**Turkish Journal of Engineering**
https://dergipark.org.tr/en/pub/tuje
**e-ISSN 2587-1366**

# Evaulation of renewable energy source alternatives prioritization

**Barış Kantoğlu [1*], İrem Düzdar Argun [1]**

[1]Duzce University, Industrial Department, Türkiye

**Keywords**
Renewable Energy
Analytical network process
Consistency ratio
Geometric mean

**Research Article**
DOI: 10.31127/tuje.1001488

Received: 29.09.2021
Accepted: 09.02. 2022
Published: 01.04.2022

**Abstract**

Today the renewable energy is an alternative energy source being more important. The reasons for its importance are minimizing the risks at environmental, economic and social areas caused by the traditional energy sources and reducing the need for energy importation. Because of these it is important to determine the affecting criteria of the renewable energy sources for the investors of this industry as a guide. In modelling and analysis of the criteria and the sub-criteria MCDM (Multi Criteria Decision Making Model) can be used. In this study, the ANP model is used to propose evaluation of the renewable energy source selection criteria. In this study, an application of the recommended basis for the renewable energy source selection problem criteria and the ANP model for the optimum renewable energy source project is proposed. The expert opinions are employed to gather data in the proposed model. The technical, environmental, economic, and social risk criteria and the importance levels of the sub-criteria are analyzed under the light of the expert opinions. The Hazardous Waste, Effects to Climate Changes, Noise, Reduction in Gas Emission and National Energy Security are found as the superior criteria.

## 1. Introduction

The energy is one of the most important elements that trigger the development and growth attempts through the human history. The technologic improvements in industries are enlarging the continuity of energy requirements. The traditional energy sources are not enough for producing goods and services because of the technical, environmental and socio-political affairs [1-2]. Besides, these traditional sources, like coal, petroleum, natural gas and nuclear energy, are damaging the environment and causing climate changes, air and water pollution, and radiation. In the last years the majority of investments to the renewable energy sources are detected to reduce these damages, when the traditional sources are using [3-4]. The renewable energy sources, hydropower, solar, wind, biomass and geothermal power constitute approximately one third of the total energy sources of the World, with 289 billion $ investment in 2018 [5].

The evaluation of renewable energy sources is a complex problem because of the interconnection of criteria and having many of sub-criteria. To solve these types of problems systematically classifying the criteria hierarchically and determining their importance levels, the MCDM (multi criteria decision models), are used [6-8]. Many of researches can be found performed in literature evaluating the technical practicability, feasibility of costs, and minority of negative effects for environment, social benefits, and the suppressibility of risk criteria in the decision process for hydropower, solar, wind, biomass and geothermal power sources [9-14].

In this study, in evaluation of renewable energy sources supplying a hierarchical structure to determine the importance levels of criteria, the ANP model, is proposed. This model is analyzed by application.

There are many studies performed on the renewable energy evaluation. One of these studies, Wu et al [15], proposed ANP Model to evaluate the risk of the renewable energy investment in China.

Most of the studies in literature are the models used for selection of renewable energy studies proposing employment of AHP, Fuzzy AHP, DEMATEL, ANP and

* **Corresponding Author**

*(bariskantoglu@duzce.edu.tr) ORCID ID 0000-0002-7832-1619
(iremduzdar@duzce.edu.tr) ORCID ID 0000-0002-7642-8121

**Cite this article**

Kantoğlu, B., & Argun, İ. D. (2023). Evaulation of renewable energy source alternatives prioritization. Turkish Journal of Engineering, 7(1), 01-08

VIKOR models (Table 1). There is no research in literature sorting the important criteria performed by using ANP. In this context, this study can help the managers of the energy evaluation industry to determine the important criteria about the environment, technical, social, economic and risks.

In the second section of this study the structure of the model, ANP is explained. In the third section, the hierarchical structure of the model is presented and the outputs of the performed analyses. In the last section, the results of this study and the proposals will be seen.

**Table 1.** Methodology of studies in renewable energy evaluation

| Authors | Publication year | Methodology |
|---|---|---|
| Algarin et al. [6] | 2017 | AHP |
| Karakaş and Yildiran [7] | 2019 | Fuzzy AHP |
| Budak et al. [8] | 2019 | AHP |
| Wang et al. [14] | 2020 | SWOT-Fuzzy AHP |
| Solangi et al. [1] | 2019 | Delphi-AHP and Fuzzy TOPSIS |
| Toklu and Taşkın [3] | 2018 | Fuzzy AHP and Fuzzy TOPSIS |
| Ahmad and Tahar [9] | 2014 | AHP |
| Çelikbilek and Tüysüz [10] | 2016 | Integrated Gray-based MCDM |
| Büyüközkan and Güleryüz [11] | 2016 | Fuzzy AHP and Fuzzy TOPSIS |
| Büyüközkan and Güleryüz[12] | 2017 | DEMATEL, ANP, TOPSIS |
| Rani et al. [13] | 2020 | Fuzzy TOPSIS |

## 2. Method

The main problem of the Multi Criteria Decision Making problems is to determine the priority, importance and weight by evaluating more than one criterion between the choices. The AHP is, one of the MCDM techniques, commonly and effectively using to find solve this problem. The objective and subjective ideas of decision makers' can be included in AHP [16].

