016). *Biodiesel handling and use guide* (5th ed., DOE/GO-102016-4875). Alternative Fuels Data Center. https://afdc.energy.gov/files/u/publication/biodiesel_handling_use_guide.pdf

U.S. Environmental Protection Agency. (2023). *Global greenhouse gas overview*. https://www.epa.gov/ghgemissions/global-greenhouse-gas-overview

Varga, B., Sagoian, A., & Mariasiu, F. (2019). Prediction of electric vehicle range: A comprehensive review of current issues and challenges. *Energies, 12*, 946. https://doi.org/10.3390/en12050946

Yisong, C., Jinqiu, M., Bin, H., Peng, Z., Haining, H., Hao, C., & Xin, S. (2018). Emissions of automobiles fueled with alternative fuels based on engine technology: A review. *Journal of Traffic and Transportation Engineering (English Edition), 5*(4), 318–334. https://doi.org/10.1016/j.jtte.2018.05.001

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ANALYSIS OF HAZARDS FROM BIOTECHNOLOGY LABORATORY EQUIPMENT

Abstract: *Biotechnology laboratories are specialized facilities that utilize biocatalysts for research, development, and production in various fields, including medicine, agriculture, industry, and ecology. These laboratories typically share standard equipment, regardless of their specific focus. The aim of this paper is to analyze the hazards associated with the use of work equipment that is commonly used in a biotechnology laboratory. The subject of the analysis is the work equipment in the biotechnology laboratory, which includes simple bench-top devices, as well as larger standalone and integrated systems, which are used for sample analysis, diagnostics, bioprocessing, providing appropriate working conditions and processes (bioreactors, centrifuges, autoclaves, microscopes, incubators, digesters, heating plates, microwave ovens, water baths, freezers, laboratory glassware, spectrophotometers, electrophoresis and PCR equipment, etc.). In the paper, identified hazards are given for each unit of work equipment, which are grouped by category, and possible causes and consequences of each of the identified hazards are given and recognized. The hazard analysis of work equipment is an essential starting point for an appropriate risk assessment of work equipment in the working environment of biotechnology laboratories.*

Keywords: biotechnology laboratories, working environment, work equipment, hazards, risk assessment

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INTRODUCTION

Safety and health at work is important in all branches of industry, business, and trade, including all work processes and working environment in facilities for production and non-production activities and facilities for education, health and social care, culture, sports, tourism, traffic, etc. Safety and health at work contribute to increased productivity in the workplace, stimulate economic growth and employment, and improve the functioning of the labour market (Goetsch, 2019).

Risk assessment represents the identification of preventive and protective measures based on the evaluation of the risk arising from the hazard, taking into account the adequacy of the existing risk control and deciding whether the risk is acceptable. Risk assessment focuses on the organization of work, work processes, means of work, raw materials and materials used in technological and work processes, means and equipment for personal protection at work, as well as other elements that can cause the risk of injuries at work, damage to the health or illness of the employee (Aven, 2015).

Identified hazards can be classified into several categories based on the severity of their possible consequences (e.g. low, medium, and high), which allows comparing these threats and prioritizing the 'dangerous'. As a result of the risk assessment, corrective measures are defined that are needed to eliminate the risks arising from these hazards (Elmontsri, 2014).

Hazard identification is realized through several activities, such as immediate inspection of the workplace and work activities with work equipment that can cause injuries or damage the health of employees. Once it has been determined where hazards may exist, it is important to look at the processes and work cycles taking place to determine if the hazards actually exist. It is important to have direct contact with the operators of the work equipment, who can provide first-hand information on whether there are any dangers during their work.

An insight into the records of previous incidents on the work equipment provides information about what has recently caused a risk for an employee, that is, led to their injury or illness. Also, reviews of the records of employees' sick days and absences can reveal hidden risks or organizational factors that affect absence, i.e. specific information that provides even more guidance on where significant hazards occur.

Analysis of the work equipment manufacturer's instructions involves checking whether the operators follow the instructions. This provides all the relevant information for the given work equipment, and allows significant hazards to be identified more easily. Also, through the appropriate regulations on measures for safe work with work equipment, as well as annual reports on work safety, information is obtained about the dangers that occur with work equipment in certain sectors of the industry. Analysis of the records of the service and maintenance regime of the work equipment identifies potential hazards on the observed work equipment, considering that the present dangers on the given work equipment are managed through the service and maintenance regime (Kharzi et al., 2020).

After hazard identification, it is recommended to group hazards into specific categories (Henderson, 2017). Creating categories makes it easier to review risks, which can help make decisions to eliminate risks. The categorization can be made on the basis of the type of impact on human health (chemical, biological, psychological, physical), on the basis of the activities at a given workplace (e.g. activities related to the handling of chemicals, work on a bioreactor), etc. In many companies, there are four groups of hazards: hazards of human origin, technological hazards, medical hazards, and other hazards.

Technological risks are a large group of risks that include risk factors that affect (or arise from) work equipment in the workplace. Most often, these types of risk factors appear due to poor condition or poor maintenance of work equipment, but this category also includes risks arising from the inexperience of workers (Hughes and Ferrett, 2007).

Biotechnology laboratories are specialized facilities where biotechnological methods are applied, using biocatalysts (microorganisms, enzymes, plant and animal cells) for research, development and production of new products or solutions in various fields (medicine, agriculture, industry, ecology, etc.). In general, all biotechnology laboratories include certain work equipment that can be marked as common to almost all biotechnology laboratories, regardless of their purpose, i.e. the field of application (Gupta et al., 2017).

Biotechnology laboratories can be classified into several types based on their purpose and application, namely: industrial biotechnology laboratories, medical biotechnology laboratories, environmental biotechnology laboratories, and agricultural biotechnology laboratories.

The aim of this paper is to analyze or identify the hazards of work equipment that is commonly used in a biotechnology laboratory, regardless of its purpose or area of application.

MATERIALS AND METHODS

The subject of analysis is selected equipment for work in a biotechnology laboratory, which includes simple desktop devices, as well as larger independent and integrated systems, which are used for sample analysis, diagnostics, performing bioprocesses, and ensuring appropriate working and process conditions (bioreactors, centrifuges, autoclaves, microscopes, incubators, digesters, heating plates, microwave ovens, water baths, freezers, burners, laboratory glass, spectrophotometers, electrophoresis and PCR equipment, etc.).

The analysis identifies hazards for each unit of work equipment, as well as the possible consequences of each identified hazard.

Hazard analysis of work equipment is a necessary starting point for an appropriate risk assessment of work equipment in the work environment of a biotechnology laboratory.

The subject of the risk assessment is the work environment of a model for a general biotechnology laboratory in which common work equipment is used, that is, equipment used in most biotechnology laboratories with a similar design of the work space.

Hazard identification was carried out on the model of a general biotechnology laboratory taking into account all risk factors arising from work equipment.

Identification of hazards is the first stage in risk assessment, followed by the stages of identification of persons exposed to hazards, risk evaluation, assessment of existing risk control and recommendations for improvement, and revision and documentation of risk assessment.

The information about the dangers of work equipment is collected through: direct insight into the work equipment at the workplace, observation of the work of employees with the given equipment, review of records of earlier incidents with the work equipment, review of the instructions of the manufacturer of the work equipment, application of regulatory guidelines, as well as review of information on the maintenance regime of the equipment and observation of posted warning pictograms for using the work equipment.

Table 1 shows the analyzed work equipment used in the biotechnology laboratory.

Table 1. *Analyzed work equipment and its use in the biotechnology laboratory*

Equipment	Description / Use
Centrifuges	They are used to separate the components of mixtures based on their density. The samples placed in them rotate at high speed, creating a strong centrifugal force, as a result of which denser materials move to the bottom of the cuvette, while materials of lower density occupy the upper layers. In biotechnology, it is primarily used for the separation of biomass from the medium, but also for the purification of biological products.
Bioreactors	Complex and diverse devices that enable the cultivation of microorganism cells, plant and animal cells, in controlled conditions for the production of a wide range of biological products, from pharmaceutical products to biofuels. Bioreactors provide controlled conditions as well as sterile conditions during operation.

Cooking and mixing plates	They are used for heating and mixing different media. They are usually used to facilitate the dissolution of substances in a liquid medium, to melt substances and to thermoregulate mixtures.
Autoclaves	They are used for sterilization with steam at a pressure of 2.1 bar and a temperature of 121 °C. Hot steam destroys the structure of the cell wall and membrane of microorganisms, which is important for the sterilization of laboratory instruments and materials.
PCR equipment	It is used for amplification (duplication) of DNA sequences, whereby the DNA sequence being examined is made into a large number of copies, which enables further manipulation with them.
Electrophoresis equipment	It is used to separate and analyze macromolecules such as DNA, RNA, and proteins based on their size, charge, and other physical properties.
Microwave ovens	They are used for rapid heating of materials, most often for faster dissolution of soluble substances or for faster reaction of the medium.

RESULTS AND DISCUSSION

The dangers associated with the use of centrifuges in a biotechnology laboratory are manifested as mechanical and electrical hazards, as well as chemical and biological hazards. The main danger when working with a centrifuge is its movement/sliding on the work surface during operation, which can occur if the centrifuge is improperly loaded or unbalanced. During the operation of the centrifuge, the unbalanced mass in the centrifuge, due to the centrifugal force, leads to an imbalance, that is, an uneven distribution of forces that act on the centrifuge itself and lead to its movement on the work surface and possible fall from it.

When working with dangerous chemicals or pathogenic microorganisms, when the centrifuge is opened, evaporation of dangerous substances can occur, which poses a danger to the respiratory organs of people in the laboratory. A similar danger exists if the centrifuge lid is not adequately closed before centrifugation begins.

Electrical energy also poses a great danger in situations where the centrifuge is not regularly serviced and maintained, which can lead to equipment failure and the risk of electric shock for the user of the centrifuge. Table 2 lists the identified hazards of working with a centrifuge, as well as possible consequences.

Table 2. *Centrifuge hazards*

Hazard	Possible consequences
Centrifuge movement	The centrifuge may move or fall off the work surface due to imbalance.
Exposure to hazardous substances or pathogens	The centrifuge lid does not close during centrifugation. When lifting the centrifuge lid, dangerous substances and pathogens can be released.
Electric shock	During frequent use of the centrifuge, a malfunction may occur, which poses a risk of electric shock to the user.

Due to the complex structure and diversity of bioreactors, they pose a great danger in the biotechnology laboratory, through mechanical and electrical hazards, physical and chemical properties of chemicals, as well as chemical and biological hazards. When analyzing the operation of a bioreactor, the main focus is on the bioprocess that takes place in it, that is, on the biocatalysts in the nutrient medium in the bioreactor. One of the biggest dangers for such equipment is the microorganisms themselves, which in some cases can be pathogenic. The danger appears mostly only after the end of the bioprocess (when the ports on the bioreactor are opened), because the concentration of pathogens can increase several thousand times compared to the initial one, and through the vapours they can easily reach human organisms. Often, in addition to microbiological biomass, organic substances (by-products or final products) can also be formed, and they can cause a harmful effect.

During bioprocesses, carbon dioxide or other gaseous metabolites are often produced as by-products, which can accumulate in bioreactors. In non-hermetically sealed bioreactors, this can be extremely dangerous, as carbon dioxide can enter the laboratory atmosphere and lead to an asphyxiation hazard.

Metabolic gases as a product of bioprocesses also represent an additional risk of explosion. During intensive gas production, the pressure inside the bioreactor can increase, which can lead to the explosion of the bioreactor vessel itself. Table 3 shows the identified hazards of working with the bioreactor, as well as the possible consequences.

Table 3. *Bioreactor hazards*

Hazard	Possible consequences
Exposure to pathogens and hazardous substances	When opening the bioreactor, there is a risk of inhaling pathogens or dangerous substances.
Lack of oxygen	During the bioprocess, carbon dioxide is often produced as a by-product to which workers are exposed.
Explosion	Metabolic gases can increase the pressure in the bioreactor, which can lead to an explosion.
Fire	If pure oxygen is used for aeration, the risk of fire may increase due to the oxygen-enriched air.
Cuts	The edges of bioreactor components (dispersers, mixers, impellers) can be sharp and lead to cuts.
Electric shock	Irregular servicing and maintenance of the bioreactor can lead to failure, which can pose a risk of electric shock.

Some bioprocesses require the use of pure oxygen for aeration in the bioreactor, but this entails an increased risk of fire. During a leak in the oxygen supply system,

the air is enriched with oxygen, which helps the fire develop and spread more quickly.

When using the bioreactor, there may be cuts from the sharp ends of the air blowing system or the impeller of the mixer. As with most electrical machinery and/or equipment, an improperly maintained device poses an additional electrical hazard.

Cooking and mixing plates serve to heat liquids, so the greatest danger is the high temperatures that develop during work. High temperatures pose a risk of burns, in case of unprofessional handling of the equipment, leading to overheating of the liquid, which further increases the risk of burns. There is also a risk of electric shock when working with cooking and mixing plates. Table 4 lists the identified hazards associated with the use of the hob and stirrer, as well as the possible consequences.

Table 4. *Cooking and mixing plates hazards*

Hazard	Possible consequences
Burns	A hob with a stirrer usually works at a high temperature, which is why there is a risk of burns during use.
Electric shock	Probability of electric shock in case of device failure.

Steam sterilization is performed in autoclaves. During sterilization, autoclaves use steam at high temperature (121 °C) and high pressure (2.1 bar), which ensures the destruction of microorganisms and sterilization of materials. Therefore, most of the dangers arise from the high pressure and high temperature prevailing in the autoclave. After sterilization, the hot steam in the autoclave can condense and come into contact with the user's body when the autoclave is opened, causing burns. Such injuries can also occur when coming into contact with hot parts of the autoclave and sterilized material.

In the event of autoclave failure, there may be an increase in pressure in the chamber and its explosion. Glass containers are often used during laboratory work, which must be sterilized after the work is finished. If working with materials that can be sensitive to the presence of hot water vapor (e.g. glass), they can break or crack due to high temperature and pressure and can cause cuts to the user of the autoclave at the moment of its discharge. Autoclave users who sterilize biologically contaminated equipment and materials are at risk of infection if the waste is not properly stored or if the sterilization cycle is not properly completed.

During the condensation of water vapor, waste water is produced, which leaves the autoclave through the water outlet. If this water is not properly collected or drained, it can create a wet floor around the autoclave, which is a slip hazard. In the event of autoclave failure, there may be a risk of electric shock to the user of the autoclave. Table 5 lists identified hazards related to the use of autoclaves, as well as possible consequences.

Table 5. *Autoclave hazards*

Hazard	Possible consequences
Exposure to pathogens or genetically modified microorganisms	Users who autoclave biologically contaminated instruments are at risk of infection if the waste is not properly stored or if the sterilization cycle is not properly completed.
High pressure	If the autoclave is faulty, there is a possibility of an explosion. This can cause injury to people near the autoclave.
Sharp glass container, cuts	Glassware may crack or break during the sterilization process.
Burns	High temperature – hot condensate is possible when the user is emptying the autoclave. Certain parts of the equipment may be heated during the sterilization cycle.
Electric shock	If the autoclave malfunctions, users may receive an electric shock.
Slipping	Spills or leaks on the floor can cause a slip hazard.

The use of PCR equipment is considered relatively safe. It is rare but possible for the user of the PCR equipment to get burned during contact with the equipment or the samples inside it, as the temperature inside it usually ranges between 50 and 100°C. Often, repetitive pipetting can lead to muscle strain, which is why it is recommended that when working with many samples, pipetting should be done by several people, who take turns regularly. The dangers and possible consequences related to the use of PCR equipment are shown in Table 6.

Table 6. *PCR equipment hazards*

Hazard	Possible consequences
Burns	The user of the PCR equipment may suffer burns during contact with the equipment after the end of the cycle.
Muscle fatigue	Frequent pipetting can lead to muscle strain.

One of the biggest risks during electrophoresis is contact with dangerous chemicals. During analysis, fluorescent markers are used to monitor the progress of test substances through the porous gel in an electric field. Among the markers, one of the most common choices is ethidium bromide, which is a well-known carcinogen. Similar to ethidium bromide, the porous gel is often based on polyacrylamide, which is also a carcinogenic material.

Electrophoresis can also lead to burns, because when pouring liquid hot gel, the gel can burst or spill onto the hands or clothes of the person performing the electrophoresis. Electrophoresis is usually performed at a voltage of 100 V, which results in a current of 25 mA, so during electrophoresis, in addition to the above, there is also a risk of electric shock if the person using the equipment comes into contact with the electrophoretic buffer. Electric shock can also result from electrophoresis equipment failure. Table 7 lists

identified hazards and possible consequences when using electrophoresis equipment.

Table 7. *Electrophoresis equipment hazards*

Hazard	Possible consequences
Exposure to carcinogenic substances	During gel electrophoresis, ethidium bromide (marker) and polyacrylamide (porous gel) are often used, which can cause carcinogenic effects when inhaled.
High temperature	Pouring and mixing of the hot gel can cause splashes and burns.
Electric shock	Electrophoresis is usually performed at a voltage of 100 V resulting in a current of 25 mA.

Microwave ovens are used to rapidly heat solutions or materials, so the primary hazard associated with the use of microwave ovens is high temperature. Materials heated in a microwave oven can reach very high temperatures, so direct contact with them or the equipment can cause burns.

The basic element of every microwave oven is a magnetron, which enables the generation of microwaves. These microwaves are reflected from the wall inside the microwave oven and enter the molecules of the material being heated, where the rays are absorbed in the form of vibrational energy. As a result of the vibration, friction is created between the molecules, which leads to the release of heat. If these microwave rays leave the microwave oven, they can cause heating of the tissues of the human body and cause burns or cataracts of the eye. Table 8 shows information about the dangers and possible consequences of using a microwave oven.

Table 8. *Microwave oven hazards*

Hazard	Possible consequences
High temperature	Contact with heated materials or equipment can cause burns.
Electromagnetic radiation (microwaves)	The eye or skin can absorb microwave energy, causing cataracts or minor burns.
Electric shock	A malfunction may result in an electric shock.

CONCLUSION

Bioreactors and autoclaves are considered the most dangerous equipment for work in a biotechnology laboratory, which have a significant number of hazards with possible severe consequences for the safety and health of the operator (explosion, high temperature, chemical and biological hazards, electric shock, pathogens, etc.). Work with bioreactors and autoclaves is recommended only to persons with appropriate professional knowledge and work experience. The dangers of electrophoresis equipment are significant, as contact with carcinogenic materials is possible, as well as the high voltage required for electrophoresis. Both dangers are significant due to possible severe consequences, which requires that the electrophoresis process itself must be performed with special attention by the operator. The use of the other analyzed work equipment also includes possible hazards to human health, but these hazards manifest minor consequences for the operator's safety and most of them are easily eliminated through careful handling and compliance with prescribed work procedures.

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REFERENCES

Aven, T. (2015). Risk assessment and risk management: Review of recent advances on their foundation. *European Journal of Operational Research, 253*(10).

Elmontsri, M. (2014). Review of the strengths and weaknesses of risk matrices, *Journal of Risk Analysis and Crisis Response, 4*(1), 49-57.

Goetsch, D. (2019). *Occupational Safety and Health*. (9th ed.). Pearson, NY, 2019.

Gupta, V., Sengupta, M., Prakash, J., Tripathy, B.C. (2017). An Introduction to Biotechnology. In: *Basic and Applied Aspects of Biotechnology*, (1st ed.). Springer, Singapore.

Henderson, D.M. (2017). *The Manager's Guide to Risk Assessment: Getting it Right*. Rothstein Publishing.

Hughes, P., Ferrett, E. (2007). *Introduction to Health and Safety at Work*. (3rd ed.). Elsevier, Limited.

Kharzi, R., Chaib, R., Verzea, I., Akni, A. (2020). A Safe and Sustainable Development in a Hygiene and Healthy Company Using Decision Matrix Risk Assessment Technique: a case study. *Journal of Mining and Environment 1-12*.

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INVESTIGATING THE OCCUPATIONAL HEALTH AND SAFETY PRACTICES IN SERBIA

Abstract: *Occupational health and safety (OHS) represents a key aspect of decent work, as recognized in the UN 2030 Agenda for Sustainable Development, particularly SDG 8 – decent work and economic growth, and especially set in the 8.8 target. Health and safety workplace is not only a fundamental labour right, but also a crucial factor in promoting sustainable economic growth, ensuring full employment, and supporting decent work for everyone. Although substantial advancements have been made in OHS over the years, many workers still experience work-related injuries and illnesses, and some tragically lose their lives due to exposure to various occupational hazards and risks. Therefore, the main aim of the paper is to assess the OHS practices in Serbia. For this purpose, a questionnaire was designed covering 7 aspects of OHS culture in organisations: vision, credibility, collaboration, feedback and recognition, responsibility, communication, and action orientation. The analysis of the obtained results revealed areas for improvement in the existing OHS practices, thus enabling the strengthening of OHS in organizations and enhancing the well-being of workers.*

Keywords: Occupational Health and Safety (OHS), Culture, Serbia

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INTRODUCTION

According to the latest ILO estimates, more than 2.93 million workers around the world die per year as a result of work-related factors, whereas some 395 million non-fatal work-related injuries take place (ILO, 2023), and economic consequences of poor OHS practices are estimated at almost 3.9 percent of global GDP each year (EU-OSHA, 2021). These statistics point to the fact that joint action is needed to provide maximum health and safety at work.

Despite decades of international effort and the integration of OHS into global development agendas, including the United Nations Sustainable Development Goals (particularly Target 8.8), the reality in many countries reveals a persistent gap between policy and practice. Serbia, like many transition economies, has aligned its legal and institutional frameworks with international standards, yet effective implementation and continuous improvement in workplace safety culture remain challenging. Fragmented oversight, limited resources in small and medium enterprises (SMEs), and insufficient engagement of workers in safety processes are just a few of the critical issues impeding progress.

While existing national statistics provide a quantitative picture of work-related injuries and occupational diseases, they often fail to capture the cultural and organizational dynamics underlying safety outcomes. In 2021 alone, the European Union recorded approximately 2.88 million non-fatal workplace accidents resulting in absences of four or more days, alongside 3,347 fatal incidents – a ratio of roughly 860 serious injuries for every death (Rađenović, 2023). Although there has been a moderate decrease in these figures compared to previous years, the persistence of high accident rates, particularly in sectors like construction, manufacturing, and transportation, underscores ongoing vulnerabilities. These incidents not only impact individual well-being but also generate substantial economic losses, with EU-wide costs of work-related accidents and illnesses estimated at €476 billion, or 3.3% of the region's GDP (EU-OSHA, 2021; Rađenović, 2023).

This issue is particularly important for countries such as Serbia, where evolving labor markets, regulatory reforms, and industrial restructuring present both opportunities and challenges in ensuring safe and healthy working environments. National-level statistics often emphasize injury counts and compliance metrics, but they provide little insight into how workers perceive safety values, leadership, and communication practices within their organizations (Živković, Rađenović, 2025).

To address this need, the present study focuses on the cultural dimensions of OHS within Serbian

organizations. Grounded in the understanding that safety culture is not just a consequence of mandated rules but a dynamic element of organizational behavior, this research delves into how safety is practically implemented at the workplace level, ultimately offering evidence-based recommendations for enhancing OHS practices in Serbia (Mixafenti et al., 2025). Safety culture plays an important role in every organization, and by changing it, fostering internal acceptance, and ensuring external alignment, better and safer working conditions can be achieved (Todorović et al., 2012). By analyzing employee responses across seven cultural dimensions – vision, credibility, collaboration, feedback and recognition, responsibility, communication, and action orientation, the paper aims to identify areas of strength and aspects requiring targeted improvement.

Furthermore, the exploration of safety culture provides organizations with a pathway to improve their competitive standing (Bautista-Bernal et al., 2023). This approach recognizes that organizational designs, safety management practices, and leadership effectiveness are all intertwined with the national culture in which an organization operates (Yorio et al., 2019).

METHODOLOGY

To assess the state of OHS culture in Serbian organizations, a quantitative survey-based approach was employed. The research instrument was a structured questionnaire consisting of statements grouped into seven key dimensions that reflect the elements of safety culture within organizations: vision, credibility, collaboration, feedback and recognition, responsibility, communication, and action orientation. Each statement was rated using a 3-point Likert scale, ranging from "Never" through "Sometimes" to "Always", enabling respondents to express how frequently they engage in or observe particular OHS-related behaviors in their organizational environment.

The survey was distributed electronically to professionals working in various sectors in Serbia, and 93 responses were collected. The sample included respondents from manufacturing, services, construction, information and communication, public administration, and other sectors.

To better understand the sample profile, several demographic variables were collected and analyzed:

- Gender distribution was nearly balanced: 49% male, 49% female, and 1% preferred not to disclose.
- Age groups were concentrated in the following range: 34% were aged 50-60, followed by 27% in both the 30-40 and 40-50 age groups, while 8% were aged 20-30, and 4% were over 60.
- In terms of educational background, the vast majority (84%) held a university degree, while smaller proportions had higher (9%) or secondary education (1%), or were vocationally trained (1%).
- Work experience levels showed that 33% of respondents had between 10 and 20 years of service, 32% had 20-30 years, 28% had 1-10 years, and 6% had more than 30 years of experience.

These figures indicate that the majority of the respondents are mid-career professionals with substantial experience and higher education, which enhances the reliability of the insights provided on workplace safety culture.

Due to the ordinal nature of the response scale, the analysis was conducted using descriptive statistics, specifically the distribution of responses across the three categories. This approach allowed the identification of patterns in how frequently certain OHS-related behaviors were observed or enacted, and made it possible to highlight which dimensions of safety culture are more or less embedded in practice.

RESULTS AND DISCUSSION

The analysis of the seven dimensions of safety culture provides valuable insights into how OHS is perceived and practiced in Serbian organizations. The data reveals both valuable strengths and notable areas for development.

