JME
Journal of Mining & Environment,
Vol. 9, No. 3, 2018, 567-579.
DOI: 10.22044/jme.2017.951

Structural analysis of impacting factors of sustainable development in underground coal mining using DEMATEL method

R. Norouzi Masir*, R. Khaloo Kakaie, M. Ataei and S. Mohammadi

Faculty of Mining, Petroleum & Geophysics Engineering, Shahrood University of Technology, Shahrood, Iran

Received 12 January 2017; received in revised form 3 June 2017; accepted 12 June 2017
**Corresponding author: raziye_norouzi@shahroout.ac.ir (R. Norouzi Masir).*

Abstract
Mining can become more sustainable by developing and integrating economic, environmental, and social components. Among the mining industries, coal mining requires paying a serious attention to the aspects of sustainable development. Therefore, in this work, we investigate the impacting factors involved in the sustainable development of underground coal mining from the structural viewpoint. For this purpose, the decision-making trial and evaluation laboratory (DEMATEL) technique, which is a graph-based method, is utilized. To do so, at first, twenty effective factors are determined for three components. Then the hierarchical structure and the systematic approach are used to determine the total exerted influence or total received influence of the components. The results obtained show that the environmental and social components are the most important, and the economic components are the least important among them.

Keywords: *Sustainable Development, Underground Mining, Coal, Decision-Making Trial and Evaluation Laboratory (DEMATEL) Technique.*

1. Introduction

Generally speaking, the progress and development of a country depend upon its economy. On the other hand, the economy is related to the mineral resources, energy, and industries, and thus, the economic growth requires increasing their capacity. Nowadays, due to rises in the world population and the growing demand of welfare to increase the production rate of mining, industries are essential. In this manner, if increasing the production rate is not attented, the future generations will have troubles. In the recent decades, to deal with this issues and challenges, a sustainable development (SD) has been widely used. In 1987, SD was defined as development by considering the demand of the present and future generations simultaneously without compromising the ability to meet them. These principles have had a growing influence on the development of environmental and social policy in the recent decades, and have been adopted and promoted by a number of international organizations including United Nations and World Bank [1-3].

Mining activity is one of the most important industries in many countries for an economic growth and a social welfare. In contrast, due to the many environmental effects of mining (e.g. water and air pollution, and soil erosion), various social and economic problems have led to enter SD into the mining sector. In modern mining, special attention is paid to SD. This would lead to obtain more welfare and wealth for industrialized countries. Coal industry, as a strategic energy resource and an infrastructure material for various industries, has a significant role in the economy of countries. This industry has many environmental impacts and social issues. Consequently, paying attention to SD is of special importance. Up to the present time, many efforts have been made for assessing SD in all fields of mining, especially coal mining [4, 5]. In what follows, the recent studies in this context are reviewed.

Chikkatur and others have reviewed and discussed the key challenges of SD in the Indian coal section. Consequently, they presented viewpoints and policy recommendations in order to move in the right direction in this field [6]. The environmental impacts of China's coal mines have been assessed in order to protect the economic resources and profits to achieve the goals of SD using the hierarchical analysis process (AHP) [7]. In 2010, Mitich described the SD strategies to improve the coal mining industry, and gave recommendations for more effective applications of the principles of SD and technology management [8]. Application of the dynamic system theory for the development of a decision-support system for coal mine programing system was suggested by Sontamino and Drebenstedt in 2011 [9]. A mathematical model for evaluation of sustainability for a tailing dam in coal mine was provided by Philips based on the results an environmental impact assessment