ANP, providing realistic and effective solutions to the complex decision-making problems. ANP is one of the multi criteria decision making techniques that involve the qualitative values as much as the quantitative values for building hierarchical models to solve the problem by evaluating the relations and interactions between the criteria formulating the model. ANP is the basic form of AHP. While the hierarchical structure from up to down is used in AHP, the decision-making criteria in hierarchical structure, the sub criteria and the interactions, feedbacks, inner and outer dependencies between choices without looking to their ranks are considered in ANP [17].

ANP, developed by Thomas L. Saaty is a method considering the measurable and experimental values to state priorities for elements affecting the solution of the problem [18]. AHP is a strong and comparative method considering the effects of qualitative and quantitative factors proposed by all of the stakeholders of the problem. The ANP can be used to make decisions by studying the social, governmental and common problems in detail. All of the elements, either tangible or intangible, affecting the optimization of problem are considered in this process. All of the internal (between cluster components) and external (between clusters) relations are evaluated in ANP. In the case of uncertainty and risk, the feedback has the ability to exhibit unexpected interacting causes for population.

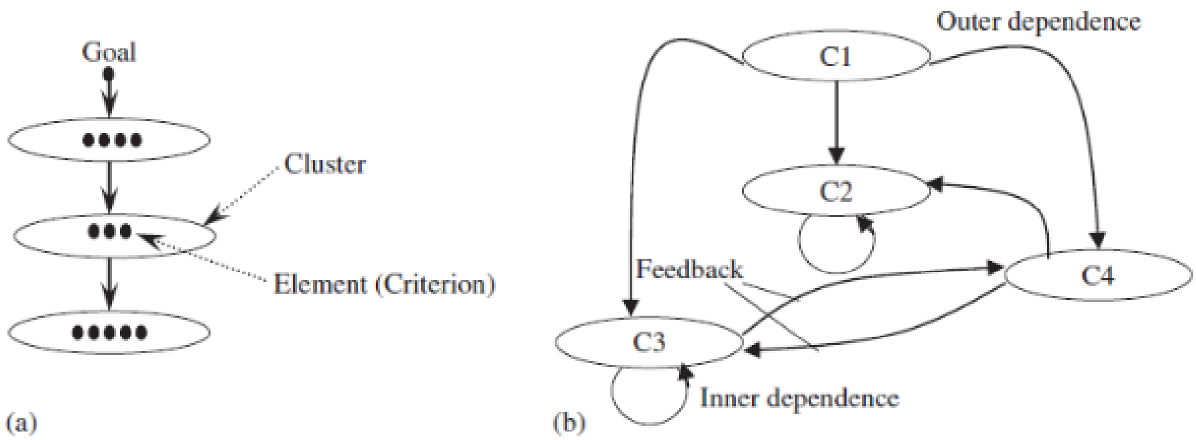


**Figure 1.** A hierarchy and a network [19].

Fig. 1(a) shows the hierarchical relation of a cluster; where a change occurs at the low-level cluster (affecting node), its influence is seen at the upper-level cluster (affected node). Fig. 1(b) exhibits the network relations. The arc from C4 to C2 defines the outer dependence of C2 on C4 and a loop in C2 indicates the inner dependence. The feedback in the network implies the mutual outer dependencies in a cluster pair [19].

All of the components and the possible relations between them are defined first. Then the pairwise comparisons are performed for all other components affecting a component to analyze priorities of them in AHP and ANP.

The pairwise comparisons and matrix algebra are used to derive the weights of criteria. The final decision depends on these derived weights of the evaluative criteria [20]. In this way, the criteria are evaluated among themselves, and the importance of criteria on the choices is transformed to numbers.

The ANP contains four main steps [21]:

The first step is building of model and problem construction: The problem must be defined in detail and divided into components in a rational format as a network.

The second step is pairwise comparisons and priority vectors: The decision factors of each cluster are compared pairwise on the importance basis against their control criteria. Another pairwise examination must be performed on the interdependencies between the criteria of a cluster. Eigenvectors represent the effect of an element on others. The relative importance is defined by using the Saaty's Scale.