The responses in the *Vision dimension* (Figure 1) suggest that employees broadly recognize and embody personal standards related to OHS. A large majority consistently affirm that they demonstrate high OHS standards and help others consider their own, indicating a strong foundation of awareness and personal responsibility. However, a slightly lower score on the statement about defining frameworks for future actions suggests opportunities for improved leadership communication and strategic clarity regarding OHS goals.

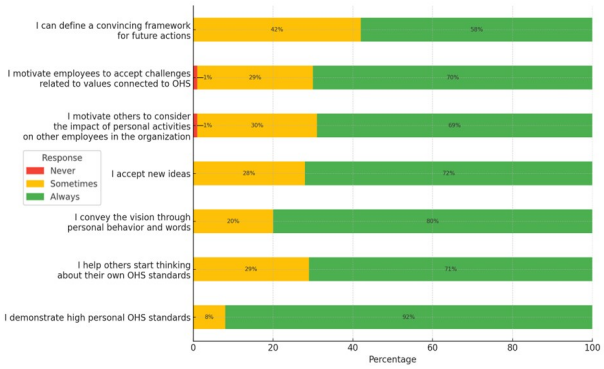


Figure 1. *Vision dimension*

In the *Credibility dimension* (Figure 2), high percentages of "Always" responses for standing up for others reflect a trustworthy interpersonal climate in many organizations. However, lower scores on riskier or career-sensitive behaviors – such as taking on unpopular solutions that benefit employee safety or admitting mistakes in front of others – suggest that systemic or cultural barriers may inhibit full transparency and advocacy. This may indicate that while individual integrity is recognized, institutional support for courageous safety leadership is still evolving.

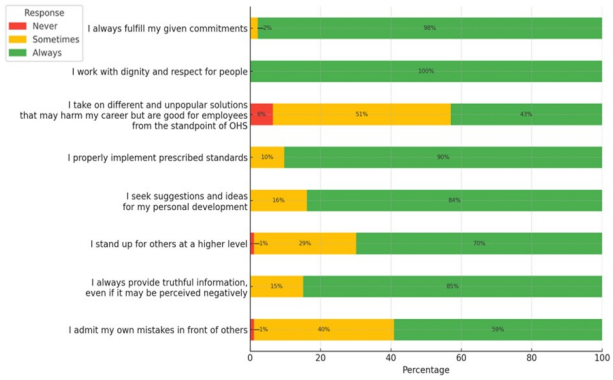


Figure 2. *Credibility dimension*

The *Collaboration* (Figure 3) results show a very positive trend in some statements. Particularly high values for "being ready to listen" and "helping others" highlight a collaborative mindset. Nonetheless, the slightly reduced responses for gaining consensus before implementing innovations may point to hierarchical communication gaps or decision-making structures that limit inclusive engagement. While the overall results for the Collaboration dimension show relatively positive engagement in teamwork and support for OHS practices, the notably low percentage (26%) of respondents who report always trusting others reveals a critical weakness in the underlying social dynamics of OHS collaboration.

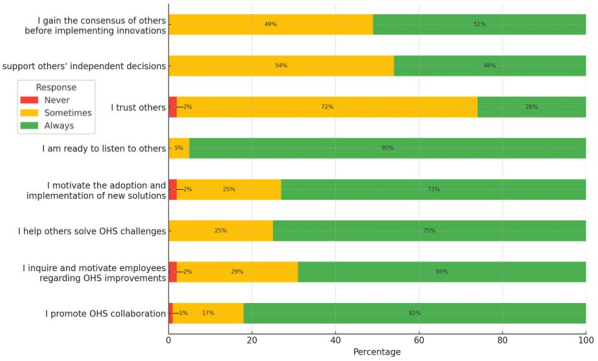


Figure 3. *Collaboration dimension*

Trust is a cornerstone of effective safety culture, particularly in high-risk work environments where reliance on colleagues' competence, communication, and ethical behavior is essential. The finding that nearly three-quarters of respondents (74%) either only *sometimes* trust others or *never* do so indicates a climate where:

- Interpersonal relationships may be cautious or guarded, especially when dealing with responsibilities tied to safety, compliance, or reporting incidents.
- Employees might hesitate to delegate or accept safety-related advice, out of fear that others may not act responsibly or consistently.
- There is potentially low psychological safety, meaning workers are reluctant to speak up, share near misses, or challenge unsafe behavior due to fear of being blamed, ignored, or misunderstood.

This deficiency in trust not only undermines the effectiveness of collaboration itself but also has broader implications, as it: can reduce team learning and the sharing of best practices; may lead to duplication of effort, lack of coordination, or reluctance to innovate in OHS procedures; and contributes to an atmosphere of risk aversion and siloed behavior, where individuals prioritize their own protection over collective safety improvement.

This issue may stem from several systemic or cultural factors in Serbian organizations: 1) Hierarchical structures where top-down authority prevails, leaving little room for horizontal peer confidence; 2) Previous negative experiences with blame or accountability systems that discourage openness; 3) Lack of team-building interventions or trust-oriented leadership behaviors in OHS implementation.

The *Feedback and Recognition dimension* (Figure 4) shows generally strong engagement from respondents. Most employees report that they always recognize contributions (87%), provide immediate acknowledgment (87%), and give positive feedback tied to successfully implemented safety measures (86%). These high scores reflect a culture where positive reinforcement is a visible and routine part of OHS practices. However, the data also reveals that slightly fewer respondents always celebrate successes (55%) or motivate others consistently (62%), suggesting that while feedback is often delivered in the moment, the broader celebration and institutionalization of recognition may be underutilized. Still, the overall results in this dimension point to a supportive and appreciative safety environment.

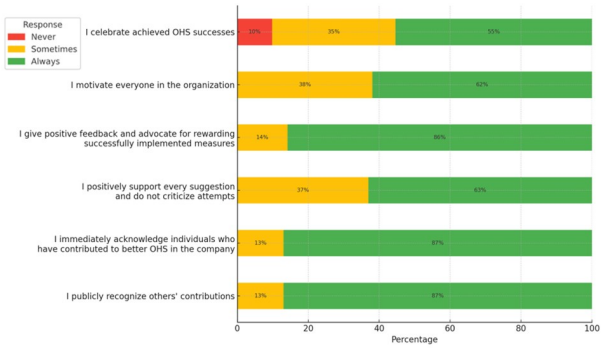


Figure 4. *Feedback and Recognition dimension*

The *Responsibility dimension* (Figure 5) reveals a generally high degree of commitment to defining and enforcing OHS-related responsibilities. Respondents overwhelmingly state that they *always* promote individual accountability (87%), demand responsibility for assigned tasks (85%), and define roles transparently (78%). However, there is a clear decline in "Always" responses for more process-oriented items: only 57% *always* analyze results based on benchmarks, and just 46% *always* implement changes. This suggests that while responsibilities are clearly articulated and assigned, systematic follow-up and change implementation are less consistently practiced,

highlighting a need for stronger mechanisms for continuous evaluation and adaptation in safety practices.

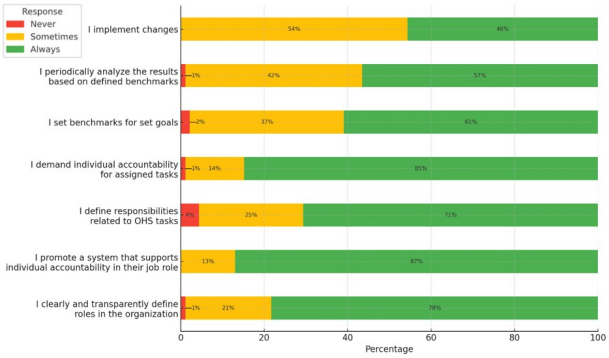


Figure 5. *Responsibility dimension*

The results in the *Communication dimension* (Figure 6) indicate a generally high level of openness and dialogue within organizations, but with important variation across specific practices. The vast majority of respondents report that they *always* listen carefully (92%) and inform others about OHS events (86%), showing strong tendencies toward respectful and informative interaction. High percentages also support statements like *frequent communication* (73%) and *sharing personal experiences* (78%). These results are supported by other research findings which show that frequent communication and information sharing between employers, employees, and OHS professionals significantly improves the effectiveness of safety measures (Cecaro, Isolani, 2013). However, the relatively lower "Always" responses for *creating an atmosphere for open expression* (68%) and *asking for others' opinions* (66%) suggest that while communication is active, it may still lean toward one-directional or leadership-centered patterns. This indicates a need to strengthen mutual dialogue and create more psychologically safe environments for open expression and employee-initiated input on OHS issues.

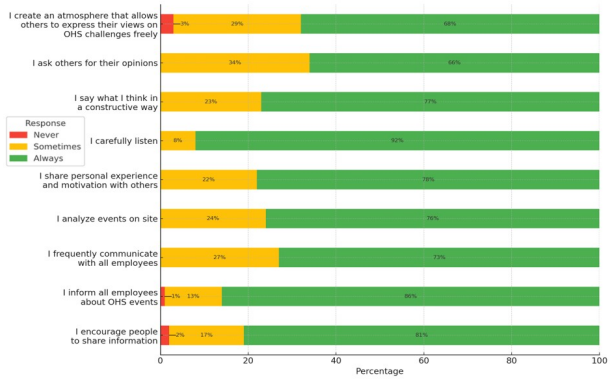


Figure 6. *Communication dimension*

The *Action Orientation dimension* (Figure 7) reveals a proactive and committed safety culture in most organizations. High percentages of respondents reported that they always seize opportunities to improve OHS solutions (84%), set reasonable priorities (83%), and actively support the resolution of safety challenges (82%). These figures reflect a strong inclination toward engaged and purposeful behaviour in managing workplace risks. However, slightly lower scores for being relentless in solving challenges (59%) and innovative in problem-solving (62%) suggest that while employees are action-oriented, they may face constraints in persistence or creative autonomy, possibly due to procedural rigidity or resource limitations. Strengthening innovation and resilience in response to OHS problems could further enhance this otherwise solid dimension.

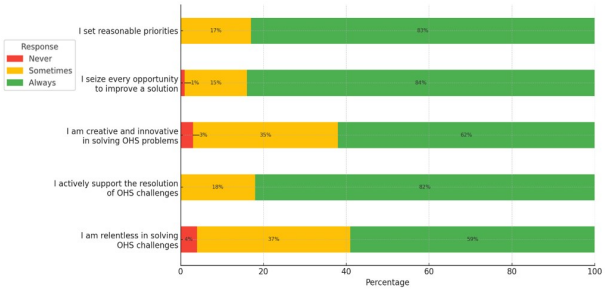


Figure 7. *Action Orientation dimension*

CONCLUSION

The analysis of safety culture across seven key dimensions – vision, credibility, collaboration, feedback and recognition, responsibility, communication, and action orientation – reveals that Serbian organizations demonstrate strong individual commitment to OHS. Many employees take initiative, support their colleagues, and recognize good safety practices. There is clear evidence of action-oriented behavior, open communication, and appreciation for safety achievements. These are important strengths that reflect a positive safety culture at the personal level.

However, several challenges persist. A significant concern is the low level of interpersonal trust, which undermines the potential for genuine collaboration and shared accountability. In addition, although responsibilities are often clearly defined, there are weaknesses in implementing follow-up mechanisms, such as benchmark-based evaluations or feedback loops. The findings also suggest that communication, while generally active, can still be top-down rather than participatory, limiting employee input in shaping safety initiatives. Finally, innovation and sustained action in OHS may be constrained by procedural rigidity or lack of empowerment.

To improve these areas, organizations may need to move beyond a focus only on individual behavior. Instead, they should work toward more integrated and inclusive approaches to managing safety. This means involving employees in decision-making, encouraging open and honest discussions, and creating a work environment where everyone feels safe to speak up. Clear leadership, shared responsibility, and regular evaluation of safety efforts are key to building a stronger, more sustainable safety culture. By making these changes, organizations can close the gap between good intentions and lasting improvement.

ACKNOWLEDGEMENTS

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REFERENCES

Bautista-Bernal, I., Quintana-García, C., & Marchante-Lara, M. (2024). Safety culture, safety performance and financial performance. A longitudinal study. *Safety science*, *172*, 106409. https://doi.org/10.1016/j.ssci.2023.106409

Cecaro, M., & Isolani, L. (2013). The Value of a Successful Communication in the Workplace Prevention. *Journal of Mass Communication and Journalism*, 2014, 1-1. https://doi.org/10.4172/2165-7912.S1-E001.

EU-OSHA – European Agency for Safety and Health at Work (2021). *An international comparison of the cost of work-related accidents and illnesses.* https://osha.europa.eu/sites/default/files/2021-11/international_comparison-of_costs_work_related_accidents.pdf

Živković, S., Rađenović, T. (2025). *Managerial and Economic Aspects of Occupational Health and Safety* [Upravljački i ekonomski aspekti bezbednosti i zdravlja na radu]. Niš: Faculty of Occupational Safety in Niš [Niš: Fakultet zaštite na radu u Nišu].

ILO – International Labour Organization (2023). *A call for safer and healthier working environments.* https://www.ilo.org/sites/default/files/wcmsp5/groups/public/%40ed_protect/%40protrav/%40safework/documents/publication/wcms_903140.pdf

Mixafenti, S., Moutzouri, A., Karagkouni, A., Sartzetaki, M., & Dimitriou, D. (2025). Assessment of Occupational Health and Safety Management: Implications for Corporate Performance in the Secondary Sector. *Safety*, *11*(2), 44. https://doi.org/10.3390/safety11020044

Rađenović, T. (2023). Analysis of the accidents at work in the European Union. *Facta Universitatis, Series: Working and Living Environmental Protection,* 20(3), 157-166. https://doi.org/10.22190/FUWLEP2303157R.

Todorović, M., Živković, S., Nikolić, V., & Markič, M. (2012). The influence of organizational culture of management on occupational safety. *Technics Technologies Education Management-TTEM*, *7*(4), 1760-1767.

Yorio, P. L., Edwards, J., & Hoeneveld, D. (2019). Safety culture across cultures. *Safety science*, *120*, 402-410. https://doi.org/10.1016/j.ssci.2019.07.021

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CHANGES IN THE REQUIREMENTS FOR ENSURING SAFE EVACUATION OF PEOPLE

Abstract: *The report analyses the requirements for ensuring safe evacuation of people from buildings, arising from the latest amendment to Ordinance No. Iz-1971 on construction and technical rules and norms for fire safety in the Republic of Bulgaria, as well as their consequences. The regulatory requirements determining the length of the evacuation route – both within a room and to the final evacuation exit – are examined. The normative requirements for the permissible evacuation time from rooms and buildings are presented, along with two calculation methods for determining the evacuation time from a building.*

Keywords: *evacuation, evacuation time, calculation methods, evacuation route*

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INTRODUCTION

Ensuring safe conditions for the evacuation of people from buildings is a fundamental element of the fire safety and life safety system. Recent amendments to Ordinance No. Iz-1971 (2009) in the Republic of Bulgaria have introduced significant changes in the regulatory requirements governing the organisation and parameters of evacuation processes. The amendments are aimed at refining the criteria for determining the number of residents, the length of evacuation routes, and the permissible evacuation time, as well as improving the methods for evacuation time calculation.

This report aims to analyse the current regulatory requirements for safe evacuation, considering their practical aspects and applicability in the design and operation of buildings. Particular emphasis is placed on the impact of the new regulations on occupant safety, the need to provide adequate evacuation routes and the time constraints imposed for leaving hazardous areas. The analysis also covers the different calculation methods used to estimate evacuation times according to the specificity of the built environment and the functional use of the facilities. Part of this matter is covered in (Dimitrov, 2019)

To determine the fire safety requirements, the buildings, according to Ordinance No. Iz-1971 (2009), are subdivided into five fire resistance levels – I-V. As the degree of fire resistance decreases, the time in which the individual structural elements of the building will lose their properties under fire conditions decreases. The main criteria required of structural building elements are fire resistance: R – load-bearing capacity (the structure retains stability in a fire), E – impermeability (no passage of flames/hot gases), I – thermal insulating capacity (no passage of dangerous levels of heat), and reaction to fire – A1-E. The degree of fire resistance required for any building is directly dependent on its functional use, storey rating, and fire compartment area. The required class of reaction to fire of the building elements and external and internal finishes is also determined in relation to the degree of fire resistance of the buildings. For buildings for which fire resistance class V is permissible, there are no normative requirements for fire resistance class and reaction class of structural elements.

DETERMINATION OF THE NUMBER OF RESIDENTS

To ensure safe conditions for evacuation from a building, it is important to anticipate the number of occupants, based on which, the required number of evacuation exits, their single and total widths, door swing direction, as well as the need for anti-panic locks, are determined. The number of occupants in a building is determined as the sum of the number of people in each room in the building.

Several ways of determining the number of residents in a premises are regulated.

The first way is according to the number of seats or workplaces designated by the investment project.

The second way is through the calculation of the area of the room and the occupancy density defined in Table 8 to Ordinance No. Iz-1971 (2009). The calculation area of the room (floor) is determined by deducting from the floor area of the room the areas of sanitary rooms, elevator shafts, stairwells, racks for the placement of goods and equipment, and storage areas

in which visitor access is restricted (Ordinance No. Iz-1971, 2009).

The third way of determining the occupancy of auditoriums where benches are provided is in relation to the numbered seats or, if there are none, 0.70 m/person. In the case of garages, the number of occupants shall be determined by reference to the number of car parking spaces provided, with two persons for each car.

Anti-panic locks shall be provided on doors to rooms that may be crowded with more than 100 persons, and on escape routes from these rooms to the final exits. Panic exit barriers shall be implemented in accordance with EN 1125 Building hardware – Panic exit devices operated by a horizontal bar, for use on escape routes – Requirements and test methods (2008). They shall be implemented with documents complying with the European requirements and detailed in Simeonova (2025).

DETERMINATION OF THE LENGTH OF THE ESCAPE ROUTE

The length of the escape route is the distance a person must travel from the farthest point in the building or facility to the nearest safe exit that leads out of the hazard area. This distance includes passage through rooms, corridors, stairways, and other transitional spaces that form part of the escape route.

The length of the escape route is normatively determined by a number of factors – the number of escape exits, the functional fire hazard class, the storey and degree of fire resistance of the building, the presence of an automatic fire alarm system, and an automatic sprinkler fire extinguishing system.

Evacuation route in a room

The length of an escape route in a room is the distance a person must travel to the nearest means of escape, not taking into account any furniture or equipment located there.

Where only one means of escape is provided, the length from the furthest point in the room to it shall not exceed 20 m. Ordinance No. Iz-1971 (2009) provides for an allowance of up to 30 m for industrial buildings in which solid combustible materials or liquids with a flashpoint exceeding 55 °C are used, provided that the room is located in a single-storey building constructed to first class fire resistance and that an automatic fire alarm system and an automatic sprinkler system are in place. In single-storey buildings with first- or second-class fire resistance, the maximum escape route distance shall be limited to 50 m if the room involves the use of non-combustible substances or materials in a hot or glowing state (emitting radiant heat, sparks, or flames), or if it contains both non-combustible and combustible substances or materials used in wet processes.

The evacuation route from any point of baths, saunas, swimming pools, spas, and the like shall be permitted to be of a one-direction length not exceeding 50 m.

Where two dispersed means of escape are provided from one room, the length of the escape route to the nearest means of escape shall not exceed 40 m. Escape routes are dispersed when the angle between the directions to them from the farthest point in the room (relative to all escape routes in the room) is greater than 45° (Ordinance No. Iz-1971, 2009).

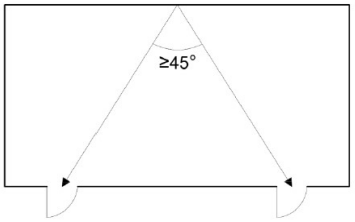


Figure 1. *Dispersed evacuation exits*

An increase in escape route lengths is permitted – up to 60 meters in rooms within industrial buildings that use solid combustible materials or liquids with a flash point above 55 °C, and up to 100 meters in rooms where non-combustible substances or materials are used in a hot or glowing state (emitting radiant heat, sparks, or flames), or where both combustible and non-combustible materials are used in wet processes. These extended lengths are allowed under conditions similar to those applied to one-way escape routes.

Where an area without direct visibility to the means of escape is provided in a room, the length of the route in that area shall be limited to 20 m, and the entire escape route to the nearest exit shall not exceed 40 m.

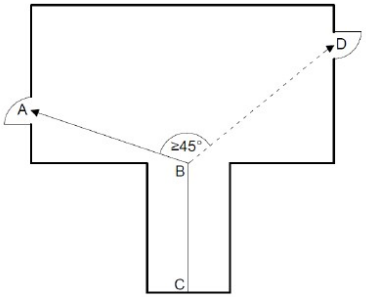


Figure 2. *Length of road from dead-end section*

CB < 20 m;
ABC or DBC < 40 m;

Where the escape route has to pass through an adjacent room, additional measures shall be provided to ensure the safety of the occupants, and the length of the escape route from the furthest point in the internal room to the escape exit from the room through which it passes shall not exceed 20 m. Evacuation through more than one adjacent room shall not be permitted.

Evacuation route to the final evacuation exit

The evacuation of occupants does not end when the occupants leave the premises. Evacuation routes continue through corridors, stairwells, lobbies, etc.

Maximum lengths of evacuation corridors are provided to ensure the safety of residents.

Where it is possible to evacuate in two or more directions, the length from the evacuation exit of each room to a stairway entrance or exit directly to the outside shall not exceed 40 m.

Where corridors are capable of one-way escape, their length shall be limited to 20 m. Similarly, corridors with one-way escape and longer than 10 m (from the doors of the rooms farthest away to the point of alternative escape) shall be separated from their adjacent rooms by self-closing smoke-tight doors with a fire resistance of no less than EI 30 for buildings of class I, II, and III fire resistance and EI 15 for buildings of class IV fire resistance. Characteristics of fire-resistant doors are described in detail in Simeonova (2024b).

Additional requirements for escape routes

The length of escape routes shall be normalized to an exit leading to the outside, an entrance to an escape stairway, or a protected area. A protected area is an area protected by fire-resistant barriers from other areas and is provided with an independent escape route (Ordinance No. Iz-1971, 2009). Partitions to other areas shall be designed as fire walls with fire resistance EI 60, and doors in them shall be self-closing, smoke-tight, and EI 60 fire-resistant. All requirements for fire doors are described in Simeonova (2024a).

Evacuation time

Permissible evacuation time

The maximum permissible time for leaving the premises and buildings is set in the regulations of the Republic of Bulgaria. This time is in direct correlation with the degree of fire resistance. For leaving premises intended for more than 100 persons in public buildings, it is 1 minute, for buildings of class I or II fire resistance, it is 2 minutes. The times for leaving the building are 1 minute and 6 minutes, respectively.

The permissible evacuation time from auditoriums with more than 3000 seats shall be determined in relation to the volume of the room accordingly (Ordinance No. Iz-1971, 2009):

- up to 30 000 m^3 – 2.0 min;
- up to 100 000 m^3 – 2.2 min;
- up to 200 000 m^3 – 3.0 min;
- greater than 200 000 m^3 – 4.0 min.

Production and storage rooms where the formation of an explosive vapour-air or dust-air mixture is possible must be evacuated in less than 0.5 minutes. In production and storage rooms in which solid combustible materials or liquids with a flammable temperature above 55 °C are used or stored, the evacuation of occupants must be completed in less than 1 minute.

Fire hazards directly affect the ability to safely exit a building by threatening human life, but they also significantly complicate the process of evacuation from buildings. These hazards include high temperature, smoke, toxic gases, and reduced visibility and they commonly lead to panic.

Calculation methods for determining the evacuation time

To determine the calculated evacuation time, it is necessary to divide the evacuation path of the residents into separate sections. Separate sections shall be provided where there is a passageway or doorway, a stairway, or a change in width of the path. Escape routes shall be subdivided into horizontal and inclined routes.

The home stretch is where people's movement is formed – the aisles between workstations, between rows of chairs in viewing rooms, around equipment, etc.

The total length of the escape routes shall be determined along their centrelines and shall be equal to the sum of the lengths of the individual sections. In determining the computational evacuation time, the time of the farthest person is sought, which is formed either by the longest evacuation path or by the path that is travelled at the highest density of human flow.

"Escape route length" method

This method is suitable for determining the calculated evacuation time from rooms designed for fewer than 50 persons.

For each of the sections, the human flow density Da_i [person/m^2] and the section length l_i [m] are determined.

For intermediate values of human flow density in the section, the nearest higher value of Da_i from Table 11 of Ordinance No. Iz-1971 (2009) shall be assumed.

Values of Da_i above the cutoff are assumed to be the human flux density cutoff.

The duration of the movement in individual sections is determined by the following formula:

$$\tau = \frac{1}{v} [min]. \quad (1)$$

The time to leave the room is calculated as the sum of the travel times through the sections, starting from the farthest point of the room.

$$\tau = \sum \tau_1 + \tau_2 + \tau_3 + \cdots + \tau_n [min] \quad (2)$$

"Specific throughput of escape route sections" method

This method takes into account the intensity of human movement, which makes it more accurate when the number of people in a room exceeds 50. Also, the method takes into account the delay time when the specific throughput of the evacuation section is greater than the maximum for this type of section (horizontal or inclined).

The method for calculating the time required to leave the initial sections of the room is analogous to the "escape route length" method.

$$\tau = \frac{1}{v}[min] \quad (3)$$

For each subsequent section, its specific capacity is calculated as a function of the specific capacities and widths of the preceding sections that flow into it.

$$q_i = \frac{q_{i-1}\delta_{i-1}}{\delta_i}\ [people/m.min], \quad (4)$$

where:

q_i – the specific throughput of section i [people/m.min];

δi – calculated width of section i [m];

$\delta_{(i-1)}$ – the calculated width of the previous section i-1[m].

