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An analytical network process model for deciding on Turkiye's Coal Mining Policy

Introduction

Coal is the most preferred energy source for developing countries despite its well-known negative effects on the environment especially when it is used for energy production purposes. At the same time, coal mining causes serious damage to the deterioration of the ecological environment caused by the exploitation and utilization of mineral resources and a decline in sustainable development capacity (Li et al. 2015). However, there is no other solution for the countries suffering from providing enough energy to use their own natural resources in order to meet energy demand even if clean and renewable energy sources are popular in the world. Coal is not only used as an energy source but also has a key role in producing specific products such as steel, cement, activated carbon, carbon fiber, and silicon metal. Metallurgical coal or coking coal is vital for sustainable steel manufacturing, as over 70% of global steel production from iron ore is primarily dependent on coal. In cement production,

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coal is also used as an energy source for high-temperature kilns (Osborne 2013). Coal is also consumed in several industries such as chemical, alumina, pharmacy, etc. as well and it is a prerequisite for producing a wide range of products such as solvents, plastics and fibers (Future Coal 2024).

As an abandoned energy source, coal is still a favorable resource for some countries when compared with other fossil fuels and energy sources such as clean and renewable energy as an alternative. Moreover, coal has represented the world's largest source of electricity generation over the past century (American Association of Petroleum Geologists, Energy Minerals Division 2014). If coal is used in thermal power plants for generating electricity, the people living in the near vicinity suffer from carbon monoxide, carbon dioxide, greenhouse gases, and harmful pollutants spreading from the plant to the environment. However, the negative impact of coal-fired power plants on the environment can be reduced only when required precautions are taken and clean coal technology is employed in these plants. Therefore, the countries that have to use coal as a primary energy source should have a strategic plan in a sustainable manner about deciding on new investments in coal mines, production, and usage of coal.

Lignite is still a non-negligible energy source due to the following aspects:

1. The production cost of lignite is relatively low when compared to that of other energy resources, and it is quite near to the coal-fired thermal plants.
2. The low emission rates paid for allowable carbon dioxide limits according to the European Emissions Trading System ensure that lignite is a favorable fuel to be used in coal-fired thermal plants.
3. The fact that the energy prices on the market are very low due to the renewable energy flow makes the electricity from the lignite used as fossil fuel still a profitable power (Appunn 2024).

Turkiye faces energy supply issues since energy demand has increased owing to rapid economic expansion, rising population, and growing industrialization (Mills and House 2014). Turkiye is heavily dependent on imported energy sources such as oil, gas, and hard coal since the country's natural energy resources are restricted to lignite and hard coal. More than 90% of Turkiye's oil and 98% of its natural gas is imported, as is much of the hard coal consumed. Turkiye's net energy import is approximately 76% of the total primary energy needs.

Coal is a vital domestic energy resource for Turkiye. The total hard coal reserve of Turkiye is approximately 1 billion 309 million tonnes (39% is proven) having a heating value of 5,400–7,200 kcal/kg and almost all the reserves are held by Turkish Hard Coal Enterprises (TTK). The Lignite reserve of Turkiye is 15 billion 365 million tonnes of which 329.5 million tonnes are proven, 21 million tonnes are probable and 15 billion 14 million tonnes are possible in different regions in the country (Demirkan 2016). 81.1% of these reserves (12,433,988,000 tonnes) are held by three public corporations: General Directorate of Turkish Coal Enterprises (TKI), Electricity Generation Company (EUAS), and General Directorate of Mineral Research and Exploration (MTA).

In Turkiye, coal has been produced from 293 open pits and 176 underground mines (Demirkan 2016). Although Turkiye's coal production is predominantly carried out by the public sector, the private sector has a share of 6.9% in total coal production (Eurocoal 2013). Coal demand has dramatically increased over the last 15 years, and an average increment of 4–5% per year in coal demand is expected in the future if this trend continues insistently. In this period, the coal production from domestic resources in Turkiye remains at the level of about 65 million tonnes. However, coal consumption in Turkiye at the end of 2016 reached approximately 100 million tonnes. For this reason, the difference between the production and consumption rate had to be supplied by coal import.

Turkiye is a country that has considerable care in coal mining and coal production. Therefore, sustainable policies and action plans should be put forward and then evaluated to determine the best coal policy. Due to the complexity of taking into account all effective decision factors and their interrelationships in the decision-making process, the decisions about coal mining policy have to be taken by using a structured and scientific method such as multiple criteria decision-making (MCDM) methods. As far as the authors are concerned, there is no scientific publication about determining coal mining policy by using MCDM methods in the literature. However, a few studies utilizing different MCDM methods in the area of general mining are available in the published literature. Bascetin (2007) developed an AHP-based model for the selection of an optimal reclamation method for coal production in an open-pit coal mine located in the Seyitomer region in Turkiye. The use of the proposed model indicates that it could be applied to improve group decision-making in selecting a reclamation method that satisfies optimal specifications. Yavuz and Alpay (2008) have published a paper about the underground mining method selection problem and they used three different MCDM methods (AHP, Yager's method, and TOPSIS). The TOPSIS method was used as the first in a mining problem in the literature. Yavuz and Tezcan (2010) analyzed the Iron Ore policy of Turkiye and they first used firstly as Analytical Network Process (ANP) method in a mining policy problem. Azimi et al. (2011) have used ANP and TOPSIS methods by considering SWOT analyses to define policies for the Iranian mining sector. Lashgari et al. (2012) have used a hybrid method of fuzzy AHP, ANP, and Fuzzy TOPSIS for loading equipment selection in the Gole Gohar iron mine in Iran. Rikhtegar et al. (2014) have developed an environmental impact assessment process for the evaluation of the possible impact of mine development and operations and proposed ANP and fuzzy SAW methods to formulate the environmental risks related to mining projects. Galos and Szlugaj (2014) have investigated wastes from the processing of hard coal mining and coal preparation processes. They have concentrated on the problem in terms of waste management and mining policy. Liu et al. (2015) evaluated the safety culture of coal mining enterprises and introduced an improved fuzzy comprehensive evaluation model and evaluation index based on ANP. Kusi-Sarpong et al. (2016) have investigated the influence and importance perceptions of green supply chain management practices in mining by utilizing fuzzy-DEMATEL and ANP methods. Zhü et al. (2016) have provided an ANP-SWOT approach for interdependent analysis and prioritizing the rare earth industry in China. They analyzed the internal and external environmental factors and developed five short-term strategies and four long-term strategies to determine the optimal strategy of the rare earth industry development plan. Ma et al. (2017) have evaluated the performances of different tailings disposal methods in deep sea mining by employing the ANP method. Galos et al. (2018) have presented the scope and general results of the MINATURA 2020 project about the national mineral policy of Poland. The main objective of the project MINATURA 2020 is to provide access to the necessary minerals, also in the long-term perspective in terms of mineral policy. Genc et al. (2018) have used the SWOT-ANP hybrid method to evaluate and rank the natural gas strategies of Turkiye based on the conditions of the Eastern Mediterranean Region. Vidovic and Solar (2018) provided a detailed overview of raw materials policy developments between 2008–2018. They are focused on presenting the policy development and trends and discussing the role of geological surveys as a data provider in the context of the EU Raw Materials Initiative. European Institute of Innovation & Technology established a project group named Raw Materials Project (IRTC; International Round Table on Materials Criticality) and they have made a review of methods and data to determine raw material criticality the solutions were published in the scientific medium (Schrijvers et al. 2020). Silvia et al. (2021) have combined a systematic literature review and a cluster analysis to investigate the progress and challenges of mining policy instruments designed to mitigate coal mining externalities. They have concluded that few successful policies exist, that there is a need for more policy evaluation, and that growth in coal mining poses challenges for our sustainable future. Ciolek et al. (2022) have published a paper aimed to indicate the importance of investment outlays and costs incurred when purchasing alternative fuels that would replace hard coal in Poland. They analyzed the process of adapting the current energy policy of Poland to the requirements of the new energy policy, which was adopted by Poland as a member of the European Union. Li et al. (2022) have developed an evaluation criteria system for Green Mining according to the specific characteristics of underground gold mines. The weights have been calculated using an integrated gray DEMATEL and ANP technique, which considers the correlation between indicators by the authors. Finally, six underground gold mines have been utilized as case studies to verify the methodological feasibility. Heydari et al. (2023) have developed a new social impact assessment model for deep open-pit mines by using 37 social impact factors. They used the Z-Fuzzy Delphi AHP technique in their studies and the methodology was applied to an active mine for verification.