The third step is construction of the supermatrix: Supermatrix has the same meaning as the Markov Chains. The local priority vectors are put into the suitable columns of the matrix for determining the global priorities with interdependent effects. This is a sectioned matrix named as the supermatrix; its each element exhibits the relation between clusters.

The fourth step is synthesizing the criteria, choices, priorities to determine the best alternative: The normalized supermatrix include the priority weights for criteria and alternatives.

At the end of the pairwise comparison matrices are achieved, the aij element of this matrix is equal to 1/aij and if, i=j then aij=1.The range of wi is in between 1 and 9. 1/1 represents both criteria have equal importance where 9/1 represents significant or absolute importance [22]. The scale for this pairwise comparison can be seen at Table 2. Whatever the real value of (i;i) pair, the result is 1 and the value of (i;j) is equal to the reciprocal of the value of (j;i) or vice versa [19].

**Table 2.** Saaty Evaluation Scale [23]

| Num value | Verbal scale |
|---|---|
| 1 | Equal importance |
| 3 | Moderate importance |
| 5 | Strong importance |
| 7 | Very strong importance |
| 9 | Extreme or absolute importance |
| 2,4,6,8 | Intermediate values |

$$\mathbf{A} = \begin{bmatrix} \mathbf{1} & \mathbf{a12} & \cdots & \mathbf{a1n} \\ \mathbf{a21 = 1/a12} & \mathbf{1} & \vdots & \mathbf{a2n} \\ \vdots & \vdots & \vdots & \vdots \\ \mathbf{an1 = 1/a1n} & \mathbf{an2} & \cdots & \mathbf{1} \end{bmatrix} \tag{1}$$

The pairwise comparison is expressed as matrix A at Equality (1) [24].

aij is the pairwise comparison value of criterion i and criterion j. It implies that where aij is the matrix element representing the relationship between components I and j,

$$\text{aij S=1/aji} \tag{2}$$

Here, the relative importance values are calculated for all decision factors. The importance of the factor may be defined as the effect on the final decision to achieve the objective of decision maker. The required calculations, for achievement to the goal by synthesizing the arguments, are performed by employing the Super Decision software including the computation the eigenvectors of each pairwise comparison matrix, derivation of supermatrix and limit matrix that is the convergence of supermatrix and, if it is required, weighted supermatrix. The priorities of sub-nodes are according to their parent node are covered in the eigenvector [9]. To calculate the eigenvector easily, each element of the matrix is divided by the sum of the column, normalizing the pairwise comparison matrix, the sum of each column will be equal to 1 [8].

To obtain the normalized matrix the Equation (3) is used [25].

$$\mathbf{aij} = \frac{\mathbf{aij}}{\sum_{\mathbf{i=1}}^{\mathbf{n}} \mathbf{aij}} \text{ where i, j= 1,2, ..., n} \tag{3}$$

For normalizing the pairwise comparison matrix the Equation (3) is employed, the normalized matrix is found. The priority vector is calculated by using the values obtained from the calculation of average of the sum of the row of normalized matrix. To verify the result, the consistency of comparison matrices is calculated. The Consistency Index Coefficient must be calculated.

$$\mathbf{CI} = \frac{\mathbf{\lambda maks - n}}{\mathbf{n - 1}} \tag{4}$$

λmax is calculated by using the Equation (5)

$$\mathbf{\lambda maks} = \left(\frac{\mathbf{1}}{\mathbf{n}}\right) . \sum_{\mathbf{i=1}}^{\mathbf{n}} \left[\frac{\sum_{\mathbf{j=1}}^{\mathbf{n}} \mathbf{aij.wj}}{\mathbf{wi}}\right] \tag{5}$$

Where

$$\mathbf{wi} = \sum_{\mathbf{i=1}}^{\mathbf{n}} \mathbf{aij} \quad \text{i,j=1,2, ..., n} \tag{6}$$

The largest eigenfactor of n-sized matrix A is λmax, its correct eigenfactor is q and the n-sized identity matrix is I.The estimation of relative priorities is generated by correct eigenfactor q. To derive the priorities, the eigenfactors must be scaled to as their sum is equal to 1. Saaty proved that where λmax=n is enough and necessary condition to achieve the consistency. In pairwise comparisons become inconsistent when λmax differs from n. The consistency of matrix A must be tested by using CI index, mentioned above [26].

At the end, the Consistency Ratio is calculated by using Equation (7).

$$\text{CR} = \frac{\text{CI}}{\text{RI}} \tag{7}$$

Where CI is the Consistency Index, RI is the Random Index obtained n-sized matrix and CR is the Consistency Ratio [27]. If CR<0.10, it means the matrix is consistent. If CR is greater than or equal to 0.10, to procure the consistency some or all of comparisons have to be iterated [7].