If more than one upstream reach flows into the reach under consideration, its specific capacity is determined as follows:

$$q_i = \frac{\Sigma q_{i-1}\delta_{i-1}}{\delta_i}[\mathbf{people/m.min}]. \quad (5)$$

After determining q_i, it is necessary to check against the maximum q_{max} for this type of section (horizontal or inclined).

If $q_i < q_{max}$, then there is no delay in the movement of people in this section and their traversal time will be calculated using the formula

$$\tau = \frac{1}{v}\ [min]. \quad (6)$$

If $q_i > q_{max}$, it means that there will be a slowdown in the flow of people in the section under consideration. This leads to the need to calculate the delay time, which will increase the travel time through the section.

The transit time of a section where there is a delay is calculated using the formula

$$\tau_i = \frac{l_i}{v_{limit\ value}} + N_i\left(\frac{1}{q_{limit\ value}\cdot\delta_i} - \frac{1}{\Sigma q_{i-1}\delta_{i-1}}\right). \quad (7)$$

Thus, the time to pass through each of the evacuation sections is calculated, and the time to leave the room is calculated, similarly to the "evacuation path length" method – the sum of the times to pass through the sections starting from the farthest point of the room.

$$\tau = \Sigma\tau_1 + \tau_2 + \tau_3 + \cdots + \tau_n\ [min] \quad (8)$$

Building evacuation time

After determining the calculation time for leaving the room, it is necessary to make a comparison with the legally permissible one. If the calculation time is less than the normative time, then a check shall be performed for the time required to leave the endangered area – to an exit leading directly outside or to a protected area.

The time for leaving the building shall be similar to that for leaving the premises.

It is necessary to calculate the travel time through each of the evacuation sections as well as the cumulative time required to leave the building. It shall then be checked whether the calculated time is less than the norm.

Doorways/passage

Doorways/passage openings shall be defined as separate sections. Two cases are possible in relation to the width of the doors – up to 1.6 m or 1.6 m or more. For each of the options, their specific throughput is tabulated, and for those up to 1.6 m wide, the limiting value is assumed in all cases.

In a similar way to the "specific throughput of escape route sections" method, the specific throughput for the section is calculated.

There are three possible cases against the result:

- If $q_i < q_{max}$ and ℓ<0.7 m, then $\tau_i = 0\ [min]$;

ℓ – length of the passage (depth of the door frame);

- If $q_i < q_{max}$ and ℓ>0.7 m, then the transit time is calculated using the formula

$$\tau = \frac{1}{v}\ [min]; \quad (9)$$

- If $q_i > q_{max}$, then the transit time is calculated by determining the delay time using the formula

$$\tau_i = \frac{l_i}{v_{limit\ value}} + N_i\left(\frac{1}{q_{limit\ value}\cdot\delta_i} - \frac{1}{\Sigma q_{i-1}\delta_{i-1}}\right)\ [min]. \quad (10)$$

The resulting times required to pass through the doors need to be added to the times required to pass through the evacuation sections in the room or building and the resulting sum will represent the calculated time to exit.

CONCLUSION

The analysis of the recent amendments to the legislation regulating the requirements for safe evacuation of people from buildings in the Republic of Bulgaria shows a significant step towards raising fire safety standards. Refining the criteria for determining the number of occupants, optimising the permissible lengths of evacuation routes, and updating the methods for calculating evacuation times have a direct impact on the protection of human life in crises.

The requirements introduced impose greater responsibility in the design, operation, and maintenance of buildings, emphasising the need for a holistic, systematic approach to risk assessment. Applying the regulations in practice requires not only strict adherence to the prescriptions, but also a thorough understanding of the basic principles of fire safety, in the context of the specific architectural and functional characteristics of each site.

The continuous improvement of the regulatory framework and its adaptation to modern conditions constitute the basis for the sustainable development of a safe and secure living and working environment.

REFERENCES

Dimitrov, S. (2019). *Fire Safety of Buildings and Construction Facilities.* Sofia.

EN 1125 Building hardware – Panic exit devices operated by a horizontal bar, for use on escape routes – Requirements and test methods. (2008).

Ordinance No. Iz-1971. (2009). *Ordinance No. Iz-1971 of 29.10.2009 on building-technical rules and regulations for ensuring fire safety.* (OJ No. 96 of 4 December 2009, as subsequently amended and supplemented, OJ No. 91 of 29.10.2024).

Simeonova, N. (2024a). Essential characteristics, construction and field of application of fire doors. *XXIV international scientific conference VSU'2024*, 331-340.

Simeonova, N. (2024b). Types of doors with fire characteristics and upcoming changes in their documents for incorporation. *XXIV international scientific conference VSU'2024*, 341-352.

Simeonova, N. (2025). *Control of the compliance of the construction products used in the buildings and facilities with the regulatory requirements for fire safety.* Sofia: Publishing house for territorial planning and construction – ITUS 98 Ltd.

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ADVANCING THE CIRCULAR ECONOMY: THE ROLE OF KEY SECTORS IN DEVELOPING COUNTRIES

Abstract: *The implementation of the circular economy in industry is essential for reducing waste, optimizing resource use, minimizing environmental impact, and fostering sustainable economic growth through recycling, reuse, and innovative production and consumption models. This paper examines the potential for adopting circular economy principles in key sectors of developing economies, with a particular focus on the Republic of Serbia. The analysis explores four critical sectors: construction, textiles, agriculture and food, and plastic packaging by evaluating their current practices, opportunities for circular transition, and the challenges involved. By assessing these sectors, the paper provides valuable insights into how Serbia can move toward a more sustainable and resource-efficient economy, aligning with broader global objectives of sustainability and circularity.*

Keywords: circular economy in Serbia, key sectors for circular transition, circular transition in developing countries

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INTRODUCTION

At a global level, the issue of sustainable development and efficient use of resources is gaining increasing importance, especially in the context of climate change, resource depletion and the increasing amount of waste generated. The traditional linear economic model of "take, make, dispose" has shown numerous weaknesses that lead to significant negative environmental impacts. In a linear economy, the production process operates by extracting resources from the environment and converting them into finished products, which are then distributed on the market and consumed. At the end of their life cycle, the products created in this way become waste, which often ends up in landfills or incinerators without further use. The linear economic model ignores the potential for material reuse, increases the demand for continuous extraction of raw materials, and contributes to the escalation of air, water, and soil pollution, as well as the degradation of ecosystems.

In response to these challenges, the concept of the circular economy has been developed, which aims to achieve a closed-loop material cycle. The circular economy is based on three key principles: elimination of waste and pollution, circulation of products and materials (at their highest value), and regeneration of natural systems (Ellen MacArthur Foundation, 2013). The circular economy represents an environmental imperative and at the same time offers significant economic potential, stimulating new jobs, diverse innovations, and sustainable economic growth. In developing countries, this concept is increasingly integrated into strategic plans and legislative frameworks. However, in developing countries, such as the Republic of Serbia, the transition to circular practices is still in an early stage of development.

This research aims to explore the potential for implementing circular economy principles in four key sectors of the Serbian economy: the textile industry, the agriculture and food sector, the plastic packaging sector, and the construction industry. By examining existing practices, potential for transformation, and barriers to implementation, this research seeks to provide insight into how Serbia can improve the sustainability of its economy and contribute to the achievement of the global sustainable development goals.

CONCEPTUALIZING THE CIRCULAR ECONOMY

The circular economy poses a significant challenge for every national economy, primarily due to the lack of a generally accepted definition (Kirchherr et al., 2017; Popović & Radivojević, 2022). An additional challenge lies in the fact that the circular economy is a holistic and multidimensional concept, and its definition often depends on the perspective of the entity defining it. As a result, the literature contains a wide range of different definitions.

The first steps towards the conceptualization and institutionalization of the circular economy within the European Union were taken with the adoption of the Circular Economy Action Plan in 2015, entitled "Closing the Loop – An EU Action Plan for the Circular Economy" (European Commission, 2015). Although the document is explicitly focused on

promoting the principles of the circular economy, it primarily presents legislative proposals and action plans related to raw materials management and waste management, without providing a concise and universally accepted definition of the circular economy model.

Other official European documents offer more practical definitions, including one of the most used, which describes the circular economy as a model of production and consumption that involves the reuse, repair, refurbishing, and recycling of existing materials and products in order to extend their life cycle as long as possible within the economy. In such a system, waste is converted into a resource, thereby reducing the total volume of waste destined for disposal and at the same time reducing the need to extract new resources.

In a circular economy, the design of products, materials, and infrastructure is oriented towards reuse and long-term resource efficiency from the outset. Rather than allowing waste to be generated and managed after consumption, a more efficient approach emphasizes waste prevention at source. Extending the life of a product through repair, remanufacturing, and reuse reduces the need for primary raw materials. When a product can no longer be used, its components can be reintegrated into new production processes. Biodegradable materials can be composted, returning nutrients to the soil. This approach supports resource conservation and mitigates negative environmental impacts. Unlike systems based on the depletion of natural resources, a circular economy emphasizes the regeneration of ecosystems. Nature does not create waste – waste is exclusively a human invention.

Circular economy strategies are aligned with R-frameworks, which serve as practical guidelines for implementing circular practices. These R-frameworks bridge the gap between theoretical concepts and real-world applications. The circular economy can be represented through the 15R framework (Fröhlich et al., 2024) – a comprehensive range of strategies for closing material loops and achieving sustainability goals.

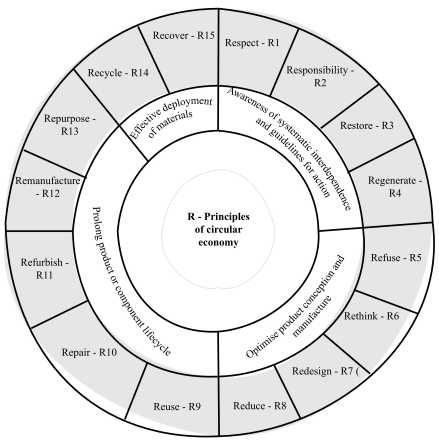


Figure 1. *R principles of circular economy*

The presented diagram offers a comprehensive visualization of the basic circular principles, structured to illustrate their interrelationships and their joint contribution to strengthening circularity within economic systems.

The true meaning of the circular economy becomes more evident when examining the business models that enable its practical application. Circular economy business models are concrete strategies that companies adopt to extend the life cycle of products, optimize resource use, and minimize generated waste – thereby creating economic, environmental, and social benefits. The five basic circular business models can be applied individually or in combination (Lacy et al., 2014):

- Circular supply chain – reforming use of renewable, recyclable, or biodegradable resources;
- Recovery and recycling – extracting value from waste through reuse or material recovery;
- Product life extension – prolonging the use phase of products through maintenance, repair, or refurbishment;
- Sharing platforms – optimising capacity use and maximizing asset utilization through shared access;
- Product as a service – delivering performance or outcomes instead of transferring product ownership.

These business models play a crucial role in translating the principles of the circular economy into strategies that are easily achievable and can be implemented.

THE ROLE OF KEY SECTORS IN CIRCULAR ECONOMY IMPLEMENTATION

The implementation of the circular economy in industrial sectors is an important step towards achieving sustainable economic development. For developing countries, such as the Republic of Serbia, directing resources and policies towards the application of circular principles and models can significantly contribute to the development of circularity at the national level. At the European Union level, seven priority sectors have been identified as key for the implementation of the circular economy: plastics, textiles, electrical and electronic waste, food, water and nutrients, packaging, batteries and vehicles, and construction (European Commission, 2020). On the other hand, during the negotiations on accession to the European Union, the Republic of Serbia adopted legal frameworks in the field of waste management, circular economy, and environmental protection, committing to transpose the regulations in these areas into its national legislation.

Accordingly, the Roadmap for Circular Economy in Serbia directly addresses sectors that have significant potential for implementing circular economy practices (Ministry of Environmental Protection, 2020):

- manufacturing industry with a focus on the textile sector;
- agriculture and food – surpluses and food waste;
- plastics and packaging;
- construction sector.

The four sectors mentioned above are of particular importance in the transition to a circular economic

model in the Republic of Serbia. The identified key sectors are responsible for significant use of natural resources, generation of large amounts of waste, and emission of harmful gases. By applying circular principles, it is possible to reduce resource consumption and mitigate environmental impact. The application of circular economy practices in these sectors contributes to the reduction of waste and pollution, but also creates new economic opportunities, improves the efficiency of production and consumption, and supports long-term sustainability. Given their significant role in the overall use of resources and the generation of waste, these sectors are essential for achieving the goals of the circular economy and sustainable development in the Republic of Serbia.

To comprehensively assess the role and potential of these sectors in the transition to a circular economy, it is necessary to apply a structured and methodologically appropriate research framework. In addition to identifying their theoretical relevance, systematic research is needed to assess the extent to which circular economy principles are currently being applied and to explore the specific opportunities and constraints that characterize each sector in Serbia. Accordingly, the research methodology outlined below provides a basis for examining these dimensions through qualitative and comparative analysis.

The methodological approach of this research is based on a qualitative analysis of secondary sources (desk research) and a comparative sectoral review, with the aim of identifying the current state, challenges, and potential for the implementation of the circular economy in selected economic sectors of the Republic of Serbia. Such an analysis allows for a holistic examination of the implementation of the circular economy in the context of a developing country, considering the economic, social, and environmental dimensions of sustainability.

Textile sector

The textile industry represents one of the most important sectors of the global economy, playing a key role in international trade, employment, and economic development – a trend that is similarly reflected in Serbia (Radić Milanović, 2024).

In recent years, there has been a significant increase in the production of textiles, clothing and fashion products, primarily due to the growth of the global population and the improvement in the standard of living of the world's population. It is estimated that the textile sector has doubled, mainly due to the expansion of the middle class and the increasing prevalence of rapid fashion cycles (i.e. fast fashion), the culture of instant gratification and the increase in consumption per capita. These trends have contributed significantly to the ecological imbalance at the global level (Denić et al., 2021).

The production, distribution, and consumption of textiles contribute to high levels of water, energy, and chemical use, as well as significant generation of waste, while textile recycling rates remain extremely low. In particular, the low rates of recycling of textiles into textiles are particularly pronounced. Current practices in this sector are predominantly based on a linear model, which is characterised by mass production of cheap clothing, minimal oversight of product life cycles, and the almost complete absence of systems for the collection and processing of textile products at the end of their life. While there are initiatives focused on upcycling and local sustainable fashion production, they remain marginal and lack institutional support.

In the Republic of Serbia, data on waste generation by origin (excluding municipal waste from households) show that the leather, fur, and textile industries generated a total of 13,062 tonnes of waste in 2023. Of this amount, only 1,508 tonnes of textile waste underwent R operations (SEPA, 2024a). Textile waste accounts for 2.8% of the total municipal waste. In Serbia, most textile waste ends up in landfills, while consumer awareness of reuse and recycling remains limited.

Establishing a textile industry in line with the principles of the circular economy requires continuous efforts and investments. A crucial step in this transition is a change in the design process that enables the reuse and recycling of products, thereby bringing environmental, social, and economic benefits while reducing the negative impacts of the textile sector. Circular design in textile products includes strategies that aim to extend the life cycle of textiles, clothing and fashion products, promote material recycling, and minimize waste generation in this sector. These strategies can be broadly categorized into two key areas: design for material circularity and design for durability (Circular fashion, 2021).

The new circular system for the textile industry is based on four key principles (Ellen MacArthur Foundation, 2017):

- eliminating harmful substances and microfiber release;
- increasing utilization of textile products,
- improving the recycling sector;
- efficient resource use and transition to renewable sources.

Based on the above principles, it can be concluded that the potential for a circular approach to this sector includes the development of systems for collecting, sorting, and recycling textiles, and the use of natural and biodegradable fibres, encouraging local high-value production and extending the life of clothing through repairs, replacements, and reuse.

In the Republic of Serbia, the main challenges for implementing a circular economy in this sector are:

- the lack of infrastructure for processing textile waste;
- the low level of awareness and environmental consciousness among producers and consumers;
- the dominance of foreign brands that do not follow circular principles in local supply chains;
- the lack of incentive mechanisms and policies, etc.

The textile industry in Serbia has the opportunity to contribute to local economic development and

environmental preservation through innovative business models, provided that appropriate institutional conditions and stronger cooperation between the design, production, and recycling sectors are created.

Agriculture and food sector

In addition to the textile sector, agriculture and the food industry show significant potential for the implementation of circular economy principles in Serbia. The high consumption of resources such as water and land, together with significant waste generation, places this sector at the centre of the circular transition process. Globally, agriculture accounts for a significant share of greenhouse gas emissions, while the food industry is one of the largest producers of waste (including food waste), packaging, and production residues.

The agricultural sector of the Republic of Serbia contributes about 10% of the gross domestic product. Agricultural residues primarily originate from agriculture, forestry, the food industry, and the wood processing industry. These residues can be categorized into three main groups: residues from the cultivation of field crops, residues from fruit production, and residues from livestock farming (Ministry of Environmental Protection, 2022). On the other hand, the agriculture and food industry sector generated a total of 232,302 tonnes of non-hazardous waste and 2 tonnes of hazardous waste in 2023. It is estimated that around 247,000 tonnes of edible food are thrown away in Serbia annually – more than 40 kilograms per capita, while the estimated amount of food waste from 'farm to fork' reaches up to 900,000 tonnes (SEPA, 2024a).

Current practice in Serbia indicates that most agricultural and food products do not apply the principles of the circular economy. These sectors face significant food losses, especially at the farm level and during distribution, while waste is largely not recycled or reused. In addition, the use of chemicals and pesticides in agriculture is still widespread, which directly contributes to soil degradation and water pollution.

The principles of the circular economy in agriculture and the food industry are based on waste prevention and its reuse. A key step towards the proper management of this type of waste is its separation, which is a necessary condition without which the implementation of circular economy practices becomes extremely difficult.

The potential for a circular transition in these sectors is multifaceted (USDN, 2025):

- Food waste prevention – These strategies offer the highest economic value per ton of food and require minimal capital investment. The focus is on preventing food waste before it occurs, through measures such as improved logistics, optimized inventory management, and consumer education.
- Food rescue – These strategies have significant potential to reduce hunger and make better use of edible surplus food. Key initiatives include tax incentives for food donations and technological solutions, such as software platforms that connect food donors with organizations that distribute food to vulnerable populations.
- Food recycling and reuse – These strategies contribute to reducing greenhouse gas emissions but require higher capital investment and infrastructure support. Key approaches include composting, anaerobic digestion, water recovery plants, etc.

When analyzing the Serbian agricultural and food sector, several main challenges stand in the way of adopting circular practices:

- There is a clear lack of infrastructure for efficient food and agricultural waste treatment.
- Small and medium-sized farmers often struggle to put the circular principes into practice, due to limited resources as well as knowledge.
- The shift towards more sustainable models such as urban and vertical farming, organic farming, and aquaponics, is slowed by a lack of financial incentives and political support.

Nevertheless, the agriculture and food sector in Serbia holds significant potential for the application of circular practices.

Plastics and packaging sector

Plastic waste causes numerous environmental problems, which are the result of the accumulation of plastic products and plastic particles in the environment (WEF, 2022). The aforementioned environmental problems have a negative impact on the environment, but also on human health. The advantage of plastic products is their low production cost, durability, and functionality, while the disadvantages become apparent through their long-term use in disposable products and the significant amount of waste generated, which is not biodegradable. One of the most critical products in terms of implementing the principles of the circular economy is plastic packaging. Plastic packaging presents one of the biggest challenges in the context of the circular economy, both at the global and local levels.

In Serbia, as in many other countries, plastic packaging accounts for a significant portion of total waste, while the recycling rate of plastic materials remains very low. Plastic waste accounts for 12.1% of total municipal waste generated in the Republic of Serbia, while plastic packaging accounts for 25% of total packaging waste (SEPA, 2024b). It is important to note that in Serbia, the largest share of plastic packaging waste comes from the food and beverage sector. Current practices in Serbia regarding plastics and plastic packaging are characterized by a high level of single-use plastic products, especially in the food and retail sectors. Although there are some efforts to reduce the use of plastics (e.g. banning plastic bags in retail), the issue of plastic packaging has not yet been fully resolved. The collection and recycling of plastic materials is also at a low level, as recycling capacities are not sufficiently

developed, and consumers are often not fully informed about proper waste segregation.

To effectively integrate circular economy principles into the plastics and plastic packaging sector, systemic changes need to be implemented through several key strategies:

- improving the design of plastic products and plastic packaging;
- extending the lifespan of plastic products,
- effectively managing plastic waste;
- restoring natural systems and reducing negative environmental impacts (e.g. use of bioplastics);
- regulatory and economic mechanisms to promote circularity (e.g. extended producer responsibility).

In the plastics and packaging sector, numerous challenges hinder the implementation of a circular economy. One of the key issues is the lack of infrastructure for recycling plastic materials, which further complicates the process of separating different types of plastics. In addition, low public awareness and insufficient engagement regarding the proper disposal and recycling of plastics pose significant obstacles. The high costs of implementing advanced recycling technologies and the production of bioplastics are often obstacles for small and medium-sized enterprises. Moreover, the market for recycled plastics is still underdeveloped and insufficiently competitive compared to products made from virgin plastics, which further slows down the transition to more sustainable plastic waste management models.

Despite these challenges, the plastics and packaging sector offers significant opportunities for the transition to a circular economy, particularly through innovations in materials, legislative initiatives aimed at reducing waste, and the development of recycling infrastructure. By implementing green initiatives and systemic changes, this sector can become a key element in achieving sustainability in Serbia.

Construction sector

The construction sector in Serbia is one of the largest consumers of natural resources and producers of waste. According to available data, construction waste accounts for a significant share of total municipal and industrial waste, while only a small percentage of the materials used are recycled. The share of construction waste in total waste generated was 0.36% in 2022, or 630,134 tonnes. Therefore, the introduction of circular economy principles in the construction sector is becoming increasingly important in order to reduce resource consumption, extend the lifespan of buildings, and minimize the amount of construction waste. The possibilities for implementing circular economy measures in construction should be defined within the entire life cycle of buildings (EDA, 2022).

Current practice in the construction sector generally does not include systematic selection, recycling, and reuse of construction waste. Demolition of buildings is often carried out without a plan for material conservation, and the waste is mainly disposed of in landfills. There are isolated examples of recycled concrete and the use of secondary materials, but they are not yet part of standard practice.

The potential for a circular transition is significant. Applying the principles of the circular economy in the construction sector can contribute to:

- reuse and recycling of construction materials (concrete, metal, glass, wood);
- reduction of the consumption of primary raw materials;
- reduction of carbon dioxide emissions by using local and sustainable materials;
- application of modular and flexible architecture that allows for adaptation and deconstruction without destruction.

Challenges in the construction sector in Serbia include the lack of infrastructure for sorting and processing construction waste, weak implementation and monitoring of legal regulations related to construction waste management, low awareness among stakeholders (investors, designers, contractors) about the benefits of a circular approach, as well as the lack of financial incentives for green construction and sustainable reconstruction.

Despite these challenges, the construction sector has great potential to become a leader in the circular transition in Serbia, provided that the regulatory framework is improved, the market for recycled materials is stimulated, and educational initiatives are implemented within the construction industry.

CONCLUSION

The sectors analyzed, each at different stages of development and readiness for the application of the principles of the circular economy, will certainly face different challenges. Even though each of them shows potential, there are also obstacles that must be adequately addressed in order to ensure sustainability and resource efficiency. The circular economy offers enormous opportunities for reducing waste and using resources, while minimizing environmental impact, especially in developing countries such as Serbia. The application of circular principles in the four sectors examined can contribute to sustainable economic development, increased competitiveness, and a reduced ecological footprint at the national level.

Despite the significant challenges and obstacles outlined in the paper for each sector, the potential for a circular transition remains significant. It is necessary to establish appropriate institutional frameworks, provide incentives for innovation, and promote education among all stakeholders involved in the transition process – from producers to end consumers.

In the coming years, the circular economy is expected to become an environmental necessity, but also an economic imperative. As such, countries such as Serbia will need to align with global trends and integrate circular practices into their development strategies, especially in sectors that are presented as key in official

documents. This shift will enable the creation of a more sustainable and efficient economic model, fostering long-term prosperity.

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REFERENCES

Circular fashion. (2021). Circular design kit: Design strategies for material cyclability and longevity. https://circular.fashion/downloads/2021_circular.fashion_circular_design_kit.pdf

Denić, D., Bošković, G., Pavlović, A., & Jovičić, N. (2021). The circular economy in the textile industry. *Tekstilna industrija*. *69*(1), 47-57. https://doi.org/10.5937/tekstind2101047D

EDA – European Demolition Association. (2022). Guide about Construction and circular economy. https://www.europeandemolition.org/library/guide-about-construction-and-circular-economy

Ellen MacArthur Foundation. (2013). *Towards the circular economy – Economic and business rationale for an accelerated transition.* Cowes, UK: Ellen MacArthur Foundation Publishing.

Ellen MacArthur Foundation. (2017). *A new textiles economy: redesigning fashion's future.* Cowes, United Kingdom.

European Commission. (2015). Closing the loop – An EU action plan for the Circular Economy. Brussels, 2.12.2015. COM(2015) 614 final.

European Commission. (2020). Circular Economy Action Plan – For a cleaner and more competitive Europe.

Fröhlich, E., Steinbiß K., Schmiedeknecht, M., & Loza Adaui, C. (2024). Circular economy in sustainable supply chains – A global perspective on challenges, concepts and cases, Springer Nature Switzerland AG.

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: an analysis of 114 definitions. *Resour. Conserv. Recycl. 127*: 221-232. https://doi.org/10.1016/j.resconrec.2017.09.005

Lacy, P., Keeble, J., & McNamara, R. (2014). Circular Advantage: Innovative Business Models and Technologies to Create Value in a World without Limits to Growth. Accenture. https://circularprocurement.ca/wp-content/uploads/2021/02/Accenture-Circular-Advantage-Innovative-Business-Models-Technologies-Value-Growth.pdf

Ministry of Environmental Protection. (2022). Waste management program in the Republic of Serbia for the period 2022-2031.

