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MULTI-CRITERIA DECISION-MAKING FOR SELECTION OF RENEWABLE ENERGY SYSTEMS

Abstract: *Multi-criteria analysis involves defining each criterion using attributes, based on a suitable alternative for achieving objectives. The method used in multi-criteria analysis is Analytical Hierarchy Process. Analytical hierarchical process (AHP) is a tool in the analysis of decision making, created in order to assist decision-makers in solving complex decision problems involving large number of decision makers, large number of criteria and in multiple time periods. AHP method is used for selecting the best renewable energy systems. The aim is to, by using the method of AHP, demonstrate which of the analyzed renewable sources of energy is the most convenient to be used in a sustainable system.*

Key words: *energy, multi-criteria decision making, analytical hierarchy process.*

INTRODUCTION

Most countries around the world will face serious energy shortages in the near future. The high consumption and population growth in the world will force the inhabitants of many countries to deal with the critical problem of dwindling domestic fossil energy resources. For these reasons, today a very popular question is which of the existing renewable energy is best used to achieve a sustainable energy system. The answer to this question can be given by analyzing sustainable energy system using AHP method.

The method AHP is one of the methods for decision making. Decision making is a process that consists of a series of activities to be taken in order to select the best solutions (alternatives). Decision making is only the first step in achieving results, and most often the implementation of decisions is much more complex job.

The selection can be done in several ways, through:

- Techniques of decision making (using a set of procedures for key expert problem solving in the decision-making process, such as diagnostic techniques, linear programming, simulation techniques, etc.);
- Decision rules (defined as a predetermined guidelines or tests for judging);
- Decision making skills (defined as the ability of effective use of knowledge in problem solving).

Any decision that is the result of the analysis from the past and which is aimed at achieving a goal, assumes that the consequences will be known only in the future. Every decision is therefore the link between the past and the future (Figure 1).

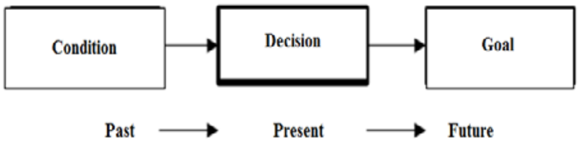

Figure 1. *Analysis of decision situation*

Phases of decision making

According to (*Čupić Suknović, 2010*), there are 11 phases of the decision process (Figure 2). These are:

Keeping records of the problem - at this stage are recorded problems for which the decision must be made.

Ranking problem - exists in situations when it is obvious that all the problems can not be solved at the same time.

Defining the problem - is one of the most important phases of decision making process. Through this phase it is necessary to provide all elements needed for the subsequent phase formation models.

Collection of facts - or create a database of relevant data for a defined problem.

Predicting the future - due to the fact that today's decision was made to be realized (with all the consequences) in a future environment.

The formation of the model - for the specific problem the interactions between variables, as well as the corresponding criteria of effectiveness solutions, are defined.

Problem solving (model) - determining the numerical or analytical ways of solving problems (models). Solving the problem (using appropriate methods and techniques) should be approached in this way to ensure getting the appropriate number of alternative solutions in order to make one of the basic assumptions of e decision-making.

Evaluation of results relates to the verification of agreement of the obtained results with the expected results of real systems.
Making decisions - no decision. The decision is made when we can accept the results from one of the alternatives, while in the opposite case a problem can not be resolved with this methodology, or should be returned to any of the previous stages, on certain corrections and additions. The mistakes can practically be made in all stages; however, the most common and most typical errors are in modeling phase.