The probable faults made in evaluations can be identified by analyzing the inconsistencies as in the real life. The logical conflicts of evaluations can be measured by inconsistencies. For example, events A, B and C are sorted according to their priorities respectively, if the judgement is C is more prior than A; this is the inconsistency [28].

The following three actions must be done when the inconsistency is greater than expected:

The most inconsistent evaluation is determined in the matrix. The interval of values is defined in which the inconsistent evaluation can be improved by changing in this interval. The decision maker must be informed, if it is possible, to change the evaluation with an acceptable value in this interval. If it is rejected by decision maker, the next evaluation is tried. If all of proposed changes are rejected the decision must be suspended to find more explicit criteria. The three acceptable ways are to correct the inconsistencies by changing the judgements [20]. The expert advices have to be combined; the reciprocal of the combined advices is equal to the combination of reciprocals of these advices. The single proven method to achieve this is using the geometric mean. The advice owners may not accept to combine their advices; the final result can be derived by using their hierarchies. In this position the geometric mean of the final outcomes is taken. The advices of the experts will be raised to power of their priorities to form the geometric mean, when their importance priorities are different [29].

The geometric mean is theoretically defined by Feng et.al.[30].

$$\mathrm{GM} = \exp\left[\int_0^\infty \ln(\mathrm{X})\mathrm{f}(\mathrm{X})\mathrm{dX}\right] \quad \text{for X} > 0 \; only \tag{8}$$

f(X) is the probability distribution of X.

## 3. Results

All of the factors affecting the decision are defined and grouped into clusters to prepare the network in model construction.

The clusters of nature are created after renewable energy description from the literature classification. It is shown in Fig. 2.

The ANP procedures are used to list and take the optimal criteria for this study, where the decision variables are quantitative or qualitative.

The criteria of this study are determined by a group of three experts. The application of geometric mean is performed to their judgements in accordance with the Saaty Scale.

The detailed submatrix of initial supermatrix of the constructed model (Fig. 3) is shown in Table 3. As an example, C defines the influences among the sub-criteria and criteria.

| | Energy Alternatives | | | | | | | Criteria | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Technical | | | | | | | | | | | | Economical | | | | | | | | Social | | | | | | | | Environmental | | | | | | | | | Risk | | | | |
| Methodology | Solar | Wind | Hydro | Biomass | Nuclear | Geothermal | Natural gaz | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 1 | 2 | 3 | 4 | 5 |
| AHP | x | x | x | x | | | | x | x | x | x | x | | | | | | | | x | x | x | x | | | | | x | x | x | x | | | | | x | x | x | x | | | | | | x | x | x | x | |
| Fuzzy AHP | x | x | x | x | | x | | x | | | | | x | | | | | | | x | x | | | | | | | x | x | | | | | | | x | x | | | | | | | | | | | | |
| AHP | x | x | x | x | x | x | | | x | | | x | | x | | | | | | x | x | | x | | | | | x | x | | x | | | | | | x | | x | | | | | | x | x | x | | |
| SWOT-Fuzzy AHP | x | x | | x | | | | x | x | | x | | | x | x | | | | | x | x | | | x | x | x | | x | x | | | x | x | | | x | | x | | x | | | | | | | | | |
| Delphi-AHP and Fuzzy TOPSIS | x | x | x | x | | x | | x | x | | x | | | | x | x | x | | | x | x | | x | | x | x | | x | x | | | x | x | x | | x | | x | | x | x | | | | | | | | |
| Fuzzy AHP and Fuzzy TOPSIS | x | x | x | x | x | x | | x | x | | | x | | | | | | | | x | x | x | | | | | | x | x | | | x | | | | x | | x | | | x | | | | | | | | |
| Fuzzy TOPSIS | x | x | x | | | x | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| AHP | x | x | x | x | | | | x | x | | | | | x | | | | | | x | x | | | | x | x | | x | x | | | | | | | x | | x | | | x | | | | | | | | |
| Grey based MCDM | x | x | x | x | | x | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fuzzy AHP and Fuzzy TOPSIS | x | x | x | x | x | x | | x | | | | x | x | | | | | | | x | x | x | | | | | | x | x | | | | | | x | x | | | x | | x | | | | | | | | |
| DEMATEL-ANP | x | x | x | x | | x | | x | x | | | x | | | x | | | x | x | x | x | x | | | x | x | | x | x | | x | x | x | x | x | x | x | x | | | | | | | | | | | |
| AHP and VIKOR | x | x | x | | | | x | | | | | | | | | | | | | x | x | | | | x | x | | x | x | x | | | | | x | x | | x | | | | x | x | | | | | | |
| DEMATEL, ANP, TOPSIS | x | x | x | x | | x | | x | x | x | | x | | | | | | x | | x | x | | | x | x | | | x | x | x | x | x | x | | x | x | x | x | | | | | | | | | | | |
| Fuzzy TOPSIS | x | x | x | x | x | x | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