When the literature is examined, it is seen that decision-making methods are applied to many areas of the mining sector in different mining problems. However, it is also known that there are not many decision-making practices in the literature in terms of determining mining policies. This study will close the gap in this field and shed light on future studies. The main purpose of this study is to investigate Turkiye's most appropriate coal policy by taking different perspectives and evaluating the issue as a decision problem. By investigating the coal mining policy ANP method, the issue will be discussed scientifically from different perspectives. For this purpose, an ANP model is developed to prioritize the coal mining policies and select the most suitable policy for Turkiye by considering alternatives, main group criteria (economic, political, social, national, and environmental), sub-group criteria, and their interrelationships.

1. Coal production and policies in Turkiye

Coal is regarded as one of the most outstanding ores among the domestic and natural resources in Turkiye. Therefore, coal mining is a vital importance since it has been produced in different regions in more than 40 provinces in the country (Figure 1). In this way, coal mining not only contributes to the country's economy but also provides job opportunities for the people living in the near vicinities.

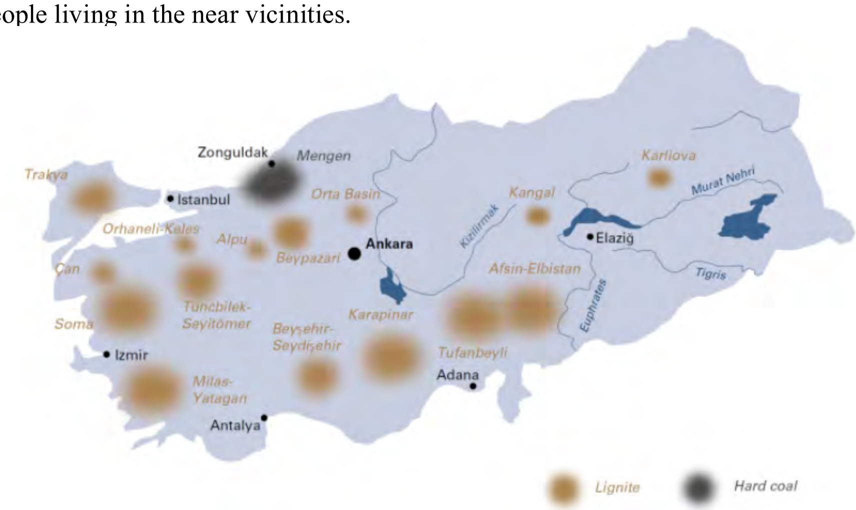

Fig. 1. Turkiye's coal map (Eurocoal 2022)

Rys. 1. Mapa węglowa Turcji

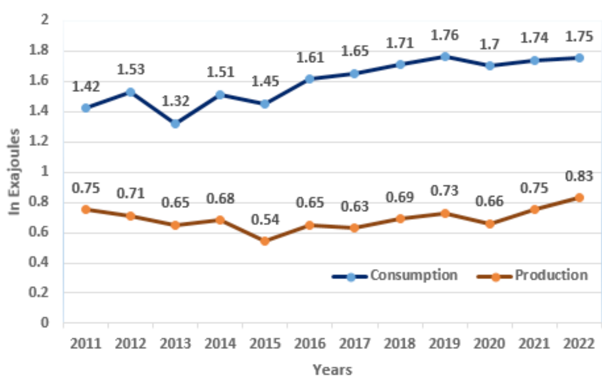

Fig. 2. Coal production and consumption rates between 2011 and 2022 in Turkiye (Statista 2024a, b)

Rys. 2. Wskaźniki produkcji i zużycia węgla w latach 2011–2022 w Turcji

Although coal demand in Turkiye is supplied by domestic coal production, the coal production rate always remained below the consumption rate over the last 12 years as shown in Figure 2. When the coal production and consumption rates in Turkiye are considered, it is evident that the country is heavily dependent on coal imports to supply enough coal.

Coal policy in Turkiye like other countries is determined considering the national energy policy. Besides, it is based on the exploration and exploitation of coal and its utilization economically and environmentally friendly as a domestic resource. Turkiye is a country that has considerable care in coal mining and coal production. Therefore, the year 2012 was designated as "domestic coal year" as a government policy to incent domestic lignite usage for electricity generation. Strategies and action plans for determining the most suitable coal mining strategy for the country were prepared to increase coal production.