Ministry of Environmental Protection. (2020). Roadmap for Circular Economy in Serbia.

Popović, A., & Radivojević, V. (2022). The circular economy – principles, strategies and goals. *Economics of sustainable development, 6* (1): 45-56. https://doi.org/10.5937/ESD2201045P

Radić Milanović, S. (2024). Circular economy in the context of the textile industry. *Planiranje i upravljanje regionalnim razvojem*. *39*(04): 546-549, https://doi.org/10.24867/26LR01Radic

SEPA – Serbian Environmental Protection Agency (2024a). Report on the State of the Environment in the Republic of Serbia 2023. Belgrade, Serbia.

SEPA – Serbian Environmental Protection Agency (2024b). Report on Waste Management in the Republic of Serbia 2011-2023. Ministry of Environmental Protection. Belgrade, Serbia.

USDN. Preventing Wasted Food. Retrieved March 27, 2025, from https://sustainableconsumption.usdn.org/initiatives-list/preventing-wasted-food

WEF – World Economic Forum. Retrieved April 15, 2025, from https://www.weforum.org/stories/2022/01/plastic-pollution-climate-change-solution/

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POTENTIAL AND IMPACT OF GREEN HYDROGEN ON GLOBAL ENERGY SECTOR

Abstract: *The use of green hydrogen represents the most likely direction for the transformation of the energy sector of modern society, on the path of transition towards the use of sustainable energy in the future. Only green hydrogen, produced by using renewable energy sources, can significantly contribute to achieving the goals of the sustainable energy strategy, with a particular contribution to reducing carbon dioxide and global greenhouse gas emissions. This paper analyzes the current state and potential of the use of green hydrogen in different sectors, with a special emphasis on Europe, as a leader in the implementation of hydrogen-based technologies. A comparative analysis of cases shows how different approaches can contribute to accelerating the adoption of green hydrogen on a global scale. Through this paper, the aim is to provide a comprehensive overview of the current state, challenges and opportunities for the wider application of green hydrogen, and to point out its potential to become a key link in sustainable energy transformation and reduction of dependence on fossil fuels.*

Keywords: renewable energy sources, green hydrogen, energy demands

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INTRODUCTION

Green hydrogen, produced through renewable energy-powered electrolysis, is emerging as a pivotal element in the global transition towards sustainable energy systems. This fuel can be used in heavy industries and transportation, leading to a growing demand, especially in Europe, where it is seen as a way to reduce reliance on fossil fuels (Le et al., 2023). Green hydrogen's adaptability positions it as a cornerstone in the energy matrix of the future, with a critical role in industrial processes because of its unique characteristics and the pressing need for cleaner energy alternatives (Segovia-Hernandez et al., 2024). Hydrogen possesses a high energy content per unit mass and produces only water when burned or used in a fuel cell, making it an attractive substitute for conventional fuels (Segovia-Hernandez et al., 2024). Hydrogen can also store renewable energy, avoiding curtailment during periods of high production and low demand (Silva et al., 2024). Ambitious hydrogen strategies, such as those outlined in the European Green Deal, aim to produce millions of tons of green hydrogen annually (Franco, 2025). However, the success of these strategies hinges on careful planning and infrastructure development to ensure efficient storage, transfer, and utilization of green hydrogen (Franco, 2025). Its versatility extends to various sectors, including power generation, industrial feedstock, and transportation, offering a pathway to decarbonize hard-to-abate sectors (Papadaki et al., 2025). Green hydrogen is capable of promoting sustainable energy development and is gaining attention in the current global energy transition framework (Guarieiro et al., 2022). A significant investment is needed to increase green hydrogen production and build the required infrastructure (Nayebossadri et al., 2025). Major challenges include the high costs of production and the lack of infrastructure for distribution (Chiroșcă et al., 2024). The production of green hydrogen through electrolysis is energy-intensive and costly, but it has the potential to considerably lower emissions when using renewable electricity (Franco, 2025). However, the potential of green hydrogen to replace fossil fuels in various sectors, including energy production, transportation and industry, makes it a worthwhile pursuit (Chiroșcă et al., 2024). The European Commission's REPowerEU plan targets the production and import of 20 million tons of green hydrogen by 2030, emphasizing the role of green hydrogen in decarbonizing sectors that are difficult to electrify (Zeyen et al., 2023). Since the Paris Climate Agreement in 2015, the adoption of green hydrogen has

become a key strategy for governments and businesses striving to meet global temperature targets and reduce greenhouse gas emissions (Guarieiro et al., 2022). This involves incorporating renewable energy sources like solar, wind, and hydroelectric power to produce hydrogen (Nayebossadri et al., 2025). Despite its potential, green hydrogen faces hurdles, including high production costs and the need for infrastructure development to facilitate its use (Franco, 2025). These issues are particularly relevant in isolated locations, where green hydrogen can offer a sustainable alternative to traditional fossil fuels (Zhao et al., 2025) (Superchi et al., 2025). Islands can especially benefit from green hydrogen technologies, substantially contributing to mitigating issues related to energy isolation and potentially minimizing emissions (Superchi et al., 2025). Integrating green hydrogen addresses long-term and short-term energy storage issues while also providing the possibility of complete decarbonization (Superchi et al., 2025). For instance, some studies have explored using hydrogen production systems to replace diesel generators with wind and photovoltaic systems, demonstrating that a fully renewable layout is feasible, but the hydrogen storage cycle would need three times the annual peak capacity of RES (Superchi et al., 2025). Green hydrogen is currently more expensive but will benefit from declining renewable electricity costs and government incentives (Curcio, 2025). However, uncertainty remains regarding the amount of green hydrogen Europe will need to produce in the coming decades, depending on demand, competition, and the success of carbon capture and storage (Greevenbroek et al., 2024). The deployment of hybrid renewable energy systems on islands demonstrates the importance of public-private partnerships, community involvement, and adaptive technologies in overcoming energy transition challenges (Papadaki et al., 2025). Islands are also uniquely positioned to adopt green hydrogen technologies early because of their decentralized energy systems, which allow for efficient integration of renewable energy sources (Papadaki et al., 2025). They can serve as testing grounds for hydrogen technologies, paving the way for broader adoption (Papadaki et al., 2025). This transition is driven by the need to decrease energy costs and increase energy independence by using local renewable resources (Papadaki et al., 2025). Several pilot projects and practical experiments are currently underway worldwide to develop and test these technologies (Marouani et al., 2023). These initiatives aim to refine the production processes, storage solutions, and infrastructure needed for a hydrogen economy (Hidouri et al., 2025) (Chiroșcă et al., 2024). These projects offer essential insights into the scalability and economic viability of green hydrogen production (Criollo et al., 2024). These projects also facilitate identifying the best hydrogen storage options, a vital aspect for the future of sustainable energy systems (Preuster et al., 2017).

These partnerships and decentralized production potentials are crucial for securing a cheap and reliable future hydrogen supply, which is a prerequisite for affordable energy in systems with high hydrogen proportions (Niepelt et al., 2023). The integration of renewable energy sources with storage systems and conventional sources facilitates overall cost reductions and promotes integrated energy systems (Superchi et al., 2025).

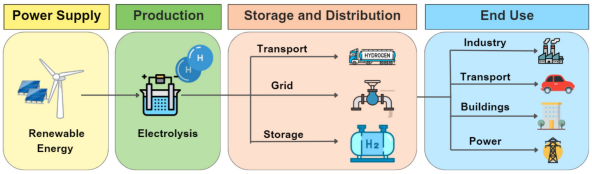


Fig 1. Green hydrogen value chain schematic representation (Gomez and Castro, 2024)

The interconnection and interdependence of hydrogen production, storage, safety, and utilization are critical for achieving a fully renewable and sustainable hydrogen economy (Dawood et al., 2020). Energy storage systems, including green hydrogen, are crucial for supporting fully autonomous electrical grids, especially in remote areas, due to their modularity and ease of installation (Superchi et al., 2025). These systems must be designed to balance energy generation and demand, especially in isolated locations (Icaza et al., 2025). This balance ensures reliability and resilience in the face of fluctuating renewable energy sources (Cheng et al., 2025). These systems require robust monitoring and control to optimize performance and adapt to changing conditions (Useche-Arteaga et al., 2024) (Superchi et al., 2025). System Integration Theory can be applied to renewable energy on islands, addressing the complexity of integrating various renewable energy source technologies with existing grid infrastructure to account for the fluctuation of renewable energy sources and improve overall system performance through coordinated operation and control (Papadaki et al., 2025). It is essential to develop effective distribution networks and infrastructure to ensure the continuous supply of green hydrogen and further reduce production and delivery costs (Gómez & Castro, 2024). Such integration is important to guarantee that renewable energy sources are used efficiently and that hydrogen technologies can be effectively used to store energy (Zhang et al., 2016). What is often overlooked is identifying coherent, scalable strategies that connect technological development with practical implementation in specific sectors (Franco, 2025).

SIGNIFICANCE OF GREEN HYDROGEN IN THE ENERGY TRANSITION

The adaptability of power-to-hydrogen (P2H) facilities is essential for integrating fluctuating renewable energy sources and delivering supplementary regulatory functions (Qiu et al., 2023). Utilizing hydrogen as an energy storage medium allows for the retention of surplus energy generated by renewable sources rather

than curtailment. Sensitivity analysis reveals that the capital cost and discount rate substantially influence the levelized cost of hydrogen generation and storage (Urs et al., 2023). Hydrogen is a promising energy carrier, capable of storing and transmitting substantial energy quantities, with prospective applications in transportation, industrial manufacturing, and heating (Preuster et al., 2017). Moreover, hydrogen generation by electrolysis can be used with renewable energy sources to alleviate the effects of fluctuation on power quality and grid stability (Nguyen et al., 2021). Hydrogen possesses a high energy density and is essential for mitigating the constraints of intermittent renewable energy supply by turning surplus electricity into hydrogen for storage and transportation (Lee et al., 2025). Hydrogen storage is a critical element of a hydrogen system, particularly for large-scale production; yet, existing systems encounter issues related to weight, volume, and hydrogen embrittlement (Meda et al., 2023). Hydrogen contributes to diminishing the carbon footprint in transportation, as it may be generated by electrolysis using excess solar and wind energy (Segovia-Hernandez et al., 2024). In the chemical sector, green hydrogen is essential for the manufacturing of ammonia and fertilizers, as well as for oil refining, hence fostering sustainable industrial practices (Segovia-Hernandez et al., 2024). Hydrogen provides seasonal energy storage solutions, mitigating variations in energy supply and demand (Superchi et al., 2025). Green hydrogen, generated through electrolysis from renewable sources, has environmental advantages by producing no greenhouse gases or air pollutants during combustion, however nitrogen oxides may be created under certain conditions (Nayebossadri et al., 2025). Its adaptability enables utilization across multiple sectors, including transportation, chemical processing, and power generation (Nayebossadri et al., 2025).

CURRENT STATE OF HYDROGEN PRODUCTION TECHNOLOGIES

Consequently, there has been increasing interest in green hydrogen production using electrolysis for large-scale renewable energy applications in various sectors (Kumar and Lim, 2022). Electrolysis-based hydrogen production offers a sustainable method that aligns with global decarbonization efforts, especially when powered by renewable energy sources like solar and wind (Hamedani et al., 2024). Numerous projects are focusing on hydrogen and related domains, reflecting the growing scientific and technical interest in this field (Franco and Giovannini, 2023). The integration of green hydrogen addresses the limitations of intermittent renewable energy sources by providing a sustainable pathway for energy storage and utilization (Kumar & Lim, 2022). Renewable energy sources have minimal greenhouse gas emissions and are abundant and sustainable, ensuring a dependable energy supply and aiding energy security (Mahmoud et al., 2024). These sources can power the production of hydrogen for use directly as fuel, synthetic fuels, ammonia, fertilizers, and heavy oil upgrading (Dinçer, 2011). The flexibility of hydrogen as an energy carrier makes it suitable for various applications, enhancing the overall efficiency and sustainability of energy systems (Ramu & Choi, 2025) (Agyekum et al., 2022). However, there is a need for studies optimizing hydrogen production, especially concerning the integration of offshore ammonia refueling stations (Zhang et al., 2025). Europe is at the forefront of research into these integrated energy systems, exemplified by Belgium's construction of Princess Elizabeth Island, designed as a central hub for offshore power generation (Zhang et al., 2025). Such efforts highlight the geographical synergies and technological potentials in leveraging wind and wave energy for hydrogen production (Xylia et al., 2023). This necessitates the exploration of innovative capacity configurations and operational simulations to fully realize the potential of offshore energy islands (Zhang et al., 2025).

The scalability of water electrolysis, particularly when powered by renewable sources, is crucial for converting electricity into hydrogen fuel, thereby addressing both the global energy crisis and environmental concerns (Fang et al., 2018) (Squadrito et al., 2023). More specifically, water electrolysis offers a method to produce high-purity hydrogen, driven by renewable energy sources like solar and wind power (Tufa et al., 2018). However, to meet the required cost targets, advancements in materials and manufacturing are essential (Ayers, 2019). Such systems can utilize the characteristics of large-scale, low-cost, and long-term sub-surface compressed hydrogen storage (Zhang et al., 2025). This method is particularly effective for producing low-carbon hydrogen in autonomous systems, though the production of large system components may present environmental and investment challenges (Terlouw et al., 2022). The versatility of ammonia, with its higher energy density per unit volume compared to compressed and liquid hydrogen, makes it suitable for long-distance marine transportation, utilizing existing infrastructure designed for liquefied petroleum gas (Zhang et al., 2025). Offshore wind power presents a promising and readily available energy source for large-scale hydrogen production, making it a viable option (Singlitico et al., 2021).

POLICY AND REGULATORY FRAMEWORKS FOR GREEN HYDROGEN

Europe needs comprehensive policy frameworks that eliminate market barriers and promote investment in renewable energy infrastructure, as well as clear standards for green hydrogen production to ensure environmental integrity (Papadaki et al., 2025). These frameworks should encourage the adoption of carbon capture and storage techniques and the replacement of fossil fuels with alternative energy sources (Papadaki et al., 2025). Also, optimized sizing methods can balance

the costs and decarbonization of the system (Superchi et al., 2025). Governments can further support green hydrogen deployment by funding R&D, increasing renewable electricity supply, and implementing carbon pricing policies (Cammeraat et al., 2022). Such policies should reduce the cost disparity between green hydrogen and conventional technologies, promote international standardization, and foster sound regulatory standards (Cammeraat et al., 2022). These strategies will facilitate the transition to a greener and more sustainable energy landscape (Marouani et al., 2023). Hydrogen can also provide sustainability and energetic independence to Europe if produced from renewable sources within its borders, with water electrolysis combined with wind or photovoltaic power being the most mature and affordable technologies (Silva et al., 2024). Case studies in regions like the Canary Islands and remote Australian islands demonstrate the feasibility of 100% renewable energy systems using wind, solar, and green hydrogen, highlighting the potential for minimizing emissions and achieving energy independence (Superchi et al., 2025). These systems often struggle to meet essential water demands, and seawater desalination effectively utilizes renewable energy and enhances the flexibility of system controls in these areas (Zhao et al., 2025). These case studies emphasize the importance of community participation, public-private partnerships, and adaptive technologies in overcoming energy transition challenges on islands (Papadaki et al., 2025). Streamlining regulatory frameworks by simplifying licensing procedures is essential to reducing regulatory challenges, which can advance sustainable energy solutions, contributing to broader climate goals and energy security (Papadaki et al., 2025). The European Union should adopt a more detailed strategic approach for low-carbon hydrogen, specifying its role in transitioning to renewable hydrogen, ensuring positive climate impacts, and regulating imports (Abánades et al., 2017). This necessitates careful evaluation of production sources and timelines to prevent inefficiencies (Franco, 2025). The EU aims to produce 10 million tonnes of renewable hydrogen and import another 10 million tonnes by 2030, which is crucial for decarbonizing sectors that are difficult to electrify (Zeyen et al., 2023). To tackle these challenges, independent testing and validation of hydrogen technologies are essential to better inform policymakers, the public, researchers, and investors, and to accelerate the development of new technologies and strategies (Nayebossadri et al., 2025) (Franco, 2025). As hydrogen gains traction as a clean energy alternative, it is crucial to foster global economic development by using it as an energy storage medium across various sectors, including transportation and industry (Criollo et al., 2024). Considering the integration of renewable energies is key to a sustainable energy system, many nations are setting ambitious goals to boost the production of solar, wind, geothermal, hydro, and biomass energy, particularly in Europe (Preuster et al., 2017). Green hydrogen, produced from renewable sources like solar and wind, offers a versatile solution for decarbonizing multiple sectors and achieving net-zero emissions (Nayebossadri et al., 2025). Islands, with their geographical isolation and abundant renewable resources, are ideal candidates for deploying hybrid renewable energy systems, reducing energy costs, and increasing energy independence (Icaza et al., 2025) (Papadaki et al., 2025) (Iliadis et al., 2020). Islands' decentralized energy systems enable them to effectively integrate renewable energy sources, thereby enhancing their capacity for autonomy and adaptability (Papadaki et al., 2025). Also, countries are forming strategic partnerships to secure cheap hydrogen supplies for the future, as access to affordable hydrogen is a prerequisite for energy affordability in systems with high hydrogen proportions (Niepelt et al., 2023). Such collaborations are essential, given that future hydrogen markets are expected to mirror natural gas markets, potentially leading to similar geopolitical dynamics ("The Geopolitics of Renewable Hydrogen in Low-Carbon Energy Markets," 2020). Tailored solutions and strong regulatory support are vital, emphasizing the suitability of islands for renewable energy projects due to their isolation and high energy import costs (Papadaki et al., 2025). Developing countries with robust renewable energy resources have the potential to produce green hydrogen locally, thereby creating economic opportunities and enhancing energy security ("Green Hydrogen in Developing Countries," 2020).

THE POTENTIAL OF GREEN HYDROGEN IN EUROPE

The European Union has positioned itself at the forefront of the green hydrogen revolution through policies like:

- European Green Deal
- Hydrogen Strategy for a Climate-Neutral Europe
- REPowerEU plan, which targets 20 million tonnes of renewable hydrogen consumption by 2030.

Pilot H2-based steel production (Germany, Sweden) As Europe aims for its 2030 sustainability targets, decreasing the levelized cost of energy and optimizing trade flows will significantly influence its future energy landscape, turning to greener energy sources and decreasing the region's reliance on fossil fuels (Guarieiro et al., 2022). Focusing on hybrid renewable energy systems demonstrates the EU's dedication to decreasing greenhouse gas emissions, especially on islands with limited dimensions and geographical seclusion (Papadaki et al., 2025). Categorizing European islands based on their economic activities, such as tourism or industry, is crucial for understanding their specific energy needs and aligning energy strategies with their economic drivers (Papadaki et al., 2025). This categorization aids in deploying hybrid renewable energy systems tailored to the unique demands of each island (Papadaki et al., 2025). Such systems, combining various renewable energy sources and storage solutions, have shown promise in

enhancing energy security and reducing carbon emissions (Papadaki et al., 2025). The production of 25 Mt/a of green hydrogen by 2040 would hedge against the risk of failing carbon capture and storage and green fuel imports, which requires subsidies but is unlikely to be overly expensive (Greevenbroek et al., 2024). Green hydrogen production is projected to constitute 95% of the world's hydrogen power production, positioning it as a crucial element in the global energy transition (Hidouri et al., 2025). Its versatility and emission reduction potential make it a cornerstone of future energy systems (Segovia-Hernandez et al., 2024). The EU anticipates that hydrogen will constitute 13–14% of its secondary energy consumption by 2050, with a significant portion derived from renewable sources (Brusiło et al., 2025). To achieve this, advancements in hydrogen storage, distribution, and transportation are essential, alongside supportive policies and infrastructure development (Guarieiro et al., 2022). Reports indicate that many hydrogen projects are being planned in Europe, highlighting the region's commitment to leveraging hydrogen for its energy transition (Agyekum et al., 2022). These initiatives will help in establishing a competitive hydrogen market and ensuring energy security (Niepelt et al., 2023). Given the EU's commitment to climate neutrality by 2050, offshore renewable energy sources, including wind, wave, and solar, are anticipated to play a vital role, especially when combined with energy storage solutions in floating offshore energy islands. These islands can convert electrical power into green hydrogen, which can then be stored and converted back to electricity, thus reaching total decarbonization of the energy system (Superchi et al., 2025). This integrated strategy considers the economic and environmental implications of hydrogen production, enabling the identification of optimal locations for large-scale production while accounting for cost and environmental constraints (Terlouw et al., 2024). The interconnection and interdependence of hydrogen production, storage, safety, and utilization must be considered to achieve a fully renewable and sustainable hydrogen economy (Dawood et al., 2020). By 2050, the demand for hydrogen energy is expected to increase tenfold compared to present levels, especially in regions like Japan, the United States, and Europe, where significant investments and innovations in hydrogen production, storage, and utilization are already underway (Jianghao, 2021). The high-energy content and clean by-products of green hydrogen position it as a viable alternative, in alignment with international agreements for a sustainable, low-emission future (Segovia-Hernandez et al., 2024).

Key projects include:

- The Hydrogen Backbone pipeline network
- The Princess Elisabeth Island offshore hub (Belgium)
- Pilot H2-based steel production (Germany, Sweden).

APPLICATIONS OF GREEN HYDROGEN IN EUROPEAN INDUSTRIES

Hydrogen can be effectively utilized in the mobility sector, industrial production, and heat market, which may significantly enhance its economic value (Preuster et al., 2017). In the marine transportation sector, for example, ammonia produced from hydrogen is expected to fuel approximately 45% of ships by 2050, which will help to achieve emission reduction targets (Zhang et al., 2025). To further reduce emissions, offshore energy islands can integrate offshore wind power, hydrogen energy, energy storage, and offshore refueling stations (Zhang et al., 2025). Hydrogen stands out as a promising energy carrier because of its high energy density, but conventional production methods that depend on fossil fuels result in carbon dioxide emissions (Wu et al., 2025). Therefore, green hydrogen production methods are essential to mitigate environmental damages caused by the combustion of fossil fuels (Dinçer, 2011). This can be achieved via electrolysis, which offers the advantage of converting surplus renewable energy into hydrogen (Zhao et al., 2025) (Nayebossadri et al., 2025).

INTERNATIONAL COLLABORATIONS IN GREEN HYDROGEN DEVELOPMENT

Comparative Case Studies of Global Hydrogen Strategies The development and deployment of green hydrogen technologies vary significantly across regions, shaped by national priorities, resource endowments, policy environments, and levels of technological readiness. A comparative analysis of key global players illustrates how different countries adopt tailored strategies to position themselves within the emerging hydrogen economy. 6.1 Japan and South Korea: Hydrogen Import and Fuel Cell Mobility Japan and South Korea have adopted hydrogen-centric strategies focused primarily on energy security and transport sector decarbonization. With limited domestic renewable energy potential, both countries have turned to the import of green hydrogen and its derivatives—notably ammonia—from resource-rich regions. Their national roadmaps emphasize the deployment of hydrogen fuel cell technologies in public transportation, passenger vehicles, and stationary power systems. Japan's "Basic Hydrogen Strategy" and South Korea's "Hydrogen Economy Roadmap" include clear targets for the number of fuel cell vehicles, refueling stations, and hydrogen power plants by 2030 and beyond. Both countries are also investing in international supply chain agreements with partners such as Australia, Saudi Arabia, and Chile. 6.2 Australia and Chile: Hydrogen Export Leadership Australia and Chile leverage their abundant renewable resources (solar and wind) to become major green hydrogen exporters. Both countries have developed hydrogen strategies centered on producing low-cost

hydrogen for international markets, particularly targeting Northeast Asia and Europe. Australia's "National Hydrogen Strategy" supports large-scale hydrogen hubs, while Chile's strategy envisions the country as the world's lowest-cost producer of green hydrogen by 2030. These strategies are supported by government incentives, pilot projects, and foreign investment in electrolyzer capacity and port infrastructure. 6.3 Germany and the Netherlands: Industrial Decarbonization and Infrastructure Development Germany and the Netherlands are positioning themselves as industrial leaders in hydrogen deployment, particularly within the steel, chemicals, and refining sectors. Their strategies prioritize the integration of green hydrogen into hard-to-abate industrial processes and the construction of cross-border infrastructure, including pipelines, terminals, and storage facilities. Germany's "National Hydrogen Strategy" includes €9 billion in funding, with a strong emphasis on electrolyzer deployment, while the Netherlands focuses on developing the Hydrogen Backbone pipeline network, enabling cross-border trade and domestic distribution of green hydrogen. Both countries are also investing in hydrogen valleys, R&D, and certification systems to facilitate market development. 6.4 Island Nations: Autonomous Energy Systems with Hybrid RES-H_2 Solutions Island nations such as Iceland, Fiji, and several EU overseas territories face unique energy challenges due to isolation and dependence on imported fossil fuels. These regions are emerging as testing grounds for fully autonomous energy systems integrating renewable energy sources (RES) with green hydrogen production and storage. Projects often combine photovoltaic (PV) and wind power with water electrolysis and hydrogen fuel cells, enabling energy self-sufficiency and zero-emission electricity generation. These systems also serve as real-world laboratories for optimizing energy balancing, grid stability, and hybrid storage configurations under variable renewable inputs. 6.5 Lessons Learned These case studies underscore the importance of context-specific strategies. Countries with limited renewable resources emphasize import and fuel cell deployment, while resource-rich nations focus on export-oriented hydrogen production. Industrialized economies prioritize infrastructure and decarbonization of heavy industry, and remote island regions explore decentralized hydrogen systems for energy autonomy. The pace and scale of green hydrogen adoption depend heavily on: Policy and regulatory frameworks Access to low-cost renewable energy Infrastructure readiness Stakeholder coordination International cooperation Understanding these diverse approaches helps identify best practices and transferable models that can support global green hydrogen development.