**Figure 2.** Methodology – Renewable Energy – Criteria matrix from literature

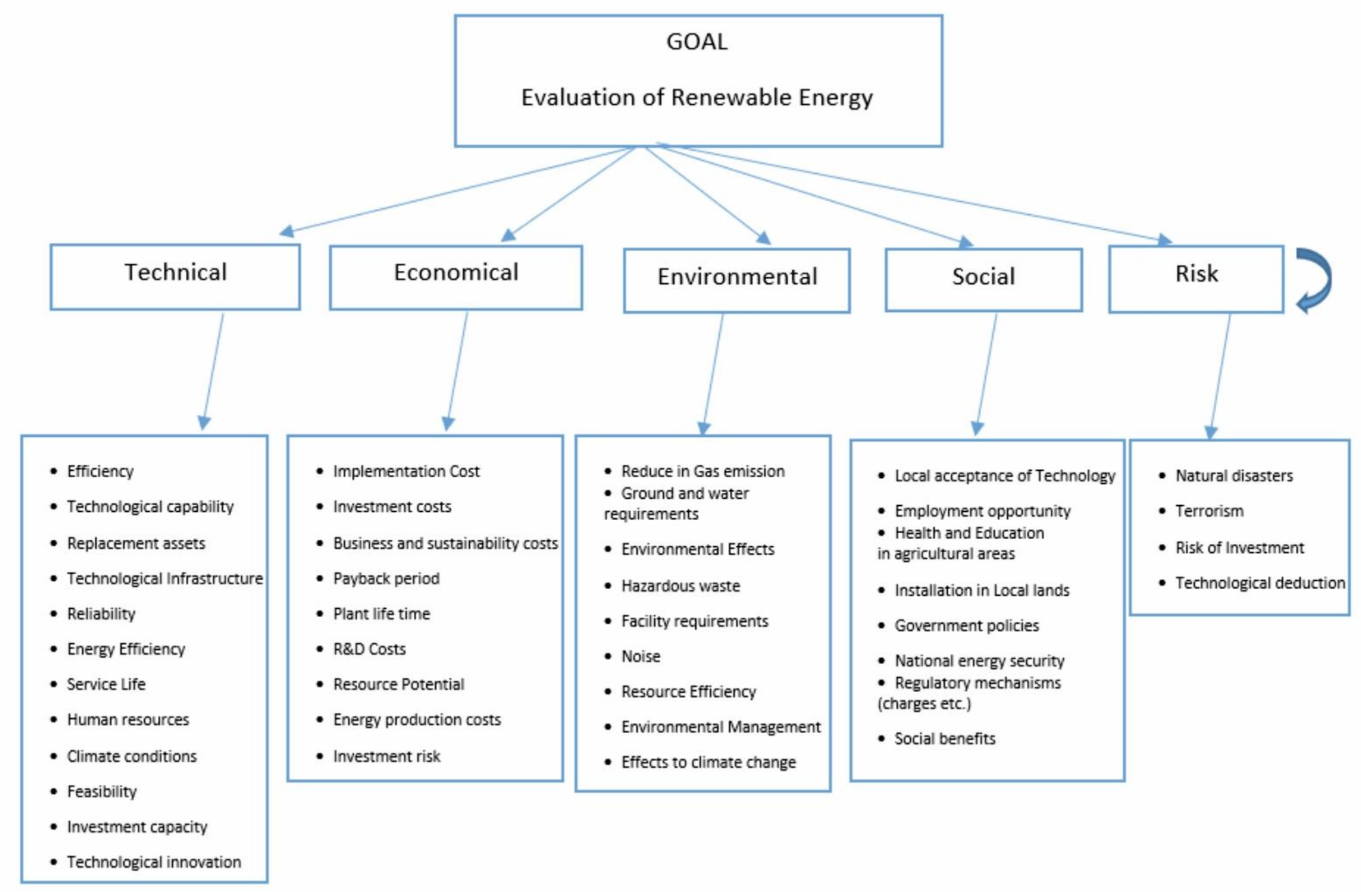


**Figure 3.** ANP model

**Table 3.** Submatrix of initial supermatrix

| Sub matrix | GOAL | Criteria | Attributes |
|---|---|---|---|
| GOAL | 0 | 0 | 0 |
| Criteria | A | B | 0 |
| Attributes | 0 | C | 0 |

Formulation of relations and pairwise comparisons of the clusters and elements: In order to compose the eigenvectors and then the supermatrix in the network, the links between the elements must be formulated and the required pairwise comparisons must be performed.