According to the data of the General Directorate of Mining and Petroleum Affairs, Türkiye's run of mine coal production in 2022; 102.09 million tons of lignite, 1.49 million tons of asphaltite, 1.79 million tons of hard coal, totaling 105.37 million tons. 119.8 million tons of coal (35.1 million tons of hard coal +79.1 million tons of lignite and asphaltite + 5.6 million tons of hard coal coke) was consumed in Türkiye in 2022. The largest share in the consumption of hard coal, lignite, and asphaltite belonged to thermal power plants with 60.2% and 83.5%, respectively (RTMENR 2024).

In Turkiye, coal is consumed in mainly four main areas: Heating purposes, electricity production, iron/steel industry, and other industrial usage (Figure 3). As shown in Figure 3, almost 75% of the total coal production of Turkiye is used for electricity generation purposes in 40 coal-fired power plants (Anac 2010). This amount of energy requirement exposes clearly that Turkiye is heavily dependent on coal, especially lignite which is produced by its own domestic and natural resources.

As mentioned before, approximately 15–16 billion tonnes of lignite reserve in Turkiye is shared between TKI, EUAS, MTA, and the private sector as shown in Figure 4. In Turkiye, 97.8% of the total reserve is under the control of the Turkish government, and the remaining part is held by the private sector (Tamzok 2017).

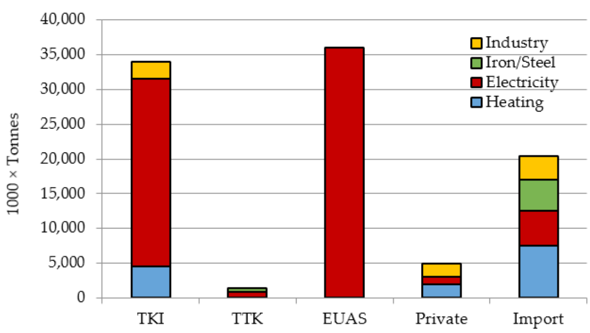

Fig. 3. Coal consumption areas in Turkiye

Rys. 3. Obszary zużycia węgla w Turcji

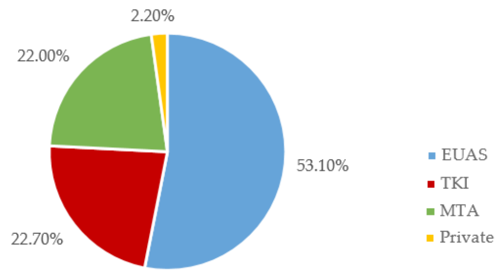

Fig. 4. Lignite reserve held by the government and private sector in Turkiye

Rys. 4. Rezerwy węgla brunatnego znajdujące się w posiadaniu sektora rządowego i prywatnego w Turcji

By the end of July 2023 in Turkiye, 22.71% of the electricity was generated from natural gas, 20.29% from imported coal, 14.35% lignite, 21.53% from hydraulic power, 11.22% from wind, 3.5% from geothermal energy and 6,4% from other sources (RTMENR 2024). To meet energy requirements and industrial demand for coal and to reduce the external dependence risks, making the right decision about coal mining in Turkiye is of quite an importance for the future.

2. Decision-making process on coal mining policy

Decision-making is defined as the selection of the best alternative among the alternative sets to obtain a certain goal. Therefore, deciding on the best coal mining policy for Turkiye can be regarded as a decision-making problem since there can be several alternative policies as follows:

1. Coal mining should entirely be held by the government (A1).
2. The share of the private sector in coal mining should be increased (A2).
3. Much more coal production should be supplied by making new investments in the sector in order to provide import independency (A3).
4. Production capacities of the current coal mines can be increased by employing new technological mining machines (A4).
5. Coal mining can be abandoned (A5).

Some alternatives are determined by investigating on the coal reports prepared by government-based corporations, the private sector, and several enterprises. Besides; a questionnaire has been prepared to reveal the alternatives to sustainable coal mining in Turkiye to take into account the experts' opinions, as well. The final five alternatives given above in this work are considered for the determination of the optimal coal mining policy for Turkiye. Deciding on the most convenient alternative is affected by several criteria which are grouped into five main criteria: economic, political, social, national, and environmental.

Besides, there are sub-group criteria that should be taken into account for determining the optimal coal mining policy. They are assigned in 5 main group criteria as shown in Figure 5. It should be noted that there are interrelationships between the factors within the main group criteria (clusters) as well as between the clusters in the network. Similar interrelationships are also available within the alternatives as well as between the clusters and alternatives.

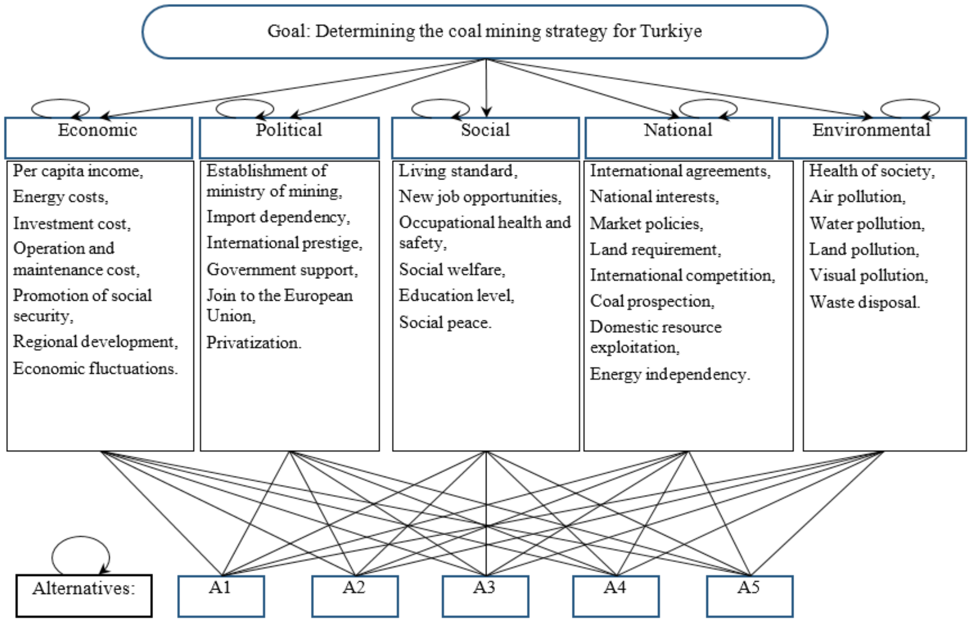

Fig. 5. The network of main group criteria, sub-group criteria and alternatives

Rys. 5. Sieć kryteriów grup głównych, kryteriów podgrup i alternatyw

In a decision problem, when interactions both among the clusters and the factors within a cluster are concerned, the problem should be structured to be able to take into account these relationships (Saaty 2008). All these complex relationships having great effects on deciding to the most convenient coal mining policy for Turkiye should be evaluated in a decision process but this cannot be fulfilled with a hierarchical decision structure. To achieve this aim, the ANP method is used to determine the most convenient coal mining policy for Turkiye in this study.