CONCLUSION

Green hydrogen has progressed from a conceptual decarbonisation vector to a cornerstone of net-zero roadmaps across industry, transport, power and agriculture. Its advantages—zero-carbon production (when powered by renewables), high gravimetric energy density, and versatility as both fuel and feedstock—make it uniquely capable of displacing fossil-derived energy carriers in hard-to-abate sectors while simultaneously providing long-duration energy storage. Europe's policy leadership, the rapid fall in renewable-electricity costs, and a surge of pilot projects on islands and industrial hubs collectively demonstrate that large-scale green-hydrogen systems are technically feasible and increasingly bankable.

Yet the analysis also reveals a set of persistent constraints—chiefly high electrolyser CAPEX and electricity costs, immature value-chain infrastructure, limited water availability in arid and offshore settings, and an absence of harmonised certification and trade standards. Overcoming these barriers will require coordinated advances in technology, finance, regulation and social acceptance. Future research should prioritize lowering electrolyzer capital costs via earth-abundant catalysts and scalable manufacturing, advancing large-scale hydrogen storage and grid-integrated infrastructure, and establishing harmonized safety and life-cycle standards for renewable hydrogen systems.

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REFERENCES

Abánades, J. C., Rubin, E. S., Mazzotti, M., & Herzog, H. J. (2017). On the climate change mitigation potential of CO2 conversion to fuels. Energy & Environmental Science, 10(12), 2491. https://doi.org/10.1039/c7ee02819a

Agyekum, E. B., Nutakor, C., Agwa, A. M., & Kamel, S. (2022). A Critical Review of Renewable Hydrogen Production Methods: Factors Affecting Their Scale-Up and Its Role in Future Energy Generation [Review of A Critical Review of Renewable Hydrogen Production Methods: Factors Affecting Their Scale-Up and Its Role in Future Energy Generation]. Membranes, 12(2), 173. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/membranes12020173

Ayers, K. E. (2019). The potential of proton exchange membrane–based electrolysis technology. Current Opinion in Electrochemistry, 18, 9. https://doi.org/10.1016/j.coelec.2019.08.008

Baral, S., & Šebo, J. (2024). Techno-economic assessment of green hydrogen production integrated with hybrid and organic Rankine cycle (ORC) systems. Heliyon, 10(4). https://doi.org/10.1016/j.heliyon.2024.e25742

Bauer, C., Treyer, K., Antonini, C., Bergerson, J., Gazzani, M., Gençer, E., Gibbins, J., Mazzotti, M., McCoy, S., McKenna, R., Pietzker, R., Ravikumar, A., Romano, M. C., Ueckerdt, F., Vente, J. F., & Spek, M. van der. (2021). On the climate impacts of blue hydrogen production. https://doi.org/10.33774/chemrxiv-2021-hz0qp

Brusiło, P., Węgrzyn, A., Graczyk, A., & Graczyk, A. M. (2025). Hydrogen SWOT Analysis of Poland's Energy Transition. Energies, 18(7), 1789. https://doi.org/10.3390/en18071789

Cammeraat, E., Dechezleprêtre, A., & Lalanne, G. (2022). Innovation and industrial policies for green hydrogen. In OECD science, technology and industry policy papers. https://doi.org/10.1787/f0bb5d8c-en

Cheng, J., Meng, J., Bao, G., & Hu, X. (2025). Control of DC Bus Voltage in a 10 kV Off-Grid Wind–Solar–Hydrogen Energy Storage System. Energies, 18(9), 2328. https://doi.org/10.3390/en18092328

Chiroșcă, A.-M., Rusu, E., & Mînzu, V. (2024). Green Hydrogen—Production and Storage Methods: Current Status and Future Directions. Energies, 17(23), 5820. https://doi.org/10.3390/en17235820

Criollo, A., Minchala, L. I., Benavides, D., Ochoa-Correa, D., Tostado-Véliz, M., Meteab, W. K., & Jurado, F. (2024). Green Hydrogen Production—Fidelity in Simulation Models for Technical–Economic Analysis. Applied Sciences, 14(22), 10720. https://doi.org/10.3390/app142210720

Curcio, E. (2025). Techno-Economic Analysis of Hydrogen Production: Costs, Policies, and Scalability in the Transition to Net-Zero. arXiv (Cornell University). https://doi.org/10.48550/arxiv.2502.12211

Dawood, F., Anda, M., & Shafiullah, G. (2020). Hydrogen production for energy: An overview. International Journal of Hydrogen Energy, 45(7), 3847. https://doi.org/10.1016/j.ijhydene.2019.12.059

Dinçer, İ. (2011). Green methods for hydrogen production. International Journal of Hydrogen Energy, 37(2), 1954. https://doi.org/10.1016/j.ijhydene.2011.03.173

Fang, Y., Zhou, H., Huang, Y., Sun, J., Qin, F., Bao, J., Goddard, W. A., Chen, S., & Ren, Z. (2018). High-performance bifunctional porous non-noble metal phosphide catalyst for overall water splitting. Nature Communications, 9(1). https://doi.org/10.1038/s41467-018-04746-z

Franco, A. (2025). Green Hydrogen and the Energy Transition: Hopes, Challenges, and Realistic Opportunities. Hydrogen, 6(2), 28. https://doi.org/10.3390/hydrogen6020028

Franco, A., & Giovannini, C. (2023). Recent and Future Advances in Water Electrolysis for Green Hydrogen Generation: Critical Analysis and Perspectives. Sustainability, 15(24), 16917. https://doi.org/10.3390/su152416917

Franzmann, D., Heinrichs, H., Lippkau, F., Addanki, T., Winkler, C., Buchenberg, P., Hamacher, T., Blesl, M., Linßen, J., & Stolten, D. (2023). Green hydrogen cost-potentials for global trade. International Journal of Hydrogen Energy, 48(85), 33062. https://doi.org/10.1016/j.ijhydene.2023.05.012

Gómez, J. L., & Castro, R. (2024). Green Hydrogen Energy Systems: A Review on Their Contribution to a Renewable Energy System [Review of Green Hydrogen Energy Systems: A Review on Their Contribution to a Renewable Energy System]. Energies, 17(13), 3110. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/en17133110

Graaf, T. V. de, Øverland, I., Scholten, D., & Westphal, K. (2020). The new oil? The geopolitics and international governance of hydrogen. Energy Research & Social Science, 70, 101667. https://doi.org/10.1016/j.erss.2020.101667

Green Hydrogen in Developing Countries. (2020). In World Bank, Washington, DC eBooks. https://doi.org/10.1596/34398

Greevenbroek, K. van, Schmidt, J., Zeyringer, M., & Horsch, A. (2024). Little to lose: the case for a robust European green hydrogen strategy. arXiv (Cornell University). https://doi.org/10.48550/arxiv.2412.07464

Guarieiro, L. L. N., Anjos, J. P. dos, Silva, L. da, Santos, A. Á. B., Calixto, E. E. da S., Pessoa, F. L. P., Almeida, J. de, Filho, M. A., Marinho, F. de S., Rocha, G. O. da, & Andrade, J. B. de. (2022). Technological Perspectives and Economic Aspects of Green Hydrogen in the Energetic Transition: Challenges for Chemistry. Journal of the Brazilian Chemical Society. https://doi.org/10.21577/0103-5053.20220052

Hamedani, E. A., Alenabi, S. A., & Talebi, S. (2024). Hydrogen as an energy source: A review of production technologies and challenges of fuel cell vehicles [Review of Hydrogen as an energy source: A review of production technologies and challenges of fuel cell vehicles]. Energy Reports, 12, 3778. Elsevier BV. https://doi.org/10.1016/j.egyr.2024.09.030

Han, Z., Yuan, S., Dong, Y., Ma, S., Bian, Y., & Mao, X. (2022). Research on the Flexibility Margin of an Electric–Hydrogen Coupling Energy Block Based on Model Predictive Control. Frontiers in Energy Research, 10. https://doi.org/10.3389/fenrg.2022.879244

Hartley, P. G., & Au, V. (2020). Towards a Large-Scale Hydrogen Industry for Australia. Engineering, 6(12), 1346. https://doi.org/10.1016/j.eng.2020.05.024

Hidouri, D., Omrane, I. B., Khalil, K., & Chérif, A. (2025). Energy Management of a 1 MW Photovoltaic Power-to-Electricity and Power-to-Gas for Green Hydrogen Storage Station. World Electric Vehicle Journal, 16(4), 227. https://doi.org/10.3390/wevj16040227

Icaza, D., Jurado, F., Østergaard, P. A., Tostado-Véliz, M., & Flores-Vázquez, C. (2025). Cornerstones for greater participation of smart renewable energy on clustered islands: The case of Guayas in Ecuador towards 2050. Energy Reports, 13, 1350. https://doi.org/10.1016/j.egyr.2025.01.006

Iliadis, P., Ntomalis, S., Atsonios, K., Nesiadis, A., Nikolopoulos, N., & Grammelis, P. (2020). Energy management and techno-economic assessment of a predictive battery storage system applying a load levelling operational strategy in island systems. International Journal of Energy Research, 45(2), 2709. https://doi.org/10.1002/er.5963

James, N., & Menzies, M. (2022). Spatio-temporal trends in the propagation and capacity of low-carbon hydrogen projects. International Journal of Hydrogen Energy, 47(38), 16775. https://doi.org/10.1016/j.ijhydene.2022.03.198

Jianghao, N. (2021). Research on the Hydrogen Production Technology. IOP Conference Series Earth and Environmental Science, 813(1), 12004. https://doi.org/10.1088/1755-1315/813/1/012004

Kumar, S. S., & Lim, H. (2022). An overview of water electrolysis technologies for green hydrogen production. Energy Reports, 8, 13793. https://doi.org/10.1016/j.egyr.2022.10.127

Lapi, T., Chatzimpiros, P., Raineau, L., & Prinzhofer, A. (2022). System approach to natural versus manufactured hydrogen: An interdisciplinary perspective on a new primary energy source. International Journal of Hydrogen Energy, 47(51), 21701. https://doi.org/10.1016/j.ijhydene.2022.05.039

Le, P.-A., Trung, V. D., Nguyen, P. L., Phung, T. V. B., Natsuki, J., & Natsuki, T. (2023). The current status of hydrogen energy: an overview [Review of The current status of hydrogen energy: an overview]. RSC Advances, 13(40), 28262. Royal Society of Chemistry. https://doi.org/10.1039/d3ra05158g

Lee, J., Lee, S. A., Lee, T. H., & Jang, H. W. (2025). Unlocking the potential of chemical-assisted water electrolysis for green hydrogen production. Industrial Chemistry and Materials. https://doi.org/10.1039/d4im00163j

Mahmoud, M., Semeraro, C., Abdelkareem, M. A., & Olabi, A. G. (2024). Designing and Prototyping the Architecture of a Digital Twin for Wind Turbine. International Journal of Thermofluids, 22, 100622. https://doi.org/10.1016/j.ijft.2024.100622

Marocco, P., Novo, R., Lanzini, A., Mattiazzo, G., & Santarelli, M. (2022). Towards 100% renewable energy systems: The role of hydrogen and batteries. Journal of Energy Storage, 57, 106306. https://doi.org/10.1016/j.est.2022.106306

Marouani, I., Guesmi, T., Alshammari, B. M., Alqunun, K., Alzamil, A., Alturki, M., & Abdallah, H. H. (2023). Integration of Renewable-Energy-Based Green Hydrogen into the Energy Future. Processes, 11(9), 2685. https://doi.org/10.3390/pr11092685

McQueen, S., Stanford, J., Satyapal, S., Miller, E. L., Stetson, N., Papageorgopoulos, D., Rustagi, N., Arjona, V., Adams, J., Randolph, K., Peterson, D., Hill, L., Koleva, M., Reinhardt, T., Frye, E., Schrecengost, R., Kokkinos, A., Litynski, J., Conrad, R., … Costa, R. T. da. (2020). Department of Energy Hydrogen Program Plan. https://doi.org/10.2172/1721803

Meda, U. S., Bhat, N., Pandey, A., Subramanya, K. N., & Raj, M. A. L. A. (2023). Challenges associated with hydrogen storage systems due to the hydrogen embrittlement of high strength steels. International Journal of Hydrogen Energy, 48(47), 17894. https://doi.org/10.1016/j.ijhydene.2023.01.292

Mekonnin, A. S., Wacławiak, K., Humayun, M., Zhang, S., & Ullah, H. (2025). Hydrogen Storage Technology, and Its Challenges: A Review [Review of Hydrogen Storage Technology, and Its Challenges: A Review]. Catalysts, 15(3), 260. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/catal15030260

Nayebossadri, S., Walsh, M., & Smailes, M. (2025). An Overview of the Green Hydrogen Value Chain Technologies and Their Challenges for a Net-Zero Future. https://doi.org/10.20944/preprints202503.1114.v1

Nguyen, B. L.-H., Panwar, M., Hovsapian, R., Nagasawa, K., & Vu, T. (2021). Power Converter Topologies for Electrolyzer Applications to Enable Electric Grid Services. IECON 2020 The 46th Annual Conference of the IEEE Industrial Electronics Society, 1. https://doi.org/10.1109/iecon48115.2021.9589044

Niepelt, R., Schlemminger, M., Bredemeier, D., Peterssen, F., Lohr, C., Bensmann, A., Hanke-Rauschenbach, R., & Brendel, R. (2023). The Influence of Falling Costs for Electrolyzers on the Location Factors for Green Hydrogen Production. Solar RRL, 7(17). https://doi.org/10.1002/solr.202300317

Noussan, M., Raimondi, P. P., Scita, R., & Häfner, M. (2020). The Role of Green and Blue Hydrogen in the Energy Transition—A Technological and Geopolitical Perspective. Sustainability, 13(1), 298. https://doi.org/10.3390/su13010298

Offshore renewable energies: A review towards Floating Modular Energy Islands—Monitoring, Loads, Modelling and Control. (2024). https://ezproxy.nb.rs:2055/science/article/pii/S0029801824025897

Papadaki, A., Savvakis, N., Sifakis, N., & Arampatzis, G. (2025). Analysis of Hybrid Renewable Energy Systems for European Islands: Market Dynamics, Opportunities and Challenges. Sustainable Futures, 100601. https://doi.org/10.1016/j.sftr.2025.100601

Preuster, P., Alekseev, A. S., & Wasserscheid, P. (2017). Hydrogen Storage Technologies for Future Energy Systems [Review of Hydrogen Storage Technologies for Future Energy Systems]. Annual Review of Chemical and Biomolecular Engineering, 8(1), 445. Annual Reviews. https://doi.org/10.1146/annurev-chembioeng-060816-101334

Qiu, Y., Zhou, B., Zang, T., Zhou, Y., Chen, S., Qi, R., Li, J., & Lin, J. (2023). Extended load flexibility of utility-scale P2H plants: Optimal production scheduling considering dynamic thermal and HTO impurity effects. Renewable Energy, 217, 119198. https://doi.org/10.1016/j.renene.2023.119198

Ramu, A. G., & Choi, D. (2025). Interfacial water engineering for enhanced pure water electrolysis. Scientific Reports, 15(1). https://doi.org/10.1038/s41598-025-98853-9

Reyes-Barquet, L. M., Rico-Contreras, J. O., Azzaro-Pantel, C., Moras-Sánchez, C. G., González-Huerta, M. Á., Vásquez, D. V., & Aguilar-Lasserre, A. A. (2022). Multi-Objective Optimal Design of a Hydrogen Supply Chain Powered with Agro-Industrial Wastes from the Sugarcane Industry: A Mexican Case Study. Mathematics, 10(3), 437. https://doi.org/10.3390/math10030437

Segovia-Hernandez, J. G., Hernández, S., Cossío-Vargas, E., Juárez-García, M., & Sánchez-Ramírez, E. (2024). Green Hydrogen Production for Sustainable Development: A Critical Examination of Barriers and Strategic Opportunities. RSC Sustainability. https://doi.org/10.1039/d4su00630e

Silva, H., Merrouni, A. A., Touili, S., & Neto, J. A. (2024). Determination of photovoltaic hydrogen production potential in Portugal: a techno-economic analysis. Frontiers in Energy Research, 12. https://doi.org/10.3389/fenrg.2024.1380543

Singlitico, A., Østergaard, J., & Chatzivasileiadis, S. (2021). Onshore, offshore or in-turbine electrolysis? Techno-economic overview of alternative integration designs for green hydrogen production into Offshore Wind Power Hubs. Renewable and Sustainable Energy Transition, 1, 100005. https://doi.org/10.1016/j.rset.2021.100005

Squadrito, G., Maggio, G., & Nicita, A. (2023). The green hydrogen revolution. Renewable Energy, 216, 119041. https://doi.org/10.1016/j.renene.2023.119041

Superchi, F., Bianchini, A., Moustakis, A., & Pechlivanoglou, G. (2025). Towards Sustainable Energy Independence: A Case Study of Green Hydrogen as Seasonal Storage Integration in a Small Island. Renewable Energy, 122813. https://doi.org/10.1016/j.renene.2025.122813

Tang, W., Tan, Q., & Cai, R. (2022). Current situation analysis of electrohydrogen production under the background of "Carbon Neutralization." IOP Conference Series Earth and Environmental Science, 983(1), 12035. https://doi.org/10.1088/1755-1315/983/1/012035

Tebibel, H. (2021). Methodology for multi-objective optimization of wind turbine/battery/electrolyzer system for decentralized clean hydrogen production using an adapted power management strategy for low wind speed conditions. Energy Conversion and Management, 238, 114125. https://doi.org/10.1016/j.enconman.2021.114125

Terlouw, T., Bauer, C., McKenna, R., & Mazzotti, M. (2022). Large-scale hydrogen production via water electrolysis: a techno-economic and environmental assessment. Energy & Environmental Science, 15(9), 3583. https://doi.org/10.1039/d2ee01023b

Terlouw, T., Rosa, L., Bauer, C., & McKenna, R. (2024). Future hydrogen economies imply environmental trade-offs and a supply-demand mismatch. Nature Communications, 15(1). https://doi.org/10.1038/s41467-024-51251-7

The Geopolitics of Renewable Hydrogen in Low-Carbon Energy Markets. (2020). Geopolitics History and International Relations, 12(1), 7. https://doi.org/10.22381/ghir12120201

Tufa, R. A., Hnát, J., Němeček, M., Kodým, R., Curcio, E., & Bouzek, K. (2018). Hydrogen production from industrial wastewaters: An integrated reverse electrodialysis - Water electrolysis energy system. Journal of Cleaner Production, 203, 418. https://doi.org/10.1016/j.jclepro.2018.08.269

Urs, R. R., Chadly, A., Al-Sumaiti, A. S., & Mayyas, A. (2023). Techno-economic analysis of green hydrogen as an energy-storage medium for commercial buildings. Clean Energy, 7(1), 84. https://doi.org/10.1093/ce/zkac083

Useche-Arteaga, M., Gomis-Bellmunt, O., Cheah-Mañé, M., Lacerda, V. A., & Gebraad, P. (2024). AC energy islands for the optimal integration of offshore wind energy resources: Operation strategies using multi-objective nonlinear programming. Sustainable Energy Grids and Networks, 101576. https://doi.org/10.1016/j.segan.2024.101576

Vedrtnam, A., Kalauni, K., & Pahwa, R. (2025). Water Electrolysis Technologies and Their Modeling Approaches: A Comprehensive Review [Review of Water Electrolysis Technologies and Their Modeling Approaches: A Comprehensive Review]. Eng—Advances in Engineering, 6(4), 81. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/eng6040081

Veras, T. da S., Mozer, T. S., Santos, D. da C. R. M. dos, & César, A. da S. (2016). Hydrogen: Trends, production and characterization of the main process worldwide. International Journal of Hydrogen Energy, 42(4), 2018. https://doi.org/10.1016/j.ijhydene.2016.08.219

Verhelst, S., & Wallner, T. (2009). Hydrogen-fueled internal combustion engines. Progress in Energy and Combustion Science, 35(6), 490. https://doi.org/10.1016/j.pecs.2009.08.001

Wu, L., Xu, Y., Wang, Q., Zou, X., Pan, Z., Leung, M. K. H., & An, L. (2025). Direct seawater electrolysis for green hydrogen production: electrode designs, cell configurations, and system integrations. Energy & Environmental Science. https://doi.org/10.1039/d5ee01093d

Wu, Q., Long, P., Han, G., Shu, J., Yuan, M., & Wang, B. (2025). Deep-Learning-Based Scheduling Optimization of Wind-Hydrogen-Energy Storage System on Energy Islands. Energy, 135107. https://doi.org/10.1016/j.energy.2025.135107

Xie, Z., Jin, Q., Su, G., & Lu, W. (2024). A Review of Hydrogen Storage and Transportation: Progresses and Challenges [Review of A Review of Hydrogen Storage and Transportation: Progresses and Challenges]. Energies, 17(16), 4070. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/en17164070

Xylia, M., Passos, M. V., Piseddu, T., & Barquet, K. (2023). Exploring multi-use platforms: A literature review of marine, multifunctional, modular, and mobile applications (M4s) [Review of Exploring multi-use platforms: A literature review of marine, multifunctional, modular, and mobile applications (M4s)]. Heliyon, 9(6). Elsevier BV. https://doi.org/10.1016/j.heliyon.2023.e16372

Zeyen, E., Victoria, M., & Brown, T. (2023). Endogenous learning for green hydrogen in a sector-coupled energy model for Europe. Nature Communications, 14(1). https://doi.org/10.1038/s41467-023-39397-2

Zhang, F., Zhao, P., Niu, M., & Maddy, J. (2016). The survey of key technologies in hydrogen energy storage. International Journal of Hydrogen Energy, 41(33), 14535. https://doi.org/10.1016/j.ijhydene.2016.05.293

Zhang, W., Li, Q., Yuan, J., & Xu, C. (2025). Configuration optimization of offshore energy islands coupled with ammonia refueling station and submarine salt cavern hydrogen storage. International Journal of Hydrogen Energy, 113, 669. https://doi.org/10.1016/j.ijhydene.2025.02.481

Zhao, W., Wang, B., Pan, T., Chen, Y., Tao, H., Guo, B., Varbanov, P. S., & Lu, J. (2025). Optimisation of island integrated energy system based on marine renewable energy.

Zhao, Y., Yuan, H., Liu, X., Zhang, J., Song, J., & Wang, H. (2025). Zero-carbon energy system for offshore Islands: Integrating freeze desalination, hydrogen storage, and fuel cells. Applied Thermal Engineering, 126702. https://doi.org/10.1016/j.applthermaleng.2025.126702

Zhu, D., Yang, B., Liu, Q., Ma, K., Zhu, S., Ma, C., & Guan, X. (2020). Energy trading in microgrids for synergies among electricity, hydrogen and heat networks. Applied Energy, 272, 115225. https://doi.org/10.1016/j.apenergy.2020.115225

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ENERGY-EFFICIENT RESIDENTIAL BUILDINGS: THE ROLES OF NATURAL VENTILATION AND DAYLIGHTING

Abstract: *Residential buildings represent one of the largest energy consumers, highlighting the need for improved energy efficiency in the housing sector. This paper investigates how natural ventilation and daylighting can improve energy efficiency in homes through passive design strategies. A literature-based methodology is adopted, including a comparative review of case studies, simulation results and statistical data. Key findings show that optimizing natural ventilation can significantly reduce cooling energy demand (with case studies showing up to 71% annual energy savings in warm climates), while efficient daylighting design can reduce lighting energy consumption by as much as 75%. However, the benefits of these strategies depend on climatic conditions and design methods, and excessive glazing without appropriate control can increase heat loads. The discussion addresses how integrating ventilation and daylight into design, through measures such as building orientation, window placement and shading, results in comfortable homes with low energy consumption. In conclusion, the use of natural ventilation and daylight is a cost-effective path towards sustainable residential architecture, and recommendations are made for urban planners and architects to incorporate these passive strategies into future housing projects.*

Keywords: natural ventilation, daylighting, energy-efficient residential buildings, passive design strategies, sustainable architecture

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INTRODUCTION

Energy consumption in buildings is a major issue in global sustainability efforts due to its large environmental impact. The building sector (including construction and operation) was responsible for approximately 36% of global energy use and 37% of energy-related CO_2 emissions in 2020 (Climate Action Accelerator, n.d.). Within the building sector, the operation of residential buildings alone accounts for approximately 22% of global energy consumption (Climate Action Accelerator, n.d.). This significant share highlights the potential impact of improving energy efficiency in homes. In the context of climate change and rising energy costs, designing energy-efficient residential buildings is both an environmental imperative and an economic opportunity.

There is a range of strategies to reduce energy demand in buildings, from advanced insulation and efficient appliances to the integration of renewable energy. Among these, passive architectural approaches—particularly natural ventilation and daylighting—stand out for their ability to reduce buildings' reliance on mechanical heating, ventilation, and air conditioning (HVAC) and electric lighting. Natural ventilation (the use of wind-driven and buoyant air flow through windows, vents, or other openings) can cool and ventilate a home without or with minimal use of fans or air conditioning. Daylighting (the practice of using natural sunlight to illuminate a building's interior) can offset the need for artificial lighting during the day. Both strategies not only save energy, but can also improve indoor environmental quality and occupant comfort by providing fresh air and connection to natural light.