Cluster Comparisons: The pairwise comparisons to state the effects between the clusters are done in accordance with the control criterion of the network. The derived decisions must have consistency with the direction of efficacy. The column elements of the supermatrix are weighted by using the resulting weights of this operation.

Comparisons of Elements: The pairwise comparisons are done on the elements of clusters. The comparison is required to see the effect of an element of a cluster on the element of same or another cluster.

Comparing the Alternatives: Comparison is done for all elements according to their relations. It is necessary for construction of pairwise comparison tables processing the expert judgements on the SuperDecision software. The SuperDecision computes the weights with this operation. The question asked to experts, who have publications on collaborative innovation, is to assess the nature of five main criteria. The Saaty Scale is used to evaluate, and the geometric means are calculated for these behaviors. If the number of variables is in series n must be greater than zero; n is equal to 3 in this study. The decisions of experts can be expressed in numerical form, between 1 and 9 or in verbal meaningful words, as moderately, strongly, etc. [31].

If the point of view is the goal, the result of the pairwise comparison, the environmental criterion is the most important of the other main criteria. The weights and distribution of attributes in goal relations with main criteria is displayed in Fig. 4.

After all iterations are performed, the weights of attributes are calculated. The results have five criteria having weights greater than 10% (Table 4), which will be used as threshold to rank the criteria in this study. All 41 criteria are directed by hazardous waste criteria. It is followed by the effects on the climate changes, reduction in the gas emission and national energy security criteria. The inconsistency level is stated as acceptable according to the results of internal criteria analysis.

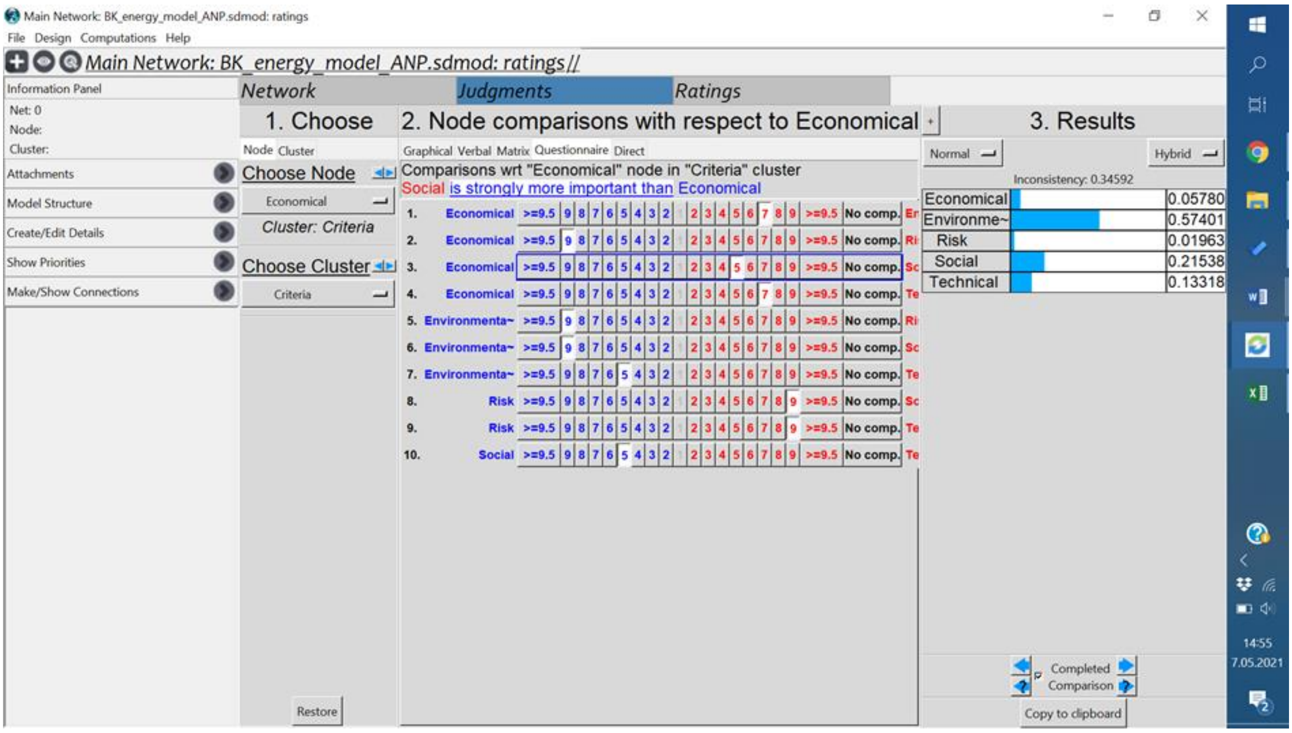


**Figure 4.** The weights and distribution of attributes.

**Table 4.** Local weights of attributes

| Attributes | Local Weights |
|---|---|
| Hazardous waste | 0,2 |
| Effects to climate changes | 0,1 |
| Noise | 0,1 |
| Reduction in gas emission | 0,1 |
| National energy security | 0,1 |