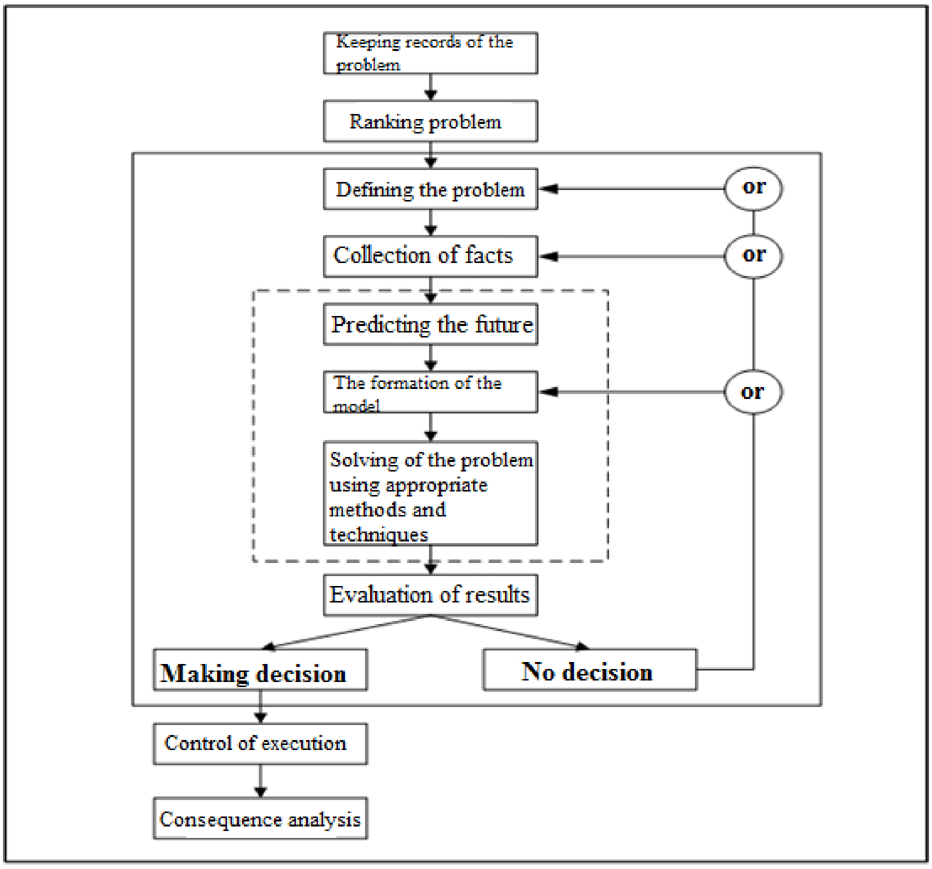

Figure 2. *Phases of decision making*

Control of execution - when the decision is made, special attention must be paid to control its execution.
Consequence analysis of the execution of the decision - is about concrete consequences on the real problem, when those consequences can be not only wrong but also unrecoverable. And then, of course, the analysis should be done bearing in mind that the same mistakes are not repeated in a similar situation.

Levels of decision making

Basic levels of decision making are:

- Individual decision making;
- Group decision making;
- Organizational decision making;
- Meta-organizational decision making.

Individual decision making. At this level, decisions are made by individuals. Different decision-makers in the same situations (decision problems) will behave differently, depending on their level of experience, education and achieved skills in decision making.
Group decision making - teamwork. In complex social environments individuals are, as a rule, members of various groups organized to satisfy different purposes.
Organizational decision making. It has been studied by a large number of highly renowned authors in the field of management.
Meta-organizational decision making. It represents a step forward in the possible applying of decision theory. At this level, we observe the totality of all organizations (of a country) as the enterprise system; of course, it varies from country to country.

Model of decision making

Characterizing decision making problem with an appropriate model is one of the first steps in the decision making process. Decision making is formalized with the set:
O={A,S,φ,Y,W,Π}
Where:
A - a set of alternatives,
S-set of possible environment states and their description,
φ - copying of decisions in the outcome,
Y - the outcome of the decision,
W - an indicator of the outcome of the decision,
Π - policy decisions choice.

Considering that the management aim can be realized in many ways, it is necessary to define a set of alternatives which achieve this. Method of forming a set of alternatives depends on the specific problem and, except general guidelines, there is no universal method with which this could be always well done. The quality of available alternatives affects the quality of decisions, although the choice of the alternative is specific and serious problem. When it comes to managing, a set of alternatives represents a set of management operations or a set of management strategies.
Criteria or decision rules allow comparison alternatives through indicators of decision outcome and selection of the best, or one of a satisfactory alternatives.

Multi-criteria decision making

Multi-criteria decision making means defining each criterion using attributes, based on which chooses a suitable alternative for achieving objectives. Each attribute should provide a means of assessment (evaluation) levels of one criteria (objective). As a rule, the greater the number of attributes should be characterized in any action (alternative) and they are selected based on a set of criteria defined by the decision maker.
During solving the problem of multi-criteria decision making, where appropriate, should undertake the following activities:

- Quantification of qualitative attributes;
- Normalization of attribute values;
- Linearization of attributes;
- Define the weight coefficients of criteria.