Despite their known benefits, natural ventilation and daylighting have sometimes been underutilized in modern residential design, especially in regions where cheap energy historically favoured mechanical climate control and fully glazed façades. Excessive dependence on air conditioning and artificial lighting in homes has contributed to high energy use. Conversely, traditional and vernacular architecture often employed climate-responsive designs—like courtyards, high ceilings, and strategically placed windows—to naturally regulate indoor conditions. There is a growing recognition that reviving and modernizing these passive techniques can yield substantial energy savings in contemporary homes. For example, ultra-low-energy building standards such as the Passive House demonstrate that

through meticulous design (superinsulation, airtight construction, heat recovery ventilation, and optimized solar gains), it is possible to cut energy use by up to 90% compared to conventional buildings (International Passive House Association, n.d.). Building on this insight, this paper focuses on natural ventilation and daylighting as key design strategies to achieve energy-efficient and sustainable residential buildings.

In the context of the Western Balkan region (Grujić et al., 2018) examined the daylight utilization potential of office spaces in Belgrade using simulation tools under local climate conditions. Their findings indicated that Window-to-Wall Ratios (WWR) above 60% combined with appropriate orientation could significantly increase the availability of natural daylight, thus reducing reliance on artificial lighting. Such studies underline the growing attention to passive design elements in Serbian architecture and confirm the relevance of this paper's focus in the local context.

The objective of this research is to evaluate the impact of natural ventilation and daylighting on residential energy efficiency and to provide guidance on integrating these strategies into housing design. The paper is structured as follows: the Methodology section outlines the research approach, including literature review and comparative analysis of case studies. The Findings and Discussion section presents quantitative and qualitative results on energy savings from natural ventilation and daylighting, along with a discussion of design considerations and case examples. Finally, the Conclusion summarizes the key takeaways and offers recommendations for sustainable urban planning and architectural design that leverages these passive strategies.

METHODOLOGY

This study adopts a qualitative and quantitative literature review methodology to analyse the effectiveness of natural ventilation and daylighting in improving residential building energy efficiency. The research process involved several steps:

Literature Review

Data have been collected from academic studies, simulation research, and documented case studies focusing on residential energy use, natural ventilation strategies, and daylighting performance. Key sources included peer-reviewed journals and conference papers on building simulation, sustainable design, and architectural case analyses, as well as reports from international energy agencies. This provided a broad knowledge base on the state-of-the-art and historical context of passive cooling and lighting in homes.

Comparative Case Analysis

From the literature, representative case studies and research findings across different climates and building types have been selected in order to compare outcomes. For natural ventilation, the cases ranged from modern simulations in hot arid regions to analyses of traditional designs in humid climates. For instance, a CFD (computational fluid dynamics) simulation study from Khartoum, Sudan (hot-dry climate) examined how incorporating natural ventilation in a dwelling could reduce energy consumption (Zeinab, 2023), while another design optimization study from Guangzhou, China (warm subtropical climate) evaluated the cooling energy savings from an atrium-driven natural ventilation system in a public building context (Zhang, Han, He, Xiong, & Zhang, 2024). Although the latter focuses on a public building, its lessons on ventilation design are applicable to large residential complexes or multi-unit buildings in similar climates.

A study by Rucińska and Trząski (2020) in Poland further integrated daylight performance with energy modelling for heating and cooling. Through simulation and real-world measurements in an educational building, they demonstrated how daylight availability impacts not only lighting loads but also thermal energy needs. Their approach highlights the importance of considering daylight as part of a holistic energy strategy, offering valuable lessons for climates with cold winters and moderate summers, similar to much of Southeastern Europe (Rucińska and Trząski, 2020).

Studies on daylighting commonly assess how architectural features such as window size, orientation, skylights, and shading devices affect indoor illuminance levels and overall energy consumption. Additionally, research often focuses on sustainable housing projects that incorporate extensive use of daylight and natural ventilation.

Statistical Analysis

Based on the gathered data, a comparative statistical analysis of energy performance indicators reported in the literature was conducted. The analysis included the extraction of metrics such as the percentage of energy savings (e.g., reduction in annual cooling or lighting energy), indoor environmental parameters (e.g., achieved air exchange rates, illuminance levels), and documented impacts on occupant comfort. By juxtaposing these values, patterns were identified that illustrate the typical energy savings achievable through natural ventilation and daylighting under varying conditions. For instance, reported savings in a best-case natural ventilation scenario in a hot climate exceeded 70% HVAC energy reduction (Zeinab, 2023), compared to lower savings observed in temperate conditions or hybrid ventilation systems.

Synthesis

The findings from the literature and case comparisons were synthesized to draw general conclusions. The results have been interpreted in light of climatic factors and design variables, noting where natural ventilation and daylighting were most effective and what limitations or trade-offs were observed. Additionally, strategies for integrating both approaches were inferred from cases that attempted to balance daylight admission with thermal performance or that used ventilation in tandem with other passive measures.

Throughout the methodology, an effort was made to ensure the sources and cases selected provide a balanced view, including both the potential benefits and the challenges of natural ventilation and daylighting. The comparative approach helps isolate the influence of these strategies on energy efficiency by examining multiple contexts. It is worth noting that our analysis is based on existing studies and simulations rather than conducting new field experiments; thus, results are interpreted within the scope of those studies' assumptions and models. Nonetheless, the range of sources (spanning different climates, building designs, and research methods) adds robustness to the conclusions drawn.

DISCUSSION

Energy Efficiency Gains through Passive Design

A clear outcome from the research is that passive design measures, particularly natural ventilation and daylighting, can yield significant energy efficiency improvements in residential buildings.

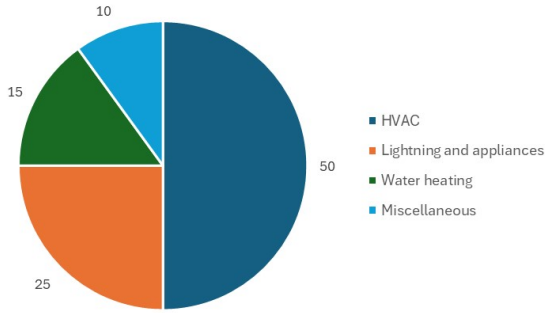


Figure 1. *Distribution of energy consumption in residential buildings (percentage)*

Figure 1 shows traditional mechanically cooled and illuminated homes consume substantial energy for air conditioning and lighting. In developed countries, HVAC systems often account for roughly half of a building's energy use, especially in climates with high cooling or heating demands (Zhang, Han, He, Xiong, & Zhang, 2024). Lighting, while a smaller fraction, typically makes up about 10–20% of total energy consumption in buildings (Powell, n.d.). By directly reducing these two major end-uses, natural ventilation and daylighting can appreciably lower a home's energy footprint.

Studies and case analyses consistently show large energy saving potential when these passive strategies are well-implemented. For example, the Passive House standard (originating in Europe) offers a proof-of-concept for what can be achieved with a holistic passive approach. Such houses use superinsulation, airtight construction, heat recovery ventilation, along with strategic placement of windows for solar gain and daylight. As a result, they require as little as 10% of the heating energy used by typical buildings – translating to up to 90% energy savings in certain climates (International Passive House Association, n.d.). While Passive House designs often rely on mechanical ventilation with heat recovery (rather than fully natural ventilation) to maintain air quality, they demonstrate the magnitude of energy reduction possible when a building is optimized for efficiency. This finding sets an upper benchmark: deep energy cuts are feasible, and natural ventilation and daylighting are among the key levers to achieve them when integrated thoughtfully into the design.

Natural Ventilation Benefits and Performance

Natural ventilation has been found to considerably decrease the cooling and ventilation energy requirements of residential buildings, particularly in climates where outdoor conditions are favourable for a good portion of the year. By harnessing wind pressure and thermal buoyancy (stack effect) to circulate air, natural ventilation can maintain comfortable indoor temperatures without constant air conditioner use. Our review of various studies highlights impressive energy savings from this approach:

Hot-Dry Climate Case: In a computational study of a dwelling design in Khartoum, Sudan, introducing optimized natural ventilation achieved a dramatic 71.1% reduction in annual energy consumption for cooling (Zeinab, 2023). This best-case scenario involved designing the home to maximize internal air speeds (on the order of 0.5–0.9 m/s in much of the interior) through features like cross-ventilation and large operable openings as shown in Figure 2.

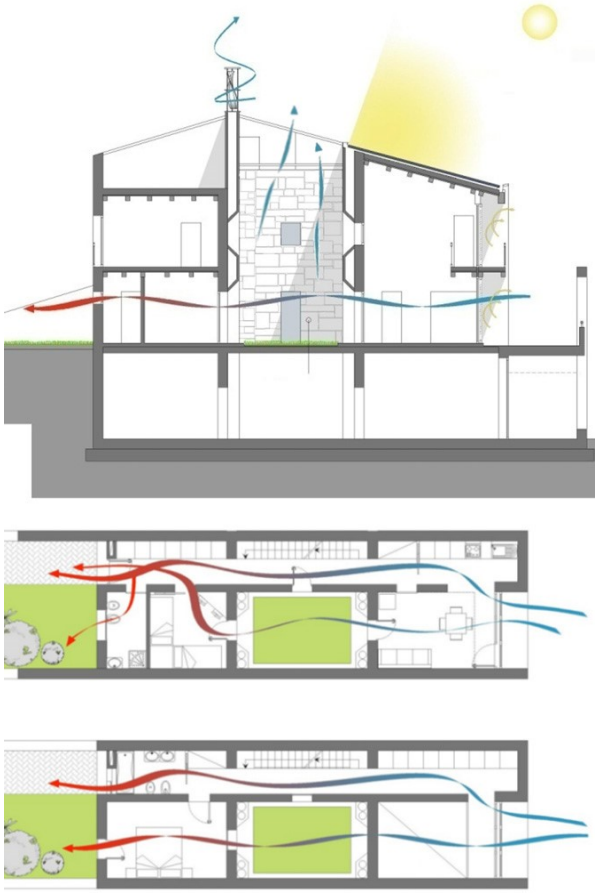


Figure 2. *Cross-ventilation diagram (airflow illustration through a multi-story building)*

The result was a substantial decrease in the need for mechanical cooling, demonstrating how effective natural airflow can be in a hot dry environment where night temperatures drop enough to allow flushing of heat. It's worth noting that this level of savings represents an idealized design under favourable conditions; nonetheless, it underscores natural ventilation's potential when the climate allows for a long season of open-window comfort.

Warm Humid Climate Case: In climates with high humidity, natural ventilation can be more challenging (due to smaller temperature differentials and discomfort from humid air), but it still offers benefits. A study of passive cooling strategies for historic houses in hot-humid San Antonio, Texas, showed that even in such environments, various natural ventilation scenarios contributed to energy savings across seasons (Storz, 2024). Among the methods analysed (e.g. fully open windows, half-open windows, cross-ventilation, stack ventilation (Figure 3), night flushing), cross-ventilation emerged as the most effective strategy (Storz, 2024).

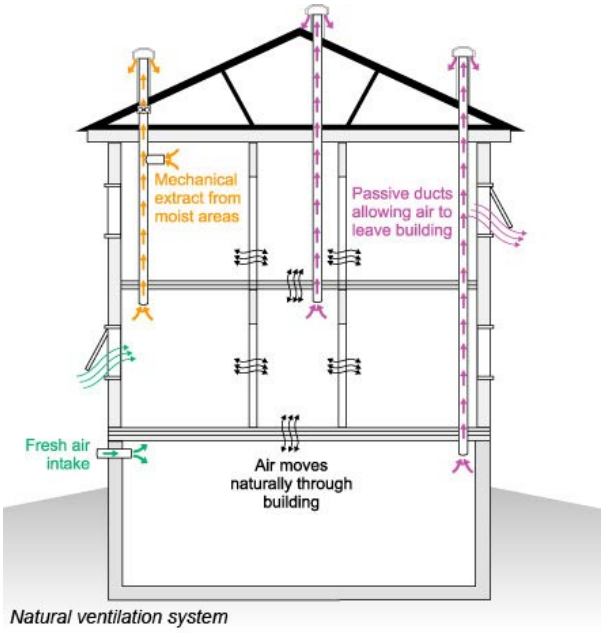


Figure 3. *Stack ventilation diagram (airflow illustration through a multi-story building)*

Cross ventilation—opening windows on opposite walls to allow breeze to flow through—significantly improved airflow and indoor temperature regulation. This finding aligns with vernacular designs in many tropical regions, where houses often have openings on multiple sides and high ceilings, allowing hot air to escape and cooler breezes to enter. The San Antonio study reinforces that even in less-than-ideal climates for natural ventilation, thoughtful use of it (especially in cooler night or shoulder-season conditions) can trim cooling energy use and enhance comfort, though purely natural means might need to be supplemented with fans or ceiling vents during peak heat.

Subtropical Climate Design Optimization: Another case from Guangzhou, China (a warm subtropical climate) quantified the impact of natural ventilation in a large building through simulation. By incorporating an atrium and ventilation shafts into the design to drive airflow, researchers found an approximate 41.2% reduction in cooling energy demand due to the "free cooling" provided by natural ventilation (Zhang, Han, He, Xiong, & Zhang, 2024). While this particular study was on a public building (a science museum), the principles apply to residential high-rises or multi-family buildings: designing architecture to facilitate the stack effect (warm air rising and escaping via high vents or atria, drawing in cooler air at lower levels) can drastically cut air-conditioning loads. The 41% cooling energy savings in this scenario are significant, showing that even in densely occupied or larger structures, passive ventilation can carry a large portion of the cooling burden if integrated from the start.

These examples illustrate that natural ventilation can yield energy savings ranging from modest to very high percentages, depending on the context. In cooler or temperate climates, natural ventilation might entirely eliminate the need for air conditioning during mild months, while in hot climates it can delay or reduce the use of AC systems, thus shaving peak loads and total energy use. Importantly, the effectiveness of natural ventilation hinges on building design and occupant behaviour. Key design considerations include: the placement and size of openings (windows, vents) to capture prevailing winds; the use of interior layouts that allow airflow (e.g., aligning doors or using open-plan arrangements for better cross-breeze paths); and architectural elements like courtyards, atria, or vented skylights to enhance the stack effect. For instance, figure 5 illustrates wind tower or "wind catcher" features in some traditional Middle Eastern homes channel breezes indoors, and modern designs have revisited these concepts. Additionally, night flushing—ventilating the house with cool night air to precool thermal mass—can be very effective in dry climates by reducing the next day's cooling needs (Storz, 2024).

It is also vital to consider that natural ventilation performance is weather-dependent. Designers should plan for periods when outdoor conditions are unsuitable (too hot, too cold, or too polluted) by either combining natural ventilation with mechanical systems (mixed-mode ventilation) or ensuring the building envelope can be closed and insulated when needed. Mixed-mode systems give flexibility: for example, a house might use natural breezes on moderate days but switch to efficient air conditioning on very hot days, still saving energy overall by minimizing AC hours. The findings from the literature suggest that a well-designed, naturally ventilated home can maintain thermal comfort within a wider range of outdoor temperatures than a sealed, mechanically cooled home, as occupants adapt by opening windows or using fans (Zhang, Han, He,

Xiong, & Zhang, 2024). Thus, natural ventilation not only reduces energy use but can increase resilience by providing passive habitability during power outages or HVAC breakdowns.

Daylighting Advantages and Considerations

Daylighting emerges from this research as another cornerstone of energy-efficient residential design. Utilizing natural light during daytime can significantly cut down electricity used for lighting, which in turn also lowers internal heat gains from lighting fixtures (reducing cooling loads). The benefits of daylighting are two-fold: energy savings and enhanced occupant well-being. Many studies have documented improvements in mood, productivity, and health in daylit environments, due to factors like better circadian rhythm alignment and visual comfort, but here we focus on the energy dimension.

In terms of energy performance, daylighting can replace a large portion of artificial lighting usage. Recent analyses indicate that maximizing the use of sunlight can save up to 75% of the energy used for lighting a building (Helgeson, 2022). In practical terms, this means that a home designed to admit ample daylight (through windows, skylights, and reflective interior surfaces) may only need electric lights for nighttime or for task lighting in enclosed spaces, thereby cutting lighting energy to a quarter of what a windowless or poorly lit house would require. For example, a simple design choice like ensuring that each regularly occupied room has a window of sufficient size (often building codes recommend a window area of at least 10% of floor area) can allow most daytime activities to occur without turning on lights. In one case study of an energy-efficient home, strategic placement of south-facing windows and light wells provided adequate illumination for 80–90% of daylight hours, nearly eliminating daytime electric light use in summer. Such strategies, combined with daylight-sensing controls (that dim or switch off lights when sunlight is available), capitalize on the free resource of the sun.

However, an important discussion point is the balance between daylighting and thermal performance. Simply increasing window area will increase daylight, but windows are also the least insulated part of a wall and can admit unwanted heat in hot weather or lose heat in cold weather. An over-glazed design can inadvertently raise energy use for heating or cooling, offsetting the lighting savings. It has been observed that while larger windows reduce the need for artificial lighting, they can drive up overall energy bills due to heat gain and loss (Powell, n.d.). For instance, floor-to-ceiling glass walls might let in plenty of light, but on a summer afternoon, they can cause overheating (solar heat gain) that forces air conditioning to work harder (Powell, n.d.). Conversely, on a winter night, big glass areas can let heat escape and make interiors colder, increasing heating demand. The World Green Building Council has noted this trade-off, cautioning that all-glass facades, if not properly managed, often require additional energy to maintain comfort and are not as energy efficient as they appear (World Green Building Council, n.d.). Occupants may also install heavy curtains or blinds to cope with glare or privacy, which can negate the daylighting if not designed properly.

Therefore, effective daylighting design is about the quality, not just the quantity, of windows. Key considerations include: orientation (placing larger windows on the south side in the Northern Hemisphere to capture consistent daylight, north side in Southern Hemisphere, while limiting east/west exposures that cause glare and heat gain); use of shading devices (overhangs, louvers, light shelves) to modulate sunlight, admitting high-angle winter sun but blocking hot summer sun; window glazing selection (low-e coatings, tinted glass, or double/triple glazing that improves insulation); and architectural features like clerestory windows or skylights to bring light into deeper parts of the floor plan.

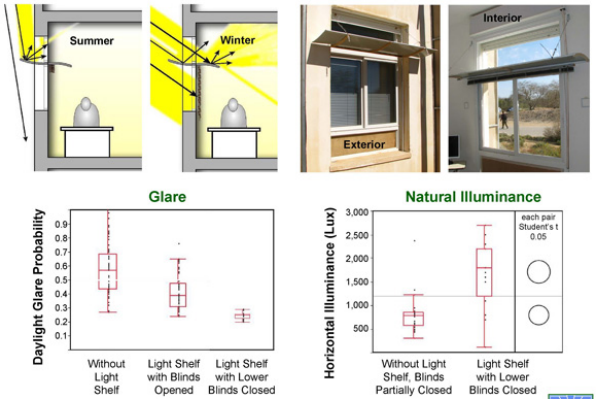


Figure 4. *Light shelves system*

One example is the use of skylights or solar tubes for top-lighting interior rooms — studies have shown that adding well-designed skylights can dramatically reduce lighting energy in single-story homes, especially for areas far from perimeter walls. Another example is the incorporation of atria or courtyards in dense housing, which act as light wells delivering daylight to lower floors.

Additional insights into daylighting performance have been reported in retrofitted industrial buildings in Belgrade. Stojković et al. analysed how adapted factory buildings can be restructured to improve daylight access by introducing larger window openings and skylights. Their study demonstrated that even in buildings not originally designed for residential use, significant daylighting improvement was achievable through passive strategies, which may be transferable to multi-purpose or residential transformations (Stojković et al., 2016).

Our findings also highlight that to maximize energy savings, daylighting should be paired with lighting controls. If a house is outfitted with sensors that dim or switch off lights in response to daylight (known as daylight harvesting controls), the reduction in

electricity use is automated and optimized. Without controls, occupants might forget to turn off lights even if a room is bright from the sun, missing out on potential savings. Many building energy codes now encourage or mandate such controls in non-residential buildings, and similar practices can benefit homes, particularly large residences or multi-unit buildings with common areas.

In summary, daylighting can substantially reduce energy use in residential buildings, but it must be implemented with an eye to avoiding adverse thermal impacts. The best designs use an integrated approach: moderate window-to-wall ratios, high-performance glazing, shading devices, and interior design (colours and surfaces) that efficiently distribute natural light. When done right, daylighting not only saves energy but also creates pleasant living spaces. Homeowners often report that naturally lit homes feel more open and cheerful, and this can increase the utilization of spaces (for example, a sunlit corner might become a favourite reading spot, reducing the need for lighting in another darker room). These qualitative benefits, while outside the scope of energy metrics, reinforce the desirability of daylighting as a core design principle.

Integrating Ventilation and Daylight in Design

An important discussion emerging from this study is how natural ventilation and daylighting can be jointly optimized in residential design. These two strategies, while distinct, often intersect in practice through the design of windows and openings. A holistic, sustainable design (shown in Figure 5) will seek to maximize both fresh air and light while minimizing energy penalties.

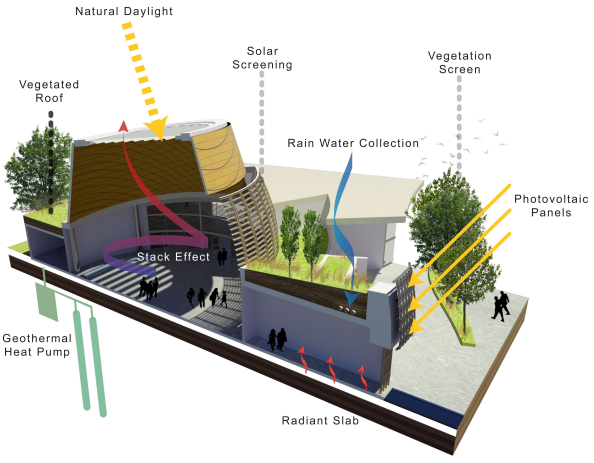


Figure 5. *Combination of natural daylight, solar screening and stack effect*

Based on the literature and cases reviewed, several integrated design considerations can be highlighted:

Building Orientation and Urban Layout: Proper orientation of a building can facilitate both daylighting and natural ventilation. Aligning a house to face prevailing breezes (for ventilation) and to capture sunlight from the appropriate direction is fundamental. For example, in many climates the ideal is to have the longer facade facing north-south: this way, one can get good southern sunlight (in the northern hemisphere) and place most windows there, while the breezier side (depending on local wind patterns) can have openings for cross-ventilation. Urban planners can contribute by designing layouts where buildings are spaced and positioned to channel winds (avoiding blocking each other's airflow) and to ensure each building's solar access is protected (avoiding one building casting long shadows on another unnecessarily). Concepts like urban wind corridors and solar envelopes are applied in sustainable urban design to maintain access to these natural resources at the city or neighbourhood scale.

Window Design and Placement: Windows are the nexus of ventilation and daylight. Operable windows placed at different heights (low windows to admit cool air, high clerestory windows to exhaust hot air) can create a convective airflow loop that also brings light deep into a room. The findings suggest using a combination of types: for instance, high-level vent windows that can stay open for ventilation even when privacy is needed, combined with large glazed areas for view and light that can be shaded when necessary. In tropical climates, high jalousie or louver windows near the ceiling can vent out hot air continuously, while larger windows might be kept open only when conditions allow. Designing windows with regard to daylight penetration (for example, using tall windows or windows above doors) can ensure light reaches further into the interior, reducing the need for artificial lighting in the back of rooms. Meanwhile, ensuring those windows are operable or complemented by vents secures the ventilation aspect.

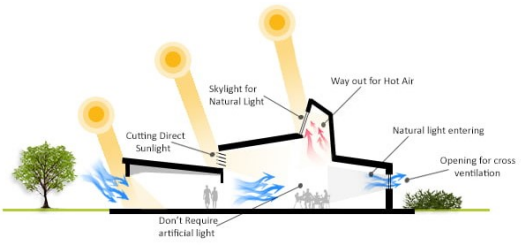


Figure 6. *Diagram of integrated natural ventilation and daylighting through skylight and stack effect*

Shading and Glazing Technology: Integrated design also means mitigating any negative impacts of one strategy on the other. Shading devices (like roof overhangs, brise-soleil, or even deciduous trees) can be positioned such that they do not obstruct wind flow while they do block high-angle sun. For example, horizontal overhangs above windows will cut out midday summer sun but have minimal effect on breezes entering the window. Similarly, modern

smart glazing can dynamically tint to reduce glare and heat when sunlight is intense, without stopping the light completely. Some new window systems even incorporate ventilation flaps that allow air in while the main glass area remains closed or shaded. The integration of such technology can help reconcile daylight and thermal requirements automatically.

Thermal Mass and Ventilation Timing: The synergy between daylight and ventilation can also be temporal. During the day, natural light warms the interior and may heat up thermal mass (floors, walls). If the building has significant thermal mass, it can store this heat and then, in the evening or night, natural ventilation can cool those masses down (night flushing), readying the building for the next day. This cycle is a form of passive solar design working hand-in-hand with ventilation. It requires materials like concrete or brick that can absorb heat, and a diurnal temperature swing that is exploited by opening windows at the right times. In design terms, this means enabling secure ventilation at night (perhaps using louvers that can be locked while open, etc.) and placing thermal mass in locations where it can interact with both sun and air flow.

Occupant Behaviour and Control: No matter how well a house is designed for natural ventilation and daylight, the realized performance depends on occupant use. A point noted in several studies is that giving occupants intuitive control (operable windows that are easy to reach and use, blinds that are easy to adjust) increases the likelihood that the passive features will be utilized. If windows are too difficult to open or if there is fear of security/insects, occupants might resort to AC. Therefore, design details like insect screens, secure window locks, and automated window openers (in some advanced homes) can encourage occupants to embrace natural ventilation. Similarly, for daylight, providing adjustable blinds or curtains helps occupants manage glare without fully darkening a room, thereby maintaining daylight use. Education of residents about the benefits and use of these features is also part of integrated design—planners and architects working on housing projects increasingly include user manuals or orientation sessions for homeowners to learn how to operate their passive design elements effectively.