## 4. Discussion and Conclusion

Based on the results, some targeted investment recommendations for critical risk factors are given as follows, which could provide a reference for investors in practice. However, there are some limitations in this study. On the one hand, further researches and improvement are required for practical overseas investment on the account of constantly changing international conditions and limited available information.

In this study, an application of the recommended basis for the renewable energy source selection problem criteria and the ANP model for the optimum renewable energy source is proposed. The expert opinions are employed to gather data in the proposed model. The evaluation of the model is improved as the result of the detailed literature survey and gathering the expert opinions. To validate the performance of the proposed model an experimental search is conducted. It is decided that this model will be helpful to develop the decision-making studies having many of criteria affecting their decisions for the local administrations, investors, and practitioners after validation of the model.

More dependable decisions can be performed with ANP method, where the processing time is slightly long. ANP is a useful method to search the interrelations between the decision criteria of the problem if there are tight dependences between the criteria and the choices. The parameters can be compared with their numerical values and classified according their importance in comparison with each other on the base of data obtained from the scientific studies.

The ANP model is proposed to perform an optimum renewable energy source project, together with the application for building the framework of the criteria selection for the project in this study. Energy sources are evaluated realistically and the sight of the decision-making staff to undefinedness of the presented choices also.

The basic elements in definition of selection criteria for renewable energy sources are examined. In measurements of correlations between the adequate elements five dimensions are employed. Totally 42 assessment features are associated with these elements.

The outputs of the application are analyzed and give positive comments to the energy experts by decision making staff. The building of pairwise comparisons must be performed; derivation of data from the expert opinions and network construction is defined as an important work. It must not be forgotten that in the presented model all of the possible decision criteria and alternatives are not covered about the renewable energy projects.

Sorting the criteria on the base of their effects on studied conditions before is achieved. The environmental criteria are seen having greater values than the preset acceptable value where the values are normalized.

The Hazardous Waste criterion is found for all dimensions having the highest weight among the results. When selecting project criteria, it is not only important to consider the impact. Based on the ranking of all the criteria, the four criteria as assessed by the experts and academicians are Effects to climate changes, Noise, and Reduction in gas emission, National energy security. This shows that the decision makers focus more on the safety and efficiency of renewable energy projects.

The results of this study emphasis some critical risk factors for usage of the investors. It is also known that this study has some restrictions. Because of the scarcity of data sources and continuous changes on the global conditions this study needs further searches and improvements.

## Author contributions

**Barış Kantoğlu:** Literature Review, Writing-Reviewing and Editing. **Irem Duzdar Argun:** Conceptualization, Methodology, Application.

## Conflicts of interest

The authors declare no conflicts of interest.