3. Analytical network process (ANP) method

In particular, the decision-making problems that multiple criteria should be considered together are called Multi-Criteria Decision Making (MCDM) problems and many MCDM methods such as AHP (Analytic Hierarchy Process), TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution), ELECTRE (ELimination Et Choix Traduisant la REalité), PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) have been developed in the literature for their solutions. The Analytic Network Process (ANP) method is another MCDM method proposed by Saaty (1996). Unlike the AHP method, which is also proposed by Saaty (1980), dealing with the criteria in a hierarchical structure, the ANP method provides a methodology that systematically considers any dependency and feedback between the criteria and sub-criteria affecting the decision-making process. In other words, the ANP method is a more general form of the AHP method (Saaty 2008). As in all MCDM methods, evaluation of alternatives and criteria in the ANP method is based on group decisions made by the experts and it is aimed to benefit from the knowledge and experience of the members of the expert groups.

The main reason for using ANP in this study is to consider possible dependency among factors, sub-factors, and alternatives (strategies). Different solution approaches such as AHP and TOPSIS can be applied to see the changes in ranking in Decision Making applications. Consideration of the different methods causes remarkable changes in ranking alternatives, especially about highly important alternatives. This approach will be very useful for decision-making processes. By using the ANP, the decision-makers can model the dependencies and feedback between the decision-making elements, and calculate more precise weights of criteria, and local and global priorities of alternatives.

Dependencies and interactions in the ANP method can be both within the cluster and among the clusters. While an interaction between the elements in the same cluster is called internal dependency, if there is an interaction between different cluster elements, it is called external dependency (Saaty 1980). In an ANP structure, the interactions and effect directions are indicated by arrows or arcs. Figure 6 shows an example of an ANP network.

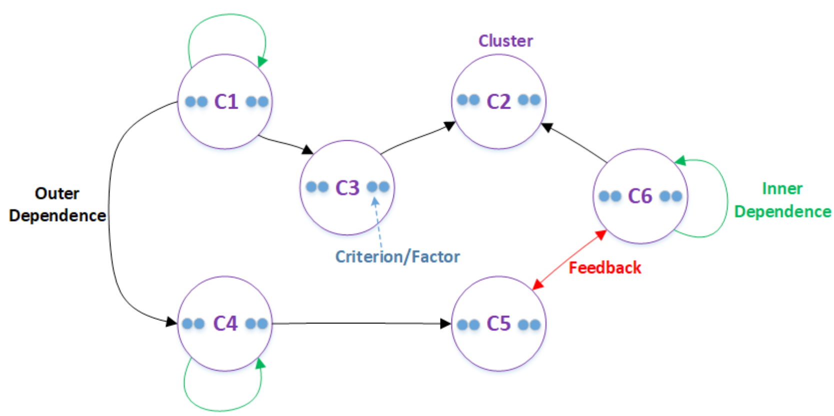

Fig. 6. ANP network

Rys. 6. Sieć ANP

Modeling and solving of a MCDM problem with the ANP method is performed in seven steps (Saaty 2001; Meade and Sarkis 2002):

1. **Define the problem and determine the decision criteria/factors:**

The goal, criteria, sub-criteria, valid alternatives, related clusters, and decision-makers of the MCDM problem are described in detail.

2. **Develop a decision network hierarchy showing the relationships (dependencies) among the decision criteria:**

Once the relevant clusters have been determined considering the main group criteria, sub-group criteria, and valid alternatives, the internal and/or external relationships and/or feedback among the clusters are defined and a decision network hierarchy is developed.

3. **Perform pairwise comparisons among the criteria influencing the decision:**

Similar to the AHP method, pairwise comparisons are made among the criteria affecting the decision using the 1–9 scale (Saaty 2000) as shown in Table 1 in the ANP, as well.

Table 1. Scale for pair-wise comparisons

Tabela 1. Skala porównań parami

Relative Intensity	Definition	Explanation
1	Of equal value	Two requirements are of equal value
3	Slightly more value	Experience slightly favors one requirement over another
5	Essential or strong value	Experience strongly favors one requirement over another
7	Very strong value	A requirement is strongly favored and its dominance is demonstrated in practice
9	Extreme value	The evidence favoring one over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgments	When compromise is needed

4. **In addition, pairwise comparisons are also made between the clusters that influence to each other, with respect to a control criterion:**

Calculate relative-importance-weight vectors (priorities) of the criteria.

To find the relative priorities of the criteria, the eigenvector theory is used. Local relative importance weight vectors are calculated by solving the equation of $A \cdot w = \lambda_{max} \cdot w$ where A denotes the pairwise comparison matrix, λ_{max} is the matrix's largest eigenvalue, and w denotes the eigenvector (relative importance weight vector).

Since pairwise comparisons are made according to subjective evaluations, a consistency ratio (CR) should be calculated based on a consistency index (CI) and a suitable random consistency index (RI) as follows:

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

$$CR = \frac{CI}{RI} \tag{2}$$

- RI – is determined by matrix size (n) by considering the index values in Table 2 (Saaty 2000).

Table 2. The consistency indices of randomly generated reciprocal matrices

Tabela 2. Wskaźniki spójności losowo generowanych macierzy wzajemnych

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51

If the calculated CR value equals or less than 0.1, the pairwise comparison matrix is accepted as consistent.

5. Form a supermatrix and normalize this supermatrix:

The ANP method can take into account the interdependence between elements by obtaining compound weights with the aid of a supermatrix, which is defined by Saaty (1996) as a parallel notion to the Markov chain process.