The quantification of the qualitative attributes

For translating qualitative attribute values in quantitative, the following scale is often used: regular, interval scale and scale relationships. The interval scale form is usually applied in decision theory:

Table 1. *Interval scale*

Qualitative assessment	*Bad*	*Good*	*Average*	*Very good*	*Excellent*	*Type of criteria*
Quantitative assessment	1	3	5	7	9	max
	9	7	5	3	1	min

In this way, the decision matrix is transformed into quantified decision matrix.

Normalization of attributes

"Equalization" of attribute values is done together with normalisation. The process of normalization includes: Calculation of norms for each j column of the matrix of decision making:

$$Norma_j = \sqrt{\sum_{i=1}^{m} x_{ij}^2}\,;\; j = 1,2,...,n$$

Where:
xij - value of the j attribute by the i alternative.

Calculating the normalized matrix elements of decision making. For attributes of type max:

$$n_{ij} = \frac{x_{ij}}{Norma_j}$$

For attributes of type min:

$$n_{ij} = 1 - \frac{x_{ij}}{Norma_j}$$

In this way, quantified decision matrix transforms into normalized decision matrix.

Linearization of attributes

The linearization is doing with the aim of reducing the value of the attribute at the interval (0,1) and translation of various units of measure in the unnamed number.

Defining the weight coefficients for the criteria

Realistic problems often have criteria of different level of significance, and it is necessary that the decision maker defines the factors of significance of criteria using appropriate weighting coefficients - weight (if their sum is equal to one it is the normalized weights). The decision maker subjectively defined weight coefficients.

Analytical Hierarchy Process

Analytical Hierarchy Process (AHP) is one of the most commonly used methods of multi-criteria analysis. The author of the idea and mathematical settings of AHP is Thomas Saaty.
The decision making process considers as a hierarchical process with multiple levels. At the top of the hierarchy is the **goal**, and the next level is composed of selected **criteria**. The lowest level consists of the possible **alternatives**, and at intermediate are under criteria.
The process of solving the problem of decision making is often extremely complex due to the presence of competing and conflicting objectives among the available criteria or alternatives.

Phases of the analytic hierarchy process

The process of applying the method has four phases:

1. Structuring the problem

Phase of structuring consists of decomposing the problem of decision making in a series of hierarchical levels, where each level represents a smaller number of manageable attributes. AHP is based on mutual comparison of elements in a given hierarchical level in relation to the elements at a higher level. If we observe the general case of hierarchy with three levels (goal - criteria - alternatives) (Figure 3), the criteria are compared in relation to the goal, in order to determine their mutual importance, and alternatives to each of the set criteria.

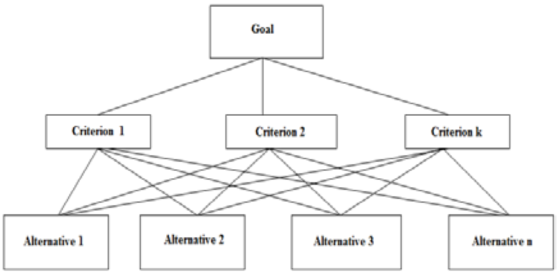

Figure 3. *Structuring the problem*

2. Data Collection

The second phase of the AHP method comprising:

- Data collection and (their) measurement;
- Assign a relative assessment in pairs with attributes of a hierarchical level, for given attributes of first and the higher hierarchical level;
- Repeat the process for all levels of the hierarchy.

To assign a weight scale is used Saati "nine-point" as shown in Table 2.

Table 2. *The scale of relative priorities*

Significance	Definition
1	Same significance
3	Weak significance
5	Strong significance
7	Demonstrated dominance
9	Absolute dominance
2,4,6,8	Intermediate value

Following this method of ranking, the decision maker will assign a weight for each pair separately, as a measure of how important is one attribute from another. Upon completion of this process will result in the appropriate matrix of pairwise comparisons corresponding to each level of the hierarchy:

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix}$$

The characteristics of the matrix A:

$a_{ii} = 1$

$a_{ji} = 1/a_{ij}$ for $i,j = 1,..., n.$

$\det A \neq 0$

3. Evaluation of the relative weight

The third phase of the AHP method is to estimate the relative weight. Based on the matrix A with elements a_{ij} the priorities of criteria, sub-criteria and alternatives are determined.

For this purpose, we use:

- The method of arithmetic mean,
- A method of geometric mean and
- Method of difference.