## References


1. Solangi, Y. A., Tan, Q., Mirjat, N. H., Valasai, G. D., Khan, M. W. A., & Ikram, M. (2019). An integrated Delphi-AHP and fuzzy TOPSIS approach toward ranking and selection of renewable energy resources in Pakistan. *Processes*, *7*(2), 118.
2. Arto, I., Capellán-Pérez, I., Lago, R., Bueno, G., & Bermejo, R. (2016). The energy requirements of a developed world. *Energy for Sustainable Development*, *33*, 1-13.
3. Toklu, M. C., & Taşkın, H. (2018). A fuzzy hybrid decision model for renewable energy sources selection. *International Journal of Computational and Experimental Science and Engineering (IJCESEN)*, *4*(1), 6-10.
4. Boran, F. E., Boran, K., & Menlik, T. (2012). The evaluation of renewable energy technologies for electricity generation in Turkey using intuitionistic fuzzy TOPSIS. *Energy Sources, Part B: Economics, Planning, and Policy*, *7*(1), 81-90.
5. Raturi, A. K. (2019). Renewables 2019 global status report. (Paris: REN21 Secretariat). ISBN 978-3-9818911-7-1.
6. Algarín, C. R. (2017). An analytic hierarchy process based approach for evaluating renewable energy sources.
7. Karakaş, E. (2019). Evaluation of renewable energy alternatives for Turkey via modified fuzzy ahp.
8. Budak, G., Chen, X., Celik, S., & Ozturk, B. (2019). A systematic approach for assessment of renewable energy using analytic hierarchy process. *Energy, Sustainability and Society*, *9*(1), 1-14.
9. Ahmad, S., & Tahar, R. M. (2014). Selection of renewable energy sources for sustainable development of electricity generation system using analytic hierarchy process: A case of Malaysia. *Renewable energy*, *63*, 458-466.
10. Çelikbilek, Y., & Tüysüz, F. (2016). An integrated grey based multi-criteria decision making approach for the evaluation of renewable energy sources. *Energy*, *115*, 1246-1258.
11. Büyüközkan, G., & Güleryüz, S. (2016). An integrated DEMATEL-ANP approach for renewable energy resources selection in Turkey. *International Journal of Production Economics*, *182*, 435-448.
12. Büyüközkan, G., & Karabulut, Y. (2017). Energy project performance evaluation with sustainability perspective. *Energy*, *119*, 549-560.
13. Rani, P., Mishra, A. R., Mardani, A., Cavallaro, F., Alrasheedi, M., & Alrashidi, A. (2020). A novel approach to extended fuzzy TOPSIS based on new divergence measures for renewable energy sources selection. *Journal of Cleaner Production*, *257*, 120352.
14. Wang, Y., Xu, L., & Solangi, Y. A. (2020). Strategic renewable energy resources selection for Pakistan: Based on SWOT-Fuzzy AHP approach. *Sustainable Cities and Society*, *52*, 101861.
15. Wu, Y., Wang, J., Ji, S., & Song, Z. (2020). Renewable energy investment risk assessment for nations along China's Belt & Road Initiative: An ANP-cloud model method. *Energy*, *190*, 116381.
16. Gülenç, İ. F., & Bilgin, G. A. (2010). Yatırım kararları için bir model önerisi: AHP Yöntemi-A model proposal for investment decisions: AHP Method. *Öneri Dergisi*, *9*(34), 97-107.
17. Ömürbek, N. (2013). Analitik hiyerarşi süreci ve analitik ağ süreci yöntemlerinde grup karari verilmesi aşamasina ilişkin bir örnek uygulama. *Süleyman Demirel Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, *18*(3), 47-70.
18. Saaty, T. L. (2005). *Theory and applications of the analytic network process: decision making with benefits, opportunities, costs, and risks*. RWS publications.
19. Burnaz, S., & Topcu, Y. I. (2006). A multiple-criteria decision-making approach for the evaluation of retail location. *Journal of Multi-Criteria Decision Analysis*, *14*(1-3), 67-76.
20. Saaty, T. L. (2004). Decision making—the analytic hierarchy and network processes (AHP/ANP). *Journal of systems science and systems engineering*, *13*(1), 1-35.
21. Görener, A. (2012). Comparing AHP and ANP: an application of strategic decisions making in a manufacturing company. *International Journal of Business and Social Science*, *3*(11).
22. Kahraman, C., Birgün, S., & Yenen, V. Z. (2008). Fuzzy multi-attribute scoring methods with applications. In *Fuzzy Multi-Criteria Decision Making* (pp. 187-208). Springer, Boston, MA.
23. Saaty, T. (1980). The analytic hierarchy process (AHP) for decision making. In *Kobe, Japan*.
24. Çakıl, E. Y. (2017). *Bir mermer fabrikasındaki makinenin çok kriterli karar verme metotları kullanılarak seçilmesi.* Master's thesis, İzmir Kâtip Çelebi University.
25. Maya, R., & Eren, T. (2018). Türk gıda sektörünün finansal performans analizinin çok kriterli karar verme yöntemleri ile yapılması. *Verimlilik Dergisi*, *3*(3), 31-60.

26. Kurttila, M., Pesonen, M., Kangas, J., & Kajanus, M. (2000). Utilizing the analytic hierarchy process (AHP) in SWOT analysis—a hybrid method and its application to a forest-certification case. *Forest Policy and Economics*. *1*(1), 41-52.
27. Saaty, T. L. (1993). What is relative measurement? The ratio scale phantom. *Mathematical and Computer Modelling*, *17*(4-5), 1-12
28. Saaty, T. L. (2003). Decision-making with the AHP: Why is the principal eigenvector necessary. *European journal of operational research*, *145*(1), 85-91.
29. Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, *1*(1), 83-98.
30. Feng, C., H. Wang, & X. M. Tu. (2013). Geometric mean of nonnegative random variable. Communications in Statistics - Theory and Methods 42 (15):2714–2717.
31. Karpak, B., & Topcu, I. (2010). Small medium manufacturing enterprises in Turkey: An analytic network process framework for prioritizing factors affecting success. *International Journal of Production Economics*, *125*(1), 60-70.