The discussion above shows that natural ventilation and daylighting should not be treated in isolation. They are part of an ecosystem of design decisions that together shape a building's sustainability profile. Encouragingly, many of the measures that improve ventilation (such as well-placed operable windows, courtyards, open plans) also facilitate more daylight, and vice versa. There can be trade-offs (e.g. very large windows help daylight but may admit too much heat), yet these can be managed with thoughtful design as described. The overall finding is that a balanced design, one that maximizes free cooling and lighting while minimizing unintended heat gain/loss, can drastically cut a home's energy consumption without sacrificing comfort. In fact, such homes often provide superior comfort by connecting occupants to the outdoors and creating more varied, pleasant indoor environments.

CONCLUSION

Energy efficiency in residential buildings can be greatly enhanced by re-integrating natural forces—breezes and sunlight—into the way we design and operate our homes. This paper analysed the impact of natural ventilation and daylighting on energy consumption in houses, drawing from a range of studies and cases. The evidence shows that these passive strategies are not merely complementary features, but powerful tools: effective natural ventilation design can reduce cooling energy usage on the order of 40–70% in suitable climates (Zeinab, 2023) (Zhang, Han, He, Xiong, & Zhang, 2024), and robust daylighting can eliminate a large fraction of electric lighting needs, saving up to roughly 3/4 of lighting energy (Helgeson, 2022). Even in less ideal climates, thoughtful use of ventilation (for example, during milder hours) and daylight can yield meaningful savings and improve indoor environmental quality.

The key takeaways from this research include: (1) Design matters immensely – simple choices like window orientation, size, and the inclusion of operable elements have a disproportionate effect on a building's energy profile; (2) Climate-responsive strategies are effective – by tailoring ventilation and daylighting techniques to local climate (such as night flushing in dry regions or shading in sunny tropical regions), one can optimize performance; (3) Integrated approach – the best results come when ventilation and daylighting are part of a holistic design strategy that also considers insulation, thermal mass, and occupant behaviour; (4) Limits and trade-offs – passive methods have limits (e.g., they may not fully meet cooling needs on the hottest days or can cause glare if not controlled), so successful projects often combine passive and active systems in a complementary way (known as hybrid or mixed-mode design).

For sustainable urban planning and architecture, these findings translate into several practical recommendations. Urban planners should prioritize layouts that ensure buildings have access to breezes and sunlight – this could involve height and spacing regulations, encouraging courtyard housing, or preserving wind corridors in dense neighbourhoods. Additionally, building codes and standards should incorporate or strengthen requirements for daylighting and natural ventilation. Many building codes already mandate a minimum window area for habitable rooms; going further, codes can encourage designs that enable cross-ventilation (such as requiring operable windows on two facades for certain dwelling types) and that limit excessive glass where not climate-appropriate, to

prevent designs that inadvertently increase energy use (Powell, n.d.).

Architects and developers are advised to employ climate analysis and simulation tools early in the design process to fine-tune the passive features of their projects. Tools for daylight simulation and airflow modelling (CFD) can predict how a design will perform and allow adjustments before construction. Using such tools can inform decisions like adding a light shelf to bounce daylight deeper into a room, or placing a ventilation stack in a multi-story building to drive airflow. The additional upfront effort in design can pay off in the building's operational cost and carbon footprint over its lifetime. Importantly, these sustainable design strategies need not conflict with aesthetics or cost – many passive design elements double as architectural expression (e.g., a shading screen that creates a visual motif, or a courtyard that provides social space) and can be achieved with local materials and traditional techniques, which keeps costs reasonable.

In conclusion, natural ventilation and daylighting are cornerstone strategies for achieving low-energy, sustainable residential buildings. As the world moves towards greener buildings, harnessing these age-old yet ever-relevant design principles will be crucial. Future residential developments, whether single-family homes or apartment complexes, stand to benefit from reduced energy bills, lower environmental impact, and improved living conditions by embracing passive cooling and lighting. The path to more resilient and eco-friendly cities is illuminated by the simple idea of working with nature's resources. By designing homes that breathe and homes that glow with daylight, we take significant steps toward a future where urban living and sustainability go hand in hand.

REFERENCES

Climate Action Accelerator. (n.d.). *Energy consumption of buildings*. https://climateactionaccelerator.org/solution-areas/energy_consumption_of_buildings/

Grujić, M. D., & Kavran, J. M. (2018). Daylight utilization potential of highly glazed individual office spaces in Belgrade climate condition. *Thermal Science*, *22*(Suppl. 4), S1105–S1116. https://doi.org/10.2298/TSCI170531224G

Helgeson, G. (2022, May 31). *The key benefits of natural light*. https://duplus.co.uk/the-key-benefits-of-natural-light/

International Passive House Association. (n.d.). *The Passive House – sustainable, affordable, comfortable, versatile*. https://passivehouse-international.org/index.php?page_id=79

Powell, C. (n.d.). *(Day)Lighting the way to greener and healthier buildings*. https://worldgbc.org/article/daylighting-the-way-to-greener-and-healthier-buildings/

Rucińska, J., & Trząski, A. (2020). Measurements and simulation study of daylight availability and its impact on the heating, cooling and lighting energy demand in an educational building. *Energies*, *13*(10), 2555. https://doi.org/10.3390/en13102555

Stojković, M., Pucar, M., & Krstić-Furundžić, A. (2016). Daylight performance of adapted industrial buildings in Belgrade. *Facta Universitatis – Series: Architecture and Civil Engineering*, *14*(1), 59–74. https://doi.org/10.2298/FUACE160010059S

Storz, E. (2024, December 5). *Open those windows: Natural ventilation in historic buildings can reduce mechanical system use, save energy and create healthier indoor environments*. https://drexel.edu/news/archive/2024/December/natural-ventilation-in-historic-buildings-can-reduce-energy-use

World Green Building Council. (n.d.). *Daylighting the way to greener and healthier buildings*. https://worldgbc.org/article/daylighting-the-way-to-greener-and-healthier-buildings/

Zeinab, E. A. (2023, March 8). Energy consumption performance using natural ventilation in dwelling design and CFD simulation in a hot dry climate: A case study in Sudan. *Frontiers in Built Environment*, *9*, Article 1145747. https://doi.org/10.3389/fbuil.2023.1145747

Zhang, M., Han, W., He, Y., Xiong, J., & Zhang, Y. (2024). Natural ventilation for cooling energy saving: Typical case of public building design optimization in Guangzhou, China. *Applied Sciences*, *14*(2), Article 610. https://doi.org/10.3390/app14020610

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EVALUATION OF ENERGY SUSTAINABILITY STRATEGIES THROUGH DIGITAL SIMULATIONS

Abstract: *As the world increasingly focuses on sustainable energy solutions, solar photovoltaics (PV) emerge as crucial components in this transition. This research examines the comparative performance of fixed-tilt and sun-tracking PV systems through digital simulations using the PVGIS tool, with a specific focus on the geographic setting of Niš, Serbia. The study confirms that sun-tracking systems significantly enhance annual energy production, with dual-axis trackers outperforming fixed systems by approximately 30%. The analysis reveals that tracking systems not only increase the overall energy yield but also reduce seasonal output variability, particularly enhancing performance during winter months. These results underscore the importance of considering both tilt and tracking mechanisms in the design of PV systems to optimize energy sustainability. The use of digital simulation tools like PVGIS provides valuable insights into the potential enhancements achievable through strategic system configuration, supporting the effective planning and optimization of solar energy projects for enhanced sustainability.*

Keywords: energy sustainability, photovoltaic systems, digital simulations, system optimization, PVGIS

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INTRODUCTION

The increasing urgency of climate change mitigation has driven a worldwide push for sustainable energy strategies. Renewable energy sources are expected to provide a major share of future electricity; for instance, one United Nations report projects that renewables could supply 65% of global electricity by 2030 (United Nations, 2021). Solar photovoltaic (PV) technology has experienced rapid growth and cost reductions, making it a cornerstone of clean energy expansion. By the end of 2020, global installed PV capacity reached approximately 710 GW, with 125 GW added in that single year (International Renewable Energy Agency [IRENA], 2021). Such growth reflects both technological advancements and policy support, aligning with climate targets to decarbonize the power sector.

Despite its favourable solar resources, Southeast Europe has only recently begun to tap into its PV potential. Serbia, for example, enjoys an average annual solar irradiation of about 1,200–1,550 kWh/m², which is higher than in some leading solar markets, such as Germany (~1,000 kWh/m²) (Pavlović et al., 2013). However, until recently, Serbia's installed PV capacity remained below 10 MW, reflecting underutilization of its solar potential (Milosavljević et al., 2022). Closing this gap requires not only supportive policies but also optimization of PV system design to maximize energy yield under local climatic conditions (Pavlović et al., 2013).

A crucial factor influencing PV energy output is the orientation and tilt of the panels relative to the sun. Fixed-mount PV systems are typically tilted at an angle close to the latitude and face due south in the northern hemisphere to capture maximum annual sunlight. However, the sun's position varies throughout the day and year, causing fixed panels to receive suboptimal irradiance during mornings, evenings, and winter months. This has motivated the development of sun-tracking systems that adjust panel orientation dynamically to follow the sun's path.

BACKGROUND AND RESEARCH OBJECTIVES

Prior studies have shown that using tracking mechanisms can significantly boost energy harvest. A single-axis tracker (which usually rotates east-west daily) can increase annual output by around 20% compared to a fixed tilt system (National Renewable Energy Laboratory [NREL], 2015), while dual-axis trackers (which follow both the sun's azimuth and elevation) can yield up to 30–45% gains in certain locations. For example, Alshaabani (2024) reported a ~37.5% energy gain with single-axis tracking and ~43.9% with dual-axis in a high-irradiance climate

(Alshaabani et al., 2024). These enhancements are especially pronounced in winter and at times of the day when a fixed panel's orientation is far from ideal. On the other hand, incorporating trackers adds complexity, maintenance, and cost. Thus, there is a need to quantitatively evaluate whether the performance benefits justify the investment in different contexts.

Advances in digital simulation tools enable a detailed assessment of PV performance under various configuration scenarios without physical installation. Tools such as PVGIS (Photovoltaic Geographical Information System) integrate solar irradiance databases with PV system models to estimate energy production for any given location (Milosavljević et al., 2022). These simulations account for local weather (solar radiation, temperature, etc.), system specifications, and losses, providing a reliable basis for comparing design options. Indeed, a recent validation study showed PVGIS to be among the most accurate PV simulation tools for climates like Serbia's, closely matching measured energy yields (Milosavljević et al., 2022). Using such digital simulations, researchers and planners can explore the impact of different tilt angles, tracking strategies, and seasonal adjustments on energy output before implementing them on the ground. This approach supports evidence-based decisions to improve the sustainability and efficiency of solar energy projects.

The present study evaluates energy sustainability strategies for PV systems through digital simulations, focusing on the effect of panel tilt and tracking under the climate conditions of Niš, Serbia. A conventional fixed-tilt grid-connected PV system is compared to systems with single-axis and dual-axis sun tracking. By analysing simulation data from PVGIS, the study quantifies the increase in energy production due to tracking and examines how this varies seasonally. The objective is to provide insights into the performance trade-offs of each configuration and to identify the most effective strategy for maximizing solar energy output in the study region. The findings can assist renewable energy planners and stakeholders in optimizing PV installations for enhanced sustainability.

METHODOLOGY

To investigate the performance of fixed versus tracking PV systems, simulations were conducted using the PVGIS tool (European Commission Joint Research Centre, 2025) for the location of Niš, Serbia. Niš is situated at approximately 43.3° N latitude, 21.9° E longitude, with an elevation of around 200 m. This location has a moderate continental climate with hot summers and cold winters, representative of many inland Balkan regions. The simulations utilized a typical meteorological year based on the PVGIS-SARAH3 solar radiation database, which provides hourly solar irradiance data derived from satellite observations. This database was selected for its high resolution and validated accuracy in simulating PV output in Southeast Europe (Milosavljević et al., 2022).

A 1 kW grid-connected PV system was modelled for consistency across scenarios. The PV technology was assumed to be crystalline silicon modules, with a system performance loss factor of 14% to account for inverter losses, temperature effects, dirt, and other inefficiencies (a typical value for well-designed systems). The same loss assumptions were applied to all scenarios so that differences in output are attributable only to orientation and tracking.

Simulation Scenarios

Four configurations of the PV system were evaluated:

1. **Fixed mount** at a tilt angle of 35° (approximately the latitude of Niš minus a few degrees), facing due south (azimuth 0°);
2. **Single-axis tracking (vertical axis),** where panels pivot around a vertical axis (azimuthal rotation) while fixed at 35° tilt;
3. **Single-axis tracking (inclined axis)**, where panels rotate around an axis tilted at 35° from horizontal, often referred to as "polar aligned" tracking; and
4. **Dual-axis tracking**, which continuously adjusts both tilt and orientation to directly face the sun.

A fixed tilt angle of 35° was selected because it approximates the annual optimum for the latitude of Niš, balancing higher winter sun angles and lower summer sun angles for maximal yearly energy capture (Siddiqui et al., 2021). For the tracking configurations, 35° was used as the tilt of the rotation axis (for vertical and inclined single-axis systems) to enable a fair comparison baseline. All tracking systems were assumed to have a full range of motion (e.g., ±180° azimuth for the vertical axis tracker, ±90° tilt for the inclined axis), and no shading or horizon obstructions were considered, with the PVGIS horizon set to "calculated" to assume an unobstructed sun path (European Commission Joint Research Centre, 2025).

Simulation Procedure

Using PVGIS's non-interactive API, each scenario was simulated to obtain monthly and annual PV energy outputs. The tool calculates the incident solar radiation on the PV plane and the resulting DC energy, then applies the specified system losses to estimate delivered AC energy. For the tracking scenarios, PVGIS internally determines the optimal panel orientation for each time step (hourly) based on the sun's position and the tracker type's constraints (European Commission Joint Research Centre, 2025).

The output includes the total yearly energy production (in kWh for the 1 kWp system), monthly averages, as well as intermediate values such as plane-of-array irradiation and loss breakdowns. These outputs were extracted and compared across the four cases. In addition, key performance indicators such as the performance ratio (implicitly indicated by total losses) and the annual variability (interannual standard deviation) were recorded, although the primary focus was placed on comparative energy yield. By analysing the simulation results, the study assesses how much

additional energy each tracking method provides relative to a conventional fixed installation and how these gains vary by month. All data were processed and plotted to facilitate comparison and to illustrate the seasonal distribution of PV production under each scenario.

INPUT PARAMETERS

The following input parameters were used consistently in the simulations for all scenarios:

- Location: Niš, Serbia (Latitude 43.327° N, Longitude 21.896° E). The site has a calculated average horizon (no significant terrain shading) and a continental climate profile.
- Solar Radiation Data: PVGIS-SARAH3 database (latest version) providing multi-year average hourly irradiance. This data source incorporates satellite-derived global, direct, and diffuse irradiance and has been validated for accuracy in European climates (Milosavljević et al., 2022)
- PV System Size: 1 kWp (1000 W) nominal capacity. This scaling allows results to be reported per kW, which can be linearly scaled to other system sizes.
- PV Module and Technology: Fixed properties for crystalline silicon modules; nominal efficiency around 15–18% under standard test conditions (not explicitly needed by PVGIS, which works in terms of kWp)
- System Losses: 14% total system loss (including inverter inefficiency, wiring, soiling, mismatch, etc.), in line with typical PV system performance assumptions.
- Fixed Tilt Angle: 35° (south-facing) for the non-tracking reference case. This tilt is close to Niš's latitude and is commonly recommended for maximizing annual yield in this region (Siddiqui et al., 2021).
- Tracking Configurations:
  - Vertical-axis single-axis tracker: panel tilt fixed at 35°, rotates 360° around a vertical axis to follow the sun's azimuth (effectively, it faces the sun's direction along the horizon throughout the day, keeping the same tilt).
  - Inclined-axis (tilted) single-axis tracker: the rotation axis is tilted 35° from horizontal and oriented north-south. The panel rotates around this axis, roughly tracking the sun's daily altitude change. This often approximates a "polar axis" tracker aligned with Earth's axis if tilt = latitude (here 35° is slightly less than latitude).
  - Dual-axis tracker: free to adjust in two degrees of freedom, ensuring the panel surface is always perpendicular to incoming sunlight (ideal tracking of both azimuth and elevation).
- Simulation Tool Settings: Grid-connected PV mode (so no storage, all energy is fed to grid load), with hourly time-step calculations. The outputs of interest – monthly and annual energy (kWh) – are aggregated from the hourly simulation results.

These parameters ensure that the only differences between scenarios arise from the geometric configuration (fixed vs tracking), enabling a clear evaluation of how tilt and tracking influence energy production. The chosen tilt of 35° for both the fixed system and as the baseline tilt in trackers provides a consistent reference, since a different fixed tilt would itself change the annual output. The methodology thereby isolates the tracking effect and ensures a consistent basis of comparison between the energy sustainability strategies.

RESULTS

Annual Energy Production

The PVGIS simulation results indicate a substantial increase in annual energy output for PV systems employing sun-tracking compared to a fixed-tilt system in Niš..

Table 1 presents the yearly energy yield (in kWh) per 1 kWp installed for each system configuration, along with the relative gain over the fixed system.

Table 1. *Simulation outputs*

Parameter	Fixed system	Vertical axis	Inclined axis	Two axis
Slope angle [°]	35	**35**	35	-
Azimuth angle [°]	0	**-**	-	-
Yearly PV energy production [kWh]	1281	1577	1646	1687
Yearly in-plane irradiation [kWh/m²]	1651	*2021*	2108	2165
Year-to-year variability [kWh]	55.37	73.4	80.1	82.5
Angle of incidence [%]	-2.76	-1.74	-1.58	-1.52
Spectral effects [%]	1.05	**1**	1.01	1.02
Temperature and low irradiance [%]	-8.17	-8.58	-8.67	-8.91
Total loss [%]	-22.4	-21.98	-21.92	-22.06

The fixed south-facing 35° tilt system produces approximately 1281 kWh per year per kW_p. This corresponds to an overall performance ratio in line with expectations given the site's ~1650 kWh/m² of annual insolation on a 35° inclined plane and 14% system losses. By contrast, all tracking systems show markedly higher outputs. The

single-axis tracker with a vertical axis (which only adjusts azimuth) yields about 1577 kWh/kW annually, which is roughly a 23% increase over the fixed tilt. The single-axis tracker with an inclined (tilted) axis generates around 1645 kWh/kW, about 28% higher than the fixed system. This suggests that the inclined-axis tracker, which better follows the sun's elevation angle, captures more irradiance than the purely azimuth-tracking vertical-axis system. The highest yield is achieved with the dual-axis tracker at approximately 1687 kWh/kW annually – about 32% greater than the fixed panel. This two-axis system essentially maximizes irradiance capture throughout the year by maintaining optimal panel orientation at all times. Table 2. Shows simulated annual energy output for a 1 kWp PV system in Niš under different configurations. The relative increase is computed against the fixed tilt case (1280.8 kWh as baseline).

Table 2. *Annual energy output and relative gains for a 1 kWp PV system in Niš.*

PV System Configuration	Yearly Energy Output (kWh)	Increase vs. Fixed (%)
Fixed tilt (35° South)	1280.8	-
Single-axis tracking (vertical axis)	1576.6	**+23.1**
Single-axis tracking (inclined axis)	1645.5	+28.5
Dual-axis tracking	1686.9	*+31.7*

These results quantitatively confirm the significant performance advantage of tracking systems in this geographic context. The magnitude of gain (~20–32%) aligns well with ranges reported in literature for similar latitudes (Alshaabani et al., 2024; NREL, 2015).

Notably, even the simpler single-axis trackers capture most of the potential improvement – the inclined-axis tracker yields nearly 98% of the dual-axis tracker's energy, indicating that allowing tilt adjustment in addition to daily rotation adds only a few percentage points more. The vertical-axis tracker (with fixed tilt) has slightly lower output, underscoring the importance of tilt optimization for maximizing irradiance (since at 35° fixed tilt, the panel orientation is not ideal in winter midday when the sun is low, as discussed below).

Seasonal and Monthly Performance

The advantage of tracking systems is even more pronounced when examining monthly energy production. Following figures show the monthly energy output for the fixed-angle PV system (figure 1) and for the tracking PV system (figure 2).

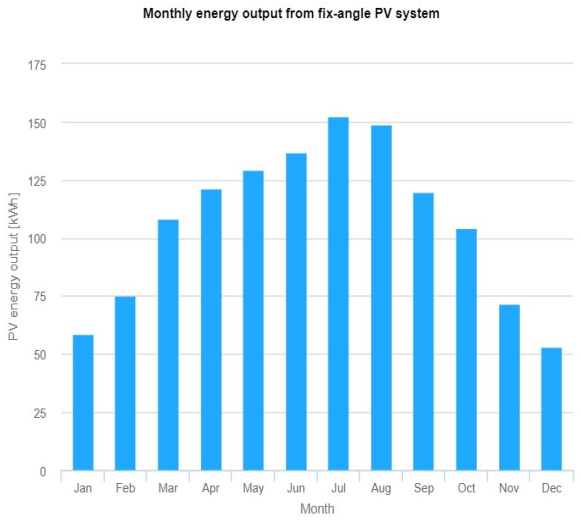


Figure 1. *Monthly energy output from fixed-angle PV system*

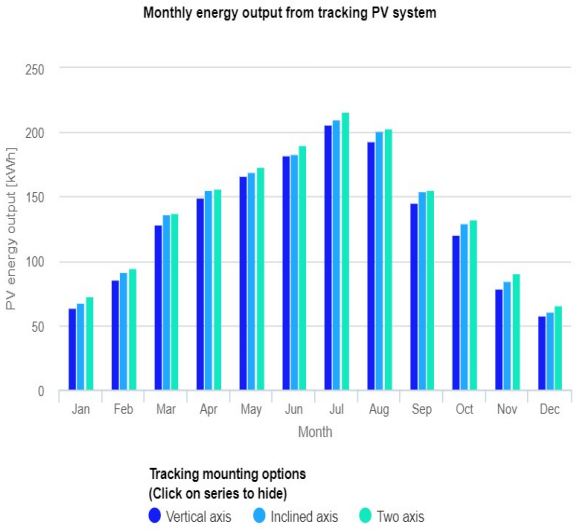


Figure 2. *Monthly energy output from tracking PV system*

All systems exhibit the expected seasonal pattern: higher output in longer, sunnier summer days and lower output during winter. However, tracking mitigates the seasonal drop-off. For instance, in the fixed-tilt scenario, the simulation indicates that December yields are around a few dozen kWh per kW (on the order of 40–50 kWh for the month, given low winter sun angle and short daylength in Niš). In contrast, the dual-axis tracker can produce roughly double that amount in December, by continuously angling the panels toward the low midday sun and even capturing some morning/afternoon sunlight that a fixed panel (stuck at 35° tilt facing south) would miss.

In these results for Niš, while snow is not explicitly modelled, the dual-axis system's relative gain is indeed largest in the winter months. The single-axis trackers also show strong winter improvement. The inclined-axis tracker, which can tilt up toward the low sun, performs almost as well as the dual-axis in winter. The vertical-axis tracker (azimuth-only) shows

improvement in winter, but to a lesser extent because its panels are still fixed at 35° tilt – during December, the optimal tilt in Niš would be much steeper (around ~60°). Even so, the vertical-axis tracker benefits from being able to orient toward the sun's azimuth, capturing some morning and afternoon radiation that the fixed panel (which faces only south) cannot. During summer months, the difference between tracking and fixed systems, in percentage terms, is smaller. In June and July, the sun is high in the sky for much of the day, and a fixed 35° panel already captures a large fraction of the irradiance around noon. Dual-axis tracking still yields higher absolute energy (by extending collection in early morning and late evening, and always perpendicular to the sun at noon), but the relative gain might be on the order of 15–20% in peak summer months, compared to 50+% in some winter months. Overall, tracking systems provide a more uniform monthly energy output profile: the seasonal swing is reduced. For example, the ratio of July-to-December output might be perhaps 4:1 for the fixed panel, whereas it could drop to ~3:1 for a dual-axis tracker. This implies improved reliability and predictability of solar generation year-round, an important consideration for energy sustainability in grids with high PV penetration.

Performance Loss Factors

According to the PVGIS output, all scenarios had similar aggregate system losses (~22% of the incoming in-plane energy) due to the fixed 14% system losses plus additional loss factors like angle-of-incidence and spectral effects. There were minor differences: for instance, the dual-axis tracker had a slightly higher angle-of-incidence loss (-1.52 %) compared to the fixed panel (-2.76 %) because it always keeps the sun close to perpendicular (Alshaabani, 2024). The temperature and low-irradiance losses were roughly similar across scenarios (~8–9%), since those depend more on climate and module characteristics than orientation. These loss breakdowns confirm that the primary driver of energy differences is the amount of irradiance captured by the panel, not changes in module efficiency or other factors. Tracking increases the irradiance on the panel (the "in-plane irradiation"), which directly translates to higher energy output. For example, the yearly in-plane irradiation for the fixed tilt was 1655 kWh/m², whereas for the dual-axis it was 2165 kWh/m² – about 31% more, closely matching the energy gain. This indicates the simulation's internal consistency: nearly all extra captured sunlight is effectively converted to extra electricity, as one would expect in linear PV performance regime. In summary, the simulation results clearly demonstrate that sun-tracking mechanisms can significantly enhance the energy yield of PV systems in Niš. Dual-axis tracking provides the greatest benefit, but even single-axis systems capture most of the potential gain. The improvements are particularly salient during periods of low sun angles (winter) and at the daily extremes (morning/evening), highlighting how tracking mitigates some of the inherent limitations of fixed-position panels. In the context of energy sustainability, these findings imply that deploying tracking can reduce the number of panels (or installed capacity) required to achieve a given annual energy target, or alternatively, increase the energy output from an existing PV capacity.