The consistency of assessment

After determining the weight, their credibility should be established. This is done by determining the consistency of the matrix A. The matrix A, in case of consistent (consequent) assessment for which $a_{ij} = a_{ik}\, a_{kj}$, satisfies the equation:

$Aw = nw$, or:

$$A = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \dots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \dots & \frac{w_2}{w_n} \\ \dots & \dots & \dots & \dots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \dots & \frac{w_n}{w_n} \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ w_2 \\ \dots \\ w_n \end{bmatrix} = n \cdot \begin{bmatrix} w_1 \\ w_2 \\ \dots \\ w_n \end{bmatrix}$$

The problem of determining the weights can be solved as a problem of solving a matrix equation with matrix columns w solution for eigenvalues λ different from 0, ie.

$Aw = \lambda w$, or

$$\begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ w_2 \\ \dots \\ w_n \end{bmatrix} = \begin{bmatrix} \lambda_1 w_1 \\ \lambda_2 w_2 \\ \dots \\ \lambda_1 w_1 \end{bmatrix}$$

If the matrix A contains inconsistent assessments, the weight vector w can be obtained by solving the following equation:

$$(A - \lambda_{\max 1})w = 0 \;\; if \;\; \sum w_i = 1$$

where λ_{max} is the largest eigenvalue of the matrix A, or:

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(Aw)_i}{w_i}$$

Due to the properties of the matrix A is valid $\lambda_{max} \geq n$, and the difference $\lambda_{max} - n$, is used in measuring consistency of assessment, or to calculate the index of consistency:

$$CI = \frac{\lambda_{max} - n}{n-1}$$

Based on this index we determine the index of inconsistency:

$$CR = \frac{CI}{RI}$$

where:
RI(Random Index)parameter which is given in Table 3.

Table 3. *Values of the index RI [4]*

n	1	2	3	4	5	6	7	8
RI	0	0	0,52	0,89	1,11	1,25	1,35	1,40

The value of CR $\leq$ 0.10 indicates that the estimates for a and j are consistent. Otherwise, the evaluation should be repeated.

4. Determination of the problem solutions

The last phase of the AHP method is finding the so-called composite normalized vector. Since the successive levels of the hierarchy are interconnected, single composite vector of unique normalized weight vectors for the entire hierarchy is determined by multiplying the weight vectors of all successive levels.
Composite vector is used to find the relative priority of the entities at the lowest (hierarchical) level, which allows the achievement of the set goals of the overall problem.

Case Study: Selection of the best energy-efficient technology

During selection of the best sustainable energy system it was used AHP method for finding the most suitable types of renewable energy for sustainable planning of energy development. Sustainable systems are considered from four perspectives: technological, economic, ecological and sociological. These aspects represent the decision making criteria.
For each aspect are defined criteria, namely: Energy Production Capacity (EPC), Technological Maturity (TM), Reliability (R) and Safety (S) for the technological aspect, the Investment Costs (IC), Expense Management (EM), Lifetime (L), and Repayment Period (RP), for the economic aspect, the Impact on the Ecosystem (IE), CO_2 emissions (E) for the environmental aspect and the Social Benefit (SB) and Social Acceptability (SA) for the social aspect.
The alternatives are different types of renewable energy: Solar Energy (SE), Wind Energy (EW), Hydropower (HE), Biomass (BM) and Geothermal Energy (GTE).
The hierarchical structure for selection of the system with a sustainable renewable energy sources is shown in Figure 4.

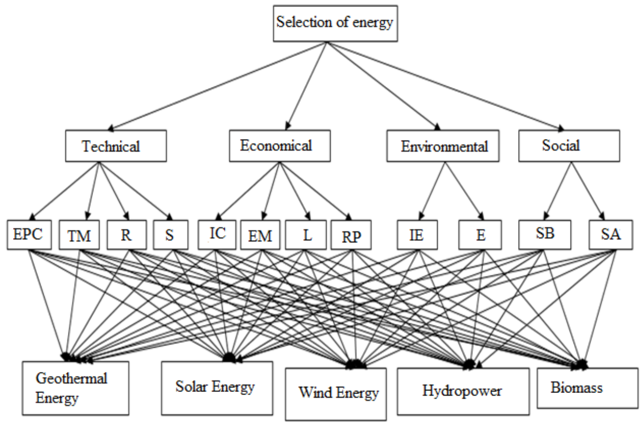

Figure 4. *Hierarchical structure of a sustainable system with sustainable renewable energy sources [1]*

Analyses are made after completion of Pairwise comparisons and determination of relative weight. The first phase of the analysis is to check the consistency of decisions. Consistency index (CI) for all matrix of comparison is appropriate ($\leq$0.10). Index of consistency in this study varied between 0 and 0.1.
The second phase of the analysis is to calculate the relative weights of the main criteria and sub-criteria. The relative weights of the main criteria and sub-criteria are shown in Figure 5.