A two-dimensional supermatrix is formed by placing the obtained relative priority weight vectors on the corresponding columns. Zero values are assigned to the corresponding matrix cells in which no influence exists. Equations 3 and 4 show the supermatrix of a network and a hierarchy, respectively.

$$\begin{array}{cc} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_N \\ e_{11}e_{12}\ldots e_{1n_1} & e_{21}e_{22}\ldots e_{2n_2} & & e_{N1}e_{N2}\cdots e_{Nn_N} \end{array} \\ \begin{array}{cc} C_1 & \begin{array}{c} e_{11} \\ e_{12} \\ \vdots \\ e_{1n_1} \end{array} \\ C_2 & \begin{array}{c} e_{21} \\ e_{22} \\ \vdots \\ e_{2n_2} \end{array} \\ \vdots & \\ C_N & \begin{array}{c} e_{N1} \\ e_{N2} \\ \vdots \\ e_{Nn_N} \end{array} \end{array} & \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1N} \\ W_{21} & W_{22} & \cdots & W_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ W_{N1} & W_{N2} & \cdots & W_{NN} \end{bmatrix} \end{array} \tag{3}$$

$$\begin{array}{c} \\ \\ C_1 e_{11} \\ \vdots \\ e_{1n_1} \\ C_2 e_{21} \\ \vdots \\ e_{2n_2} \\ \vdots \\ C_N e_{N1} \\ \vdots \\ e_{Nn_N} \end{array} \begin{array}{c} \begin{array}{cccccc} C_1 & C_2 & \cdots & C_{N-2} & C_{N-1} & C_N \\ e_{11} \cdots e_{1n_1} & e_{21} \cdots e_{2n_2} & & e_{(N-2)1} \cdots e_{(N-2)n_{N-2}} & e_{(N-1)1} \cdots e_{(N-1)n_{N-1}} & e_{N1} \cdots e_{Nn_N} \end{array} \\ \begin{bmatrix} 0 & 0 & \cdots & 0 & 0 & 0 \\ W_{21} & 0 & \cdots & 0 & 0 & 0 \\ 0 & W_{32} & \cdots & 0 & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & W_{n-1,n-2} & 0 & 0 \\ 0 & 0 & \cdots & 0 & W_{n,n-1} & I \end{bmatrix} \end{array} \quad (4)$$

The supermatrix is then normalized so that the numbers in every column sum to one.

6. Calculate converged (stable) weights from the normalized supermatrix:

To obtain steady-state priorities/weights using the formula of , the supermatrix is raised to powers until the limit values are obtained (Saaty 2008). Equation 5 shows the kth power of the supermatrix as a hierarchic composition.

$$W^k = \begin{bmatrix} 0 & 0 & \cdots & 0 & 0 & 0 \\ 0 & 0 & \cdots & 0 & 0 & 0 \\ \vdots & \vdots & \cdots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & 0 & 0 & 0 \\ W_{n,n-1}W_{n-1,n-2}\cdots W_{32,21} & W_{n,n-1}W_{n-1,n-2}\cdots W_{32} & \cdots & W_{n,n-1}W_{n-1,n-2} & W_{n,n-1} & I \end{bmatrix} \quad (5)$$

7. Choose best alternative:

The best alternative is chosen by taking into account the stable weights/steady-state values in the limit supermatrix.

4. Results

To prioritize available coal mining policies for Turkiye and decide on the most convenient coal mining policy, an ANP model is developed based on 5 alternatives, 5 main group criteria, and a total of 33 sub-group criteria and their relationships presented in Figure 5 in Section 2.1. The developed ANP model was converted into a survey form and sent to experts on the subject. An example showing the comparisons of decision-makers in the survey form is given in Figure 7.

After the surveys are collected and the data is evaluated, the 'Super Decision' software (Adams and Saaty 2003) is used to make pairwise comparisons and perform the ANP method. Figure 8 shows the developed ANP model.

Compare the options according to the criteria given below.

Example marking:

For example, if you think that "Alternative A" is 5 times greater than "Alternative D", you should make the mark below.

A	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**D**

If you think that "Alternative D" is 5 times more beneficial than "Alternative A", you should make the mark below.

A	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**D**

Note: If you think the two options are of equal importance, tick 1. If you find the criteria used to compare two options meaningless, do not mark.

Fig. 7. An example part of the survey form sending decision-makers

Rys. 7. Przykładowa część formularza ankiety wysyłanego do decydentów

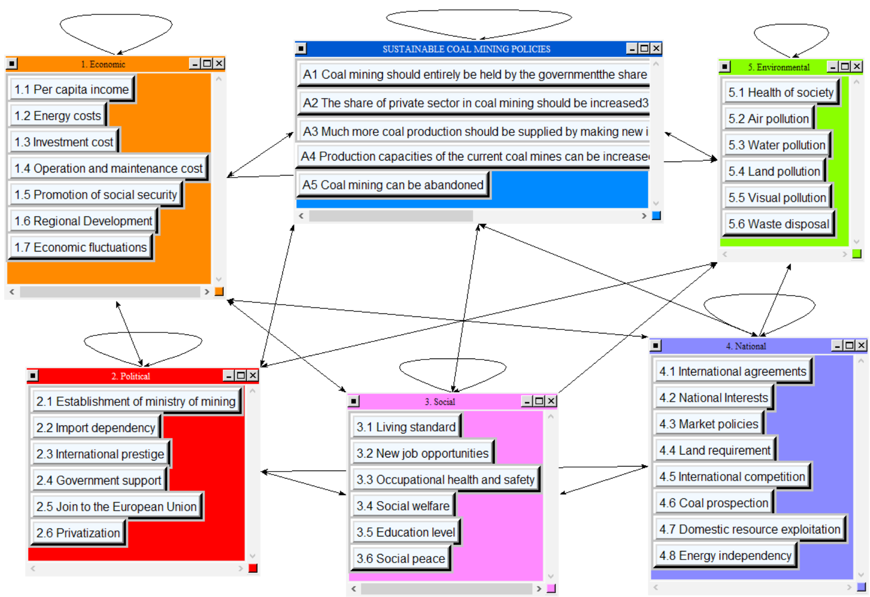

Fig. 8. Developed ANP model by using Super Decision software

Rys. 8. Opracowany model ANP przy użyciu oprogramowania Super Decision

To construct the supermatrix, several pairwise comparisons concerning the interrelationships and feedbacks shown in the ANP model in Figure 8 are required to perform in matrix forms and calculate the local relative importance weight vectors. All pairwise comparison values were determined by an expert group of people (consisting of mining engineers, politicians, economists, specialists in energy and investment, and ecologists) having at least 15 years of experience and knowledge in the related area. Figure 9 shows an example