DISCUSSION

The above results emphasize the strong impact that orientation and tracking strategies have on photovoltaic energy output. In a location like Niš with a continental climate, a fixed PV array tilted for optimal annual performance still leaves substantial energy uncaptured, especially during early/late hours and winter months. By employing sun-tracking, one can harness a larger portion of available solar radiation, thus improving the capacity factor of the PV system. The dual-axis tracker, effectively normal to the sun at all times, represents the theoretical maximum yield for a given PV array area. Our simulations showed roughly a one-third increase in annual generation with dual-axis tracking versus a fixed tilt – a result that aligns with both the PVGIS-based study (Mirjanić et al, 2020) and general expectations (20–40% range of improvement) in the literature (Alshaabani, 2024). This consistency lends confidence to the use of digital tools like PVGIS for evaluating performance enhancements due to tracking.

Energy Output Variability and Reliability

An important observation is that tracking systems reduce the variability of solar power output on both daily and seasonal scales. The flatter, broader power curves mean that a tracker begins producing significant power earlier after sunrise and continues later before sunset than a fixed panel. This can be advantageous for applications where a more stable power supply is desired, or to better match electricity demand patterns. Seasonally, while PV output will always be lower in winter than summer, the boost from tracking can partly compensate for the short days and low sun. In our case, the dual-axis system generated as much as 80–100% more energy in mid-winter months than the fixed system. This can improve the economics of PV in climates with sharp seasonal differences, since the winter "low period" yields are less debilitating. That said, tracking cannot eliminate seasonal variation entirely – other solutions like oversizing PV capacity or integrating storage might be needed to ensure year-round energy security.

Tilt Angle Optimization vs. Tracking

One alternative to full tracking is to adjust the tilt angle a few times per year (seasonally) to better capture winter vs. summer sun. This practice is sometimes employed in small off-grid systems. Research suggests that performing about four tilt adjustments per year can notably increase the energy yield relative to never adjusting. (Binghamton University, 2017) found that four optimally timed adjustments could provide an additional ~25 kWh/m² per year compared to just using the seasonal extremes.

. In essence, manual adjustment is a low-tech way to approximate tracking during key periods. However, even quarterly adjustments cannot match the performance of continuous tracking, which optimizes orientation at every hour. Our results indicate what the upper bound is – for example, no fixed tilt, even if changed monthly, would achieve the dual-axis's ~1687 kWh/kW year output, because the sun's daily path still causes losses.

Implications for Sustainable Energy Planning

By leveraging digital simulations, it can quantify how much a given strategy contributes to energy sustainability objectives. For Niš and similar climates, implementing single-axis tracking on solar farms could increase the renewable energy yield substantially without needing additional land or panels – a significant advantage when trying to maximize clean energy within existing constraints. On the other hand, if the priority is simplicity and low maintenance (e.g., for a community solar project or off-grid system with limited technical support), fixed mounts might be preferred, accepting a lower yield. The analysis in this paper provides a framework for such decisions: policymakers and engineers can weigh a ~25–30% energy gain against the costs and complexity of trackers. From an environmental perspective, higher PV output per installed capacity means greater displacement of fossil fuel generation (per panel deployed), thereby improving the sustainability payoff of the solar investment.

These findings also underscore the value of simulation tools in planning. The use of PVGIS allows to conduct a detailed evaluation of different configurations under realistic weather conditions specific to Niš. This approach can be extended to other locations and scenarios – for example, analysing how the optimal strategy might differ in a more cloudy climate, or under future weather patterns. Simulations can also be combined with economic analysis to determine the break-even costs of trackers given the energy gains. Additionally, while this study focused on grid-tied systems (where excess energy simply feeds into the grid), in off-grid or battery-coupled systems, the seasonal and daily distribution of PV output is crucial. A tracker that produces more winter energy might significantly reduce the required battery storage or backup generation for year-round autonomy, thus influencing system design for sustainable off-grid living.

In conclusion of the discussion, the digital simulation of energy sustainability strategies shows that careful optimization of PV system orientation can meaningfully increase renewable energy generation. Tracking systems, by actively following the sun, leverage the full potential of solar resources available to a site. The decision to implement such systems should balance the energy gains against practical constraints, but as solar technology costs continue to decrease, it may see broader adoption of tracking even in smaller installations. The continued development of robust simulation platforms like PVGIS ensures that stakeholders can make informed, data-driven choices to accelerate the transition to sustainable energy systems.

CONCLUSION

This study evaluated the performance of fixed versus sun-tracking photovoltaic systems in Niš through detailed digital simulations, providing insights into how different deployment strategies can enhance energy sustainability. Using PVGIS, a well-validated PV simulation tool, the analysis compared a conventional fixed-tilt PV array with single-axis and dual-axis tracking configurations under identical conditions. The results clearly demonstrate that incorporating tracking significantly increases solar energy yield: the dual-axis tracking system produced roughly 30–32% more annual electricity than the fixed-tilt system, while even single-axis trackers achieved gains of 20–28%. These improvements were especially notable during winter months and at times when the sun's angle is far from optimal for fixed panels, highlighting how tracking mitigates seasonal and diurnal variability in solar power output.

A fixed tilt of 35° (approximately the latitude of Niš) was identified as a good overall choice for annual energy maximization, yet it remains inherently a compromise. Sun-tracking systems outperform this static approach by continuously aligning the PV panels with the sun, thereby capturing a larger fraction of available irradiance. The inclined-axis tracker's performance, nearly matching that of a dual-axis system, suggests that much of the benefit can be obtained with a simpler single-axis mechanism oriented parallel to Earth's axis. This represents an important finding for practical implementation, as it points to a cost-effective way to gain most of the energy advantage offered by dual-axis tracking.

The analysis of energy output variations due to tilt and tracking confirms that optimizing panel orientation is crucial for improving the reliability of solar energy supply. A fixed system in Niš experiences large swings between summer and winter output, whereas a tracking system yields a more balanced production throughout the year. This has positive implications for grid stability and for applications requiring consistent energy generation. On the other hand, the complexity, maintenance requirements, and costs associated with tracking were acknowledged. The discussion addressed how these factors might influence the decision to use tracking in different scenarios, such as utility-scale versus residential applications and high versus moderate irradiance climates. In contexts where simplicity and low maintenance are paramount, alternatives like seasonally adjusting tilt or accepting a moderate loss in annual yield may be preferred. Nonetheless, the trend in large-scale solar installations is increasingly toward single-axis tracking, driven by its clear energy benefits.

In conclusion, digital simulations have proven to be a valuable approach for evaluating energy sustainability

strategies in the renewable energy domain. By virtually modelling PV system configurations, it is possible to predict performance outcomes with reasonable accuracy and thus inform strategic decisions. For Niš and similar locales, the simulations indicate that adopting sun-tracking PV installations can substantially boost renewable electricity generation and make better use of the region's ample solar resource. This contributes to sustainability goals by increasing clean energy output without requiring additional panels or land area. Future research can extend this work by integrating economic analyses (such as cost-benefit assessments of trackers), exploring hybrid solutions and examining other renewable integration strategies, including the combination of solar with storage or wind. Ultimately, the path to a sustainable energy future will be shaped by both innovative technologies and smart deployment strategies, and studies such as this demonstrate how computational tools enable the identification and quantification of those strategies for maximum impact.

REFERENCES

Alshaabani, A. (2024). Developing the Design of Single-Axis Sun Sensor Solar Tracking System. Energies, 17(14), 3442. DOI: 10.3390/en17143442

Binghamton University. (2017, April 18). Adjusting solar panel angles a few times a year makes them more efficient. ScienceDaily. Retrieved from https://www.sciencedaily.com/releases/2017/04/170418160025.htm

European Commission, Joint Research Centre. (2020). Photovoltaic Geographical Information System (PVGIS) – Tracking PV systems. Retrieved from https://joint-research-centre.ec.europa.eu/pvgis-tools/tracking-pv-systems_en

International Renewable Energy Agency (IRENA). (2021). Solar energy: A renewable energy leader. Retrieved from https://www.irena.org/solar

Milosavljević, D. D., Kevkić, T. S., & Jovanović, S. J. (2022). Review and validation of photovoltaic solar simulation tools/software based on case study. Open Physics, 20(1), 431–451. DOI: 10.1515/phys-2022-0042

Mirjanić, D. Lj., Pavlović, T. M., Radonjić, I. S., Pantić, L. S., Marić, A. V., & Sazhko, G. I. (2020). Solar radiation atlas in Trebinje in the Republic of Srpska. In Proceedings of the International Scientific Conference UNITECH 2020 (pp. 18–23). Gabrovo, Bulgaria

National Renewable Energy Laboratory. (2015). System advisor model (SAM): Photovoltaic model technical reference. U.S. Department of Energy. https://www.energy.gov/sites/prod/files/2019/03/f61/NREL%202015a.pdf

National Renewable Energy Laboratory. (2016). Facility-Scale Solar Photovoltaic Systems Guidebook. U.S. Department of Energy. Retrieved from https://www.nrel.gov/docs/fy16osti/67122.pdf

Pavlović, T. M., Milosavljević, D. D., Radonjić, I. S., Pantić, L. S., Radivojević, A. R., & Pavlović, M. T. (2013). Possibility of electricity generation using PV solar plants in Serbia. Renewable and Sustainable Energy Reviews, 20, 201–218. DOI: 10.1016/j.rser.2012.11.070

Siddiqui, M. U., Hammami, S., & Rehman, S. (2021). Optimum tilt angle and maximum possible solar energy gain: A review. Solar Energy, 219, 399–419. https://scispace.com/pdf/optimum-tilt-angle-and-maximum-possible-solar-energy-gain-at-2oy7txvbzg.pdf

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INDUSTRIAL FIRES - A CRUCIAL FACTOR FOR MEGA INCIDENTS

Abstract: *The risk of an uncontrolled fire can seriously threaten the corporate security and stability of every company in the industry. Two-thirds of the refineries and installations in the Republic of North Macedonia that faced a major fire (which affected 50% of the company's assets) ended up in bankruptcy. Therefore, timely identification, analysis and assessment of fire threats, along with the selection of the most appropriate control measures, should be considered as a challenge and a red line for every safety manager in the industry. This process can be viewed as a comprehensive conceptual framework that effectively integrates various areas of corporate operations, focusing on identifying all potential risks, dangers, and threats to the company. It guides the effective use of company resources in order to prevent losses, reduce failures and errors in operations and thus increase profits and improve the stability of the company. In this paper, we will present a worst-case fire scenario for the Skopje region in the Republic of North Macedonia, due to the presence of industrial facilities in the area. Furthermore, the paper outlines the stages undertaken to address the ongoing fire hazard at the OKTA company and presents a fire risk reduction strategy that has been successfully implemented in practice.*

Keywords: fire risk, vulnerability control, treatment of fires

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INTRODUCTION

Current events in the last decade of the 20th century, as well as the beginning of the new millennium, point to numerous risks and dangers arising from accidents, incidents, malfunctions, natural disasters, and other forms of destructive impacts on human life, natural and material assets, and the environment as a whole.

Emergency events such as industrial accidents, fires, floods, earthquakes, and other natural disasters not only threaten the lives and property of individuals but can also disrupt the ecological balance of entire regions and affect overall socio-economic development.

Fire is an uncontrolled combustion that occurs when three basic elements combine (Group of Authors, 2010): a combustible material (any flammable substance such as wood, paper, plastic, oil, fuel, etc.), oxygen (present at a concentration of about 21%), and a source of heat (a spark, open flame, friction, electric arc, etc.).

The fundamental principles of fire protection include measures and actions aimed at preventing the outbreak and spread of fire, as well as ensuring effective fire extinguishing and the rescue of people and property (Erić, 2003).

Fires in railway transportation can cause dramatic and long-lasting adverse effects on the environment and the population, and the serious consequences of such disasters confirm a real threat that requires a systematic approach to resolution.

The causes of fires in railway transport can be numerous and varied, resulting from technical failures, lack of equipment maintenance, human error, or external factors (Cote, 2023; Klinoff, 2019).

The most common **technical failures** that lead to fires include:

- *Short circuits in electrical installations* (faulty or worn-out electrical systems in the train or infrastructure, e.g., the overhead contact line).
- *Overheating of components* (engines, braking systems, transformers, or other electrical parts can overheat due to malfunction or lack of maintenance).
- *Fuel or oil leaks* (in diesel locomotives, leaks of fuel or lubricants can lead to ignition, especially in the presence of sparks).
- *Malfunctioning heating systems* (stoves or heating devices inside train cars can cause fires if not properly maintained).

Human error is also a common cause of fires in railway transport. Human factors that lead to fires include:

- *Smoking in prohibited areas* (discarding cigarette butts in or around the train).

- *Improper use of equipment* (inexpert handling of electrical devices, cables, or flammable materials).
- *Failure to follow maintenance procedures* (skipping mandatory inspections and servicing can lead to latent failures).
- Among the **external causes** that can lead to fires in railway systems, the following can be identified:
  - *Wildfires* (smoke and flame can spread to trains or railway infrastructure).
  - *Sparks from wheels or brakes* (under dry conditions, sparks from braking systems can ignite dry grass or vegetation alongside the tracks).
  - *Sabotage or vandalism* (intentional setting of fires, for example, by throwing flammable objects).

Fire protection in railway transportation should be organized and implemented at all locations and facilities exposed to fire hazards, encompassing the application of regulatory, administrative, organizational, educational, and other measures.

In this paper, we will present a worst-case fire scenario in the Republic of North Macedonia. This scenario has been developed as a worst-case fire threat situation for the Skopje region since those industrial capacities are located within the area. If there is a fire hazard among them, it may significantly threaten the city with serious consequences.

The situation has been chosen for a specific city area due to records of fire-related events over five years (2016-2020). Based on the reviewed information for this period, the risk of fire is assessed as very serious for the City, for two main reasons: a high likelihood of a fire occurring and a major potential impact in case of a fire, with the ability to escalate quickly over a large area, potentially leading to loss of life, damage to property, and disaster for nature.

CASE STUDY - INDUSTRIAL FIRES

Due to the extended period of transition in the Republic of North Macedonia, unfortunately, a lot of negative impacts have been felt across many sectors of industry. One of the most affected is the railway sector. This paper will try to look at it specifically from a fire hazard perspective. The Railway Infrastructure Public Enterprise has been greatly financially exchequer, so it has minimized routine railway corridor maintenance, especially in terms of spraying and vegetation control. This negligence has directly led to a significant increase in the number of wildfires along the railway lines.

The description of the scenario

The international train service running on the Budapest–Belgrade–Niš–Skopje–Thessaloniki line, after passing through the city of Kumanovo on its way to Skopje, travels 20 kilometers as it descends from the highest point of 459 meters above sea level (Romanovce Toll Station) to 280 meters, a vertical drop of 179 meters in less than 15 minutes (Figure 1).

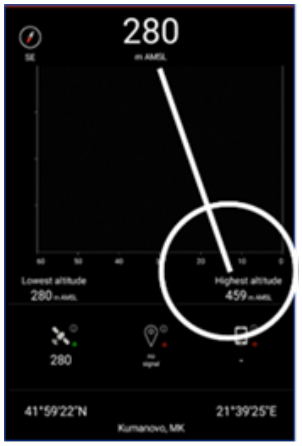


Figure 1. *Train height distance - vertical (179m)*

For this segment, the train driver must apply continuous braking, which concludes near the village of Miladinovci, where large fuel storage facilities are located (Figure 2). These facilities house petroleum derivatives and liquefied gas for the two largest suppliers, which together account for approximately 90% of the domestic market share in petroleum products.

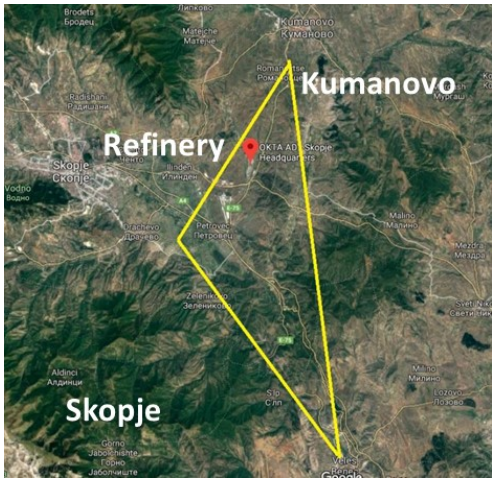


Figure 2. *The location of large fuel storage facilities (the critical triangle)*

On this stretch, fires often occur in the summer, on average 4-6 per year, and in dry years, this number can rise to as many as 10, of which at least one is severe (Figure 3).



Figure 3. *Total number of fires by 2020*

The steep descent, coupled with continuous braking and friction, leads to the generation of sparks, which ignite the dry vegetation along the railway line. During the summer period, this vegetation becomes highly flammable and susceptible to rapid combustion. The principal concern is the potential for uncontrolled fire

propagation, exacerbated by persistent winds in the area, which could allow the fire to reach and breach the external perimeter of the fuel storage facilities, posing an extreme risk of escalation into a major industrial fire or explosion.

The braking reaches its climax at the height of the Central Administration Building of the refinery, which is located on the right, and the LPG installation of the other oil company positioned on the left.

Incident Cause Analysis

A freight train on the Belgrade–Skopje route experienced a mechanical failure after an extended braking sequence (Sunday, 25 July 2021, 11:47 a.m.). One of the locomotive's wheels got locked and created a lot of friction and sparks along the track for a significant part of the railway (Figure 4). This created multiple ignition points and fires along the railway.



Figure 4. *The braking and friction/sparks*

In addition to the sparks from the locked wheel, hot brake lining fragments detached from the locomotive. One of these fragments acted as an ignition source and set fire to a wooden railway sleeper and the surrounding vegetation (Figure 5). It was Sunday, a day when the company was operating with minimum staff which was an unfavorable circumstance for effective firefighting.



Figure 5. *The fire on a wooden railway sleeper*

The fire developed fast – in 12 minutes – and was detected by the company's Monitoring Center via surveillance cameras. According to the procedure, the Monitoring Center alerted the Firefighting Unit's team leader via radio and public address system.

The reaction time from the moment of alert to on-site arrival was 150 seconds. The Firefighting Unit Commander, Safety and Fire Protection Manager, and duty personnel arrived 25 minutes after the alert was issued. This marked the start of the coordinated response to contain the fire within the company premises.

At 12:33 p.m., the Territorial Firefighting Unit of the City of Skopje arrived on site, 49 minutes after the alert.

By 1:55 p.m., the fire had reached its peak in terms of spread. Four active fire fronts had developed in the northeastern sector, extending over 2 kilometers in length (Figure 6).

The spread of the fire significantly endangered the coordination of suppression efforts, which in turn divided the available firefighting resources across four separate locations. Due to the variable and unexpected progress of the fire, it was necessary to continuously reorganize personnel, equipment, and suppression resources in real time to respond effectively.



Figure 6. *Four active fire fronts and direction of fire spread*

Wind was out of the south at between 5 and 8 m/s. The wind, which played a role in slowing the fire's advance down the rail line at times, also directed the flames toward the perimeter of the OKTA AD petrol station.

Given the variable wind conditions, the fire reached the facility's perimeter in 17 minutes. The ignition and initial growth phase of the fire lasted 12 minutes, and within a total of 29 minutes from its initial outbreak, the fire had reached the perimeter, posing a significant threat. During this period, internal alert systems were activated, response teams were mobilized, and the remaining personnel reported to the site. It is important to note that the minimum response time for the national (public) fire service is 45 minutes.

This indicates that whenever a northerly wind—commonly originating from the slopes of Mount Skopska Crna Gora—blows at speeds exceeding 15 m/s, a critical risk scenario for OKTA AD arises. In such a scenario the fire may reach the perimeter of the facility in less than 15 minutes. This creates a 14-minute gap needed for the company's internal fire team to assemble, equip and become operational, rendering a timely and effective response operationally infeasible under standard conditions.

Fire suppression operations lasted for a total of 2 hours and 21 minutes, and were conducted under extremely bad weather conditions, with an ambient temperature of 42.5ºC.

A total of 17 company employees participated in the firefighting efforts, including:

- 7 professional firefighters from the internal fire protection unit,
- 4 security officers,
- 2 operators from the tank storage area,
- 2 logistics/grounds workers, and
- 1 maintenance technician.

The City Firefighting Unit deployed one fire engine with a three-member crew.

At 14:30, the fire was fully extinguished, ending the intervention 2 hours and 30 minutes after it started.

Risk Analysis

The case under review identifies the key variables for risk assessment:

1. Time required for the fire to spread from the railway track to the company's perimeter (a distance ranging from 40 to 90 meters depending on the sector) and subsequently to breach the premises — in the present case, the fire reached the perimeter within 29 minutes, under ambient conditions of 42.5ºC and wind speeds ranging from 5 to 8 m/s.
2. The on-duty internal fire response team is capable of conducting initial fire suppression operations within 2.5 to 3 minutes from the moment of alert.
3. The full mobilization of the internal firefighting unit, including off-duty personnel (home standby), requires approximately 25 to 30 minutes.

If the wind velocity exceeds 20 m/s, the fire is projected to reach the company's perimeter boundary in less than 10 minutes (hypothetical scenario).

The estimated fire spread time is shorter than the full deployment time of internal fire response resources, which indicates a critical response gap and highlights the need for enhanced preventive measures and faster initial suppression capabilities.

The following figure shows the fire risk assessment matrix used in the OKTA Company in North Macedonia.

OKTA - Threat & Hazard Assessment Matrix

Threat & Hazard	Probability				Vulnerability Company resistance	Impact				Risk Level
	Incidents per year			Index of Probability	External resources ⟷ Internal resources	Human impact	Property impact	Business impact		Index of jeopardize
	2019	2020	2021	High 5 ⟷ Low 1	Weak resources ½ ⟷ Strong resources 1	High impact 5 ⟷ Low impact 1				High level 10 ⟷ Low level 1
Risk of explosion	1	/	1	→ 2	¼	5	5	5	→ 5	2.25
Risk of fire	6	4	5	→ 5	⅓	3	4	5	→ 7	5.25

Rating scale		
Low >1	Medium - 3	Hight - 5
minor	tolerant	unacceptable

Figure 7. *Threat and Hazard Assessment Matrix (OKTA, 2022)*

Implemented mitigation measure

As part of the 2022/2023 fire risk mitigation strategy, the company installed a remote-activated water curtain system along the perimeter adjacent to the railway (Figure 8). The system is remotely controlled via SCADA by the Operational Monitoring Center.



Figure 8. *Water curtain system adjacent to the railway*

Key technical specifications of the system include:

- Length: 1,225 meters;
- Operating pressure: 5–7 atmospheres;
- Total number of sprinklers installed: 520;
- Coverage width of water barrier: 3 meters.

This water curtain serves as a rapid-response containment barrier, designed to inhibit or delay fire ingress, thus buying critical time for the mobilization of internal and territorial firefighting units.

CONCLUSION

Fire protection is organized and continuously implemented in all facilities and locations exposed to fire hazards. The fundamental elements of fire protection include (Sekulović, Bogner, Pejović, 2012):

- Prevention, planning, and implementation of preventive measures to reduce the risk of fire outbreaks and limit their spread;
- Detection and reporting of fires;
- Installation of smoke detectors and other early fire detection systems, as well as ensuring clear procedures for fire reporting;
- Fire extinguishing and provision of adequate firefighting equipment, such as fire extinguishers, hydrants, and trained firefighting personnel;
- Evacuation of people from endangered facilities, including clearly marked exits and staff training for evacuation procedures;
- Training and informing personnel;
- Educating the public about fire hazards, preventive measures, and procedures to follow in case of fire.
- Prevention of potential fires in railway transportation involves:
- Regular technical maintenance of trains and tracks;
- Installation of smoke detectors and fire protection systems on trains;
- Staff training and passenger education;
- Strict adherence to safety procedures.

Based on everything presented in this case study, we can conclude the following:

- The railway line between Kumanovo and Skopje, although operating at a moderate traffic frequency, is expected to remain active with regular freight movement. Given the unchanged topographic and environmental conditions, the probability of future fire incidents remains high.
- The proximity of two major industrial installations—both with large storage capacities of petroleum derivatives and liquefied petroleum gas (LPG), which are highly flammable and energy-dense substances—results in the highest fire load per unit area within the urban territory.
- The presence of multiple rural communities (village settlements) within the designated risk zone, with a fluctuating population numbering in the thousands, introduces a critical third parameter in the risk assessment matrix – the human impact factor – which further elevates the overall risk classification to the highest level.

REFERENCES

Cote, A. E. (2023). *Fire protection handbook (21st ed.)*. Vol. 2., Quincy, MA: National Fire Protection Association.

Erić, M. (2003). *Protivpožarna i preventivno-tehnička zaštita*. Inženjersko-tehnički priručnik. Čačak: "Jel&Mil.

Grupa autora (2010). *Osnove zaštite od požara.* Priručnik. Varaždin: Centar za integralnu sigurnost d.o.o.

Klinoff, R. W. (2019). *Introduction to fire protection (6th ed.)*. Burlington, MA: Jones & Bartlett Learning.

OKTA (2022). *An internal document of the OKTA AD Company.* Republic of North Macedonia.

Sekulović, Z., Bogner, M., Pejović, S. (2012). *Preventivna zaštita od požara*. Autorsko izdanje.

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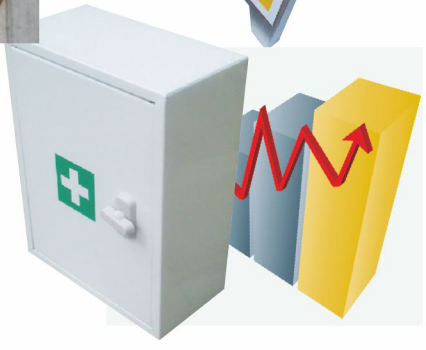
















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