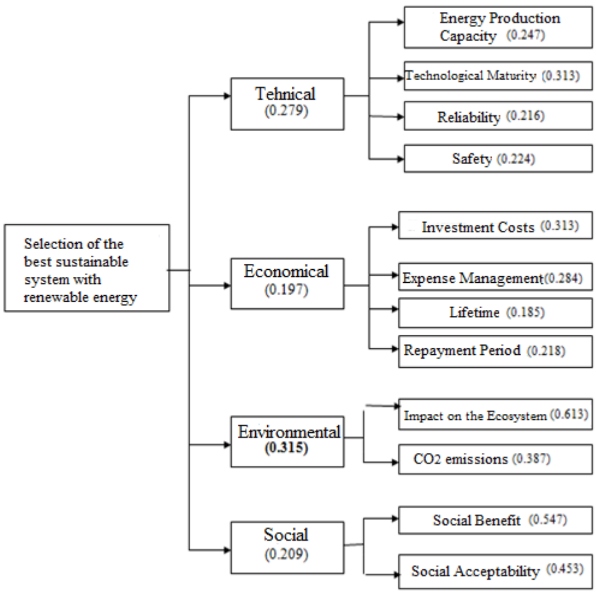

Figure 5. *The relative weight in relation to the main criteria and sub-criteria in a hierarchical structure.*

Based on the relative weights of the criteria we see that the most significant is environmental criteria, whereas economic criteria is the least significant. After this, the significance is determined by used alternatives. The importance of used alternative technology has been shown in Table 4.

Table 4. *Significance of used alternative technologies*

Technology	Relative Weight	Results
Geothermal Energy	0.184	3
Solar Energy	0.175	4
Wind Energy	0.298	1
Hydropower	0.145	5
Biomass	0.198	2

From the table it can be concluded that wind energy is a renewable energy source for sustainable system (RT=0.298), while hydropower has the lowest priority (RT=0.145).

CONCLUSION

Renewable energy sources and new technologies which use these sources are becoming increasingly important segment in all areas, especially in the energy sector. Using renewable energy has reduced consumption of nonrenewable energy resources. The use of these sources is very important from the aspect of environmental protection. The results show that the choice of type of renewable energy sources depends on the selected criteria and sub-criteria of decision making. However, regardless of the different approach to the problem, our case study showed that wind energy is the most cost effective renewable energy source.

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BIOGRAPHY

Milica Stojanovic was born in Leskovac, Serbia 1990. She graduated from Chemical- technological school in Leskovac, and in 2009 she enrolled undergraduate studies at the Faculty of Occupational Safety in Niš, where she obtained B.Sc. in Environmental Engineering. She finished master academic studies at the Faculty of Occupational Safety and obtained master's degree in Environmental Safety in 2014.

VIŠEKRITERIJUMSKO ODLUČIVANJE PRI IZBORU ENERGETSKI ODRŽIVIH SISTEMA

Milica Stojanović

Rezime:. *Višekriterijumska analiza podrazumeva definisanje svakog kriterijuma pomoću atributa, na osnovu kojih se bira odgovarajuća alternativa za realizaciju postavljenog cilja. Korišćena metoda višekriterijumske analize je Analitički hijerarhijski proces. Metoda analitičkog hijerahijskog procesa (AHP), predstavlja alat u analizi odlučivanja, kreiran sa ciljem pružanja pomoći donosiocima odluke u rešavanju kompleksnih problema odlučivanja u kojima učestvuje veći broj donosilaca odluka, veći broj kriterijuma i u višestrukim vremenskim periodima. AHP metoda je korišćena pri odlučivanju o izboru najbolje energetski održivog sistema. Cilj rada je da se pomoću metode AHP pokaže koji od analiziranih obnoljivih izvora energija je najpogodniji za upotrebu i postizanje održivog sistema.*

Ključne reči: energija, višekriterijumsko odlučivanje, analitički hijerarhijski proces.