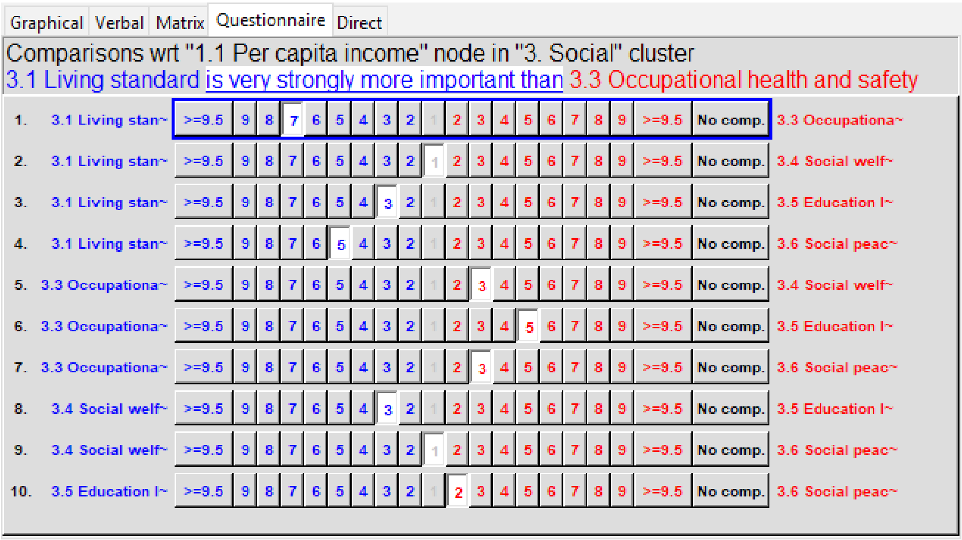

Fig. 9. Criteria comparisons with respect to Per Capita Income

Rys. 9. Porównanie kryteriów w odniesieniu do dochodu na mieszkańca

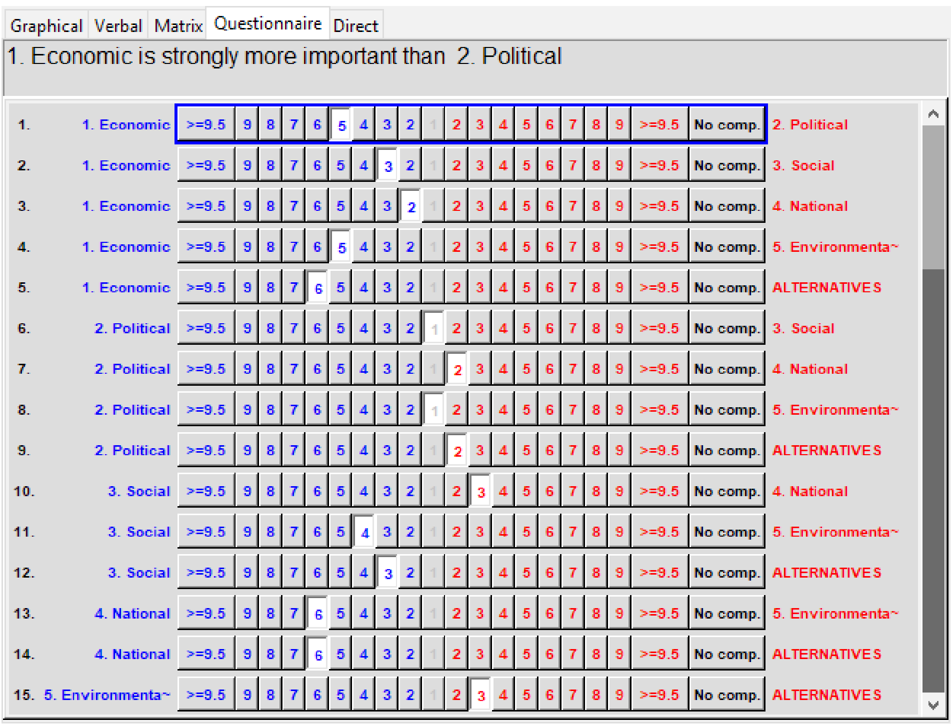

Fig. 10. Cluster comparisons with respect to Economic

Rys. 10. Porównanie klastrów pod względem ekonomicznym of pairwise comparisons of the criteria/factors within a cluster (concerning the Per Capita Income criterion).

After completing pairwise comparisons for linked elements in every cluster, the clusters are also subjected to pairwise comparisons with their linked clusters to determine the cluster weights. Figure 10 is an example of cluster pairwise comparisons (concerning Economics).

During the pairwise comparisons, the consistency ratios for all matrices are checked for their consistency. It is approved that the consistency ratios are less than 0.10, which is acceptable.

The supermatrix is then established by placing the obtained relative importance weight vectors on the corresponding columns in it and raised to powers until it converges to yield the limit supermatrix. Figure 10 shows the limit supermatrix for the developed ANP model. Although the size of the limit supermatrix is 38×38 in this problem, all column values are the same as each other. Therefore, only the first 4 columns of the matrix are shown in Figure 11.

