21st International Conference Man and Working Environment
SEMSIE
Safety Engineering & Management - Science, Industry, Education

ORIGINAL SCIENTIFIC PAPER

DOI: 10.46793/SEMSIE25.219S

ANA STOJKOVIĆ[1]
IVAN KRSTIĆ[2]
MIODRAG STANISAVLJEVIĆ[3]
AMELIJA ĐORĐEVIĆ[4]
DUNJA STOJANOVIĆ[5]

[1,2,4,5]University of Niš,
Faculty of Occupational Safety, Serbia
[3]The Academy of Applied Studies
Polytechnic, Serbia

[1]*ana.stojkovic@znrfak.ni.ac.rs*
[2] *ivan.krstic@znrfak.ni.ac.rs*
[3]*mstanisavljevic@politehnika.edu.rs*
[4]*amelija.djordjevic@znrfak.ni.ac.rs*
[5]*dunja.stojanovic@znrfak.ni.ac.rs*

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

ORCID iDs:		
	Ana Stojković	https://orcid.org/0000-0002-2043-7424
	Ivan Krstić	https://orcid.org/0000-0001-7181-0885
	Miodrag Stanisavljević	https://orcid.org/0009-0002-6003-4117
	Amelija Đorđević	https://orcid.org/0000-0002-3260-2626
	Dunja Stojanović	https://orcid.org/0009-0008-3806-8488

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.

ACKNOWLEDGEMENTS

This paper was supported by the Agreement on implementation and financing of scientific research work, Registration number: 451-03-137/2025-03/ 200148.

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.