Main Network: CoalMiningStrategy_ANP.sdmod: Limit Matrix

Clusters	Nodes	1.1 Per capita income	1.2 Energy costs	1.3 Investment cost	1.4 Operation an
1. Economic	1.1 Per capita income	0.018217	0.018217	0.018217	0.018217
	1.2 Energy costs	0.035890	0.035890	0.035890	0.035890
	1.3 Investment cost	0.011831	0.011831	0.011831	0.011831
	1.4 Operation and maintenance cost	0.025845	0.025845	0.025845	0.025845
	1.5 Promotion of social security	0.018642	0.018642	0.018642	0.018642
	1.6 Regional Development	0.019565	0.019565	0.019565	0.019565
	1.7 Economic fluctuations	0.001069	0.001069	0.001069	0.001069
2. Political	2.1 Establishment of ministry of mining	0.009188	0.009188	0.009188	0.009188
	2.2 Import dependency	0.027287	0.027287	0.027287	0.027287
	2.3 International prestige	0.030658	0.030658	0.030658	0.030658
	2.4 Government support	0.038873	0.038873	0.038873	0.038873
	2.5 Join to the European Union	0.021805	0.021805	0.021805	0.021805
	2.6 Privatization	0.021603	0.021603	0.021603	0.021603
3. Social	3.1 Living standard	0.054336	0.054336	0.054336	0.054336
	3.2 New job opportunities	0.031175	0.031175	0.031175	0.031175
	3.3 Occupational health and safety	0.084925	0.084925	0.084925	0.084925
	3.4 Social welfare	0.031194	0.031194	0.031194	0.031194
	3.5 Education level	0.015084	0.015084	0.015084	0.015084
	3.6 Social peace	0.071001	0.071001	0.071001	0.071001
4. National	4.1 International agreements	0.014114	0.014114	0.014114	0.014114
	4.2 National Interests	0.039488	0.039488	0.039488	0.039488
	4.3 Market policies	0.025468	0.025468	0.025468	0.025468
	4.4 Land requirement	0.014444	0.014444	0.014444	0.014444
	4.5 International competition	0.028581	0.028581	0.028581	0.028581
	4.6 Coal prospection	0.024059	0.024059	0.024059	0.024059
	4.7 Domestic resource exploitation	0.027019	0.027019	0.027019	0.027019
	4.8 Energy independency	0.028993	0.028993	0.028993	0.028993
5. Environmental	5.1 Health of society	0.017752	0.017752	0.017752	0.017752
	5.2 Air pollution	0.005153	0.005153	0.005153	0.005153
	5.3 Water pollution	0.005153	0.005153	0.005153	0.005153
	5.4 Land pollution	0.005280	0.005280	0.005280	0.005280
	5.5 Visual pollution	0.005852	0.005852	0.005852	0.005852
	5.6 Waste disposal	0.008101	0.008101	0.008101	0.008101
ALTERNATIVES	A1 Coal mining should entirely be held by t...	0.030044	0.030044	0.030044	0.030044
	A2 The share of private sector in coal minin...	0.044815	0.044815	0.044815	0.044815
	A3 Much more coal production should be s...	0.051902	0.051902	0.051902	0.051902
	A4 Production capacities of the current coal ...	0.033987	0.033987	0.033987	0.033987
	A5 Coal mining can be abandoned	0.021608	0.021608	0.021608	0.021608

Done

Fig. 11. The limit supermatrix for the developed ANP model

Rys. 11. Graniczna supermacierz dla opracowanego modelu ANP

The relative priority values for coal mining policies (alternatives) are obtained from the last 5 rows in the limit supermatrix in Figure 10. In addition, the overall synthesized priorities for the alternatives are shown in Figure 12.

As shown in Figure 11, the order of coal mining policies for Turkiye is A3, A2, A4, A1, and A5 to be ranked from the most suitable alternative to the least. According to the developed ANP model's results, it seems that the best coal mining policy for Turkiye is the alternative of A3.

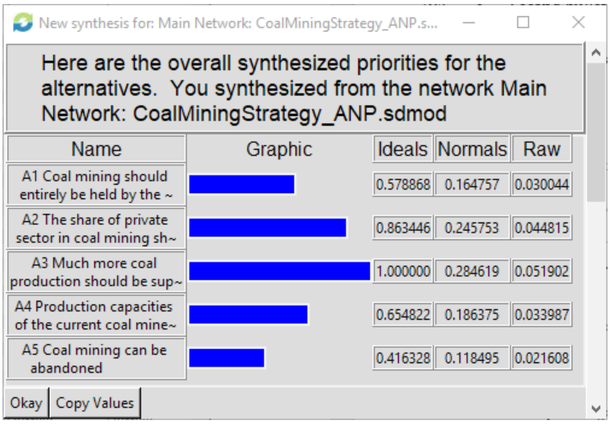

Fig. 12. The overall priorities of alternatives for the developed ANP model

Rys. 12. Ogólne priorytety alternatyw dla opracowanego modelu ANP

5. Discussion

In this study, a multi-criteria decision-making model based on ANP is proposed for the selection of the best coal mining policy in Turkiye by taking into account effective factors and their interrelationships. The results obtained from the proposed ANP model based on the expert group knowledge and experience reveal that three important factors namely occupational health and safety (0.084925), social peace (0.071001), and living standards (0.054336) from out of 33 sub-group criteria have the most effect on determining the coal mining policy for Turkiye when the priority values in Figure 10 are considered.

Occupational health and safety criterion is found as the most effective criterion in this study since the expert group's evaluations could have been influenced by Turkiye's worst-ever coal mining accident in the local coal mine in Soma on 13 May 2014, in which 301 miners died, some burnt alive, others suffocating.

According to the statistical records in 2022, 42,985 miners working in the coal mining sector in Turkiye constitute 0.25% of Turkiye's total household labor force (RTSSI 2022). Therefore, it is plausible that both social peace and living standards criteria take place in the most effective three criteria in the developed ANP model. The result that three sub-group criteria are the most effective factors in the decision-making process is also consistent with Turkiye's current economic conditions and social structure. In addition, sustainability of livelihoods and new job opportunities for local people living in the near vicinity of coal mines is another reason why these two criteria are important in the decision-making process.

The overall priorities in Figure 11 show that the alternative of A3 'Much more coal production should be supplied by making new investments into the sector to provide import independence' is the most convenient coal mining policy which has the highest priority of 0.051902 (28.46%). The order of other alternative policies based on the priorities is as follows: A2 'The share of the private sector in coal mining should be increased' with the priority value of 0.044815 (24.58%), A4 'Production capacities of the current coal mines can be increased by employing new technological mining machines' having the priority value of 0.033987 (18.64%), A1 'Coal mining should entirely be held by the government' with the priority value of 0.030044 (16.48%) and A5 'Coal mining can be abandoned' having the priority value of 0.021608 (11.85%).

Since the priority values of A3 and A2 are found as close to each other, the policy of A2 which proposes the increment of the share of the private sector in coal mining in Turkiye can also be thought of as another sustainable coal policy. The part of 97.8% of the total coal reserve in Turkiye is under the control of the Turkish government. However, the coal production rate is currently insufficient to supply coal demand. If the share of the private sector is increased, the coal may be extracted more productively by the private sector in Turkiye. In this way, the private sector can find an opportunity to make new investments in coal mining to enhance the current conditions of coal mines in Turkiye.

The study reveals that Turkiye should never give up coal mining since this alternative has the lowest priority value and takes place at the last end of the order of alternatives. Currently, the coal production is always below the coal consumption rate in Turkiye as mentioned before. Besides, the amount of net coal imported into Turkiye has dramatically increased for the last 10 years. For this reason, Turkiye should carry on producing much more coal for the sustainability of independence on coal import as a result of the developed ANP model.

Conclusions

This study aims to determine a sustainable coal mining policy for Turkiye among the five alternatives by taking into account many important decision factors. For this purpose, an ANP model is developed to prioritize the coal mining policies by considering five main group criteria namely economic, political, social, national, and environmental, and a total of 33 sub-group criteria based on their interrelationships.

The pairwise comparisons among the criteria and the alternatives are performed based on the expert group decisions and the ANP method is processed. According to the obtained results, the most convenient coal mining policy for Turkiye is found as 'Much more coal production should be supplied by making new investments into the sector to provide import independence'.

The main contributions of this study are listed below:

1. It is the first scientific research in which the determination of coal mining policy is modeled as a multi-criteria decision-making problem by considering several criteria and solved by using the ANP method.
2. The complex interrelationships available in the determination of the best coal mining policy can be taken into account successfully by employing the ANP method since it allows interactions and feedback within the clusters and between the clusters.
3. It includes the evaluations based on group decision-making that minimizes the biases effect on the selection of the right coal mining policy.
4. The ANP model provides an evaluation of which criterion or factor is of more importance to the selected coal mining policy.

Although the ANP model developed in this study has been used to determine the correct policy for coal mining, it can be used in future studies to be able to determine the right policies for other natural resources as well if there are complex interrelations between the alternatives and factors having importance on the selection of a policy.

Mineral and energy raw materials are of strategic importance for every country's economic growth and societal development. At the same time, the national security of countries is also closely related to their easy access to energy resources. After the 1973 World Energy Crisis, the tone of coal in international markets did not show major changes for approximately 50 years. However, 6 months after the start of the Russia–Ukraine war, natural gas and coal prices doubled. For this reason, those who do not want coal mining in their countries must anticipate price fluctuations in imported coal and new supply options. Although green energy and sustainable environment themes have gained importance today, it is clear that the world would not be a livable place without mining activities. For this reason, to make the best decisions while carrying out mining activities based on sustainability, a detailed decision analysis study should be carried out to determine the most appropriate raw material policy for each country.

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AN ANALYTICAL NETWORK PROCESS MODEL FOR DECIDING ON TURKIYE'S COAL MINING POLICY

Keywords

coal mining, sustainable policy, decision making, MCDM, Analytical Network Process (ANP)

Abstract

Coal is a necessary energy source for electric generation and other industrial uses. Countries that use this energy source as a domestic and natural resource should consider their coal mining policies. It is a hard task for the people who are responsible for the development and planning of investments since coal mining policy is affected by economic, political, social, national, and environmental factors. In addition; lots of sub-factors, which can be clustered under these factors, have a great impact on deciding on a coal mining policy. These factors and sub-factors are not independent from each other but also have interrelationships. This paper proposes a multi-criteria decision-making model for selecting the best coal mining policy in Turkiye by using the Analytical Network Process (ANP) method in which all these effective factors and their relationships are considered. Turkiye faces energy supply issues since energy demand has increased owing to rapid economic expansion, rising population, and growing industrialization. Turkiye is heavily dependent on imported energy sources such as oil, gas, and hard coal since the country's natural energy resources are restricted to lignite and hard coal. In this respect, Turkiye needs to develop a coal mining policy according to its conditions. The main purpose of this study is to investigate Turkiye's most appropriate coal policy by taking different perspectives and evaluating the issue as a decision problem. After the modeling studies by using ANP, it is concluded that much more coal production should be supplied by making new investments in the coal mining sector in Turkiye. The ANP method found as a useful and practical technique for deciding on mining policy problems.

ANALITYCZNY MODEL PROCESU SIECIOWEGO SŁUŻĄCY DO PODEJMOWANIA DECYZJI W SPRAWIE POLITYKI WYDOBYCIA WĘGLA W TURCJI

Słowa kluczowe

górnictwo węgla kamiennego, zrównoważona polityka,
podejmowanie decyzji, MCDM, proces sieci analitycznej (ANP)

Streszczenie

Węgiel jest niezbędnym źródłem energii do wytwarzania energii elektrycznej i innych zastosowań przemysłowych. Kraje wykorzystujące to źródło energii jako zasób krajowy i naturalny powinny rozważyć swoją politykę wydobycia węgla. Jest to trudne zadanie dla osób odpowiedzialnych za rozwój i planowanie inwestycji, gdyż na politykę wydobycia węgla wpływają czynniki ekonomiczne, polityczne, społeczne, narodowe i środowiskowe. Ponadto, wiele czynników cząstkowych, które można pogrupować w ramach tych czynników, ma ogromny wpływ na podejmowanie decyzji dotyczących polityki wydobycia węgla. Czynniki te i podczynniki nie są od siebie niezależne, ale również pozostają ze sobą w relacjach. W artykule zaproponowano wielokryterialny model podejmowania decyzji umożliwiający wybór najlepszej polityki wydobycia węgla w Turcji przy użyciu metody *Analytical Network Process* (ANP), w której uwzględniane są wszystkie te efektywne czynniki i ich relacje. Turcja stoi w obliczu problemów z dostawami energii, ponieważ zapotrzebowanie na nią wzrosło w wyniku szybkiego rozwoju gospodarczego, rosnącej liczby ludności i rosnącej industrializacji. Turcja jest w dużym stopniu uzależnione od importowanych źródeł energii, takich jak ropa naftowa, gaz i węgiel kamienny, ponieważ naturalne zasoby energetyczne kraju ograniczają się do węgla brunatnego i kamiennego. W tym zakresie Turcja musi opracować politykę wydobycia węgla zgodnie ze swoimi warunkami. Głównym celem tego badania jest zbadanie najwłaściwszej polityki węglowej Turcji poprzez przyjęcie różnych perspektyw i ocenę tej kwestii jako problemu decyzyjnego. Po badaniach modelowych z wykorzystaniem ANP stwierdzono, że znacznie większa produkcja węgla powinna zostać zapewniona poprzez nowe inwestycje w sektorze wydobycia węgla w Turcji. Metodę ANP uznano za przydatną i praktyczną technikę decydowania o problemach polityki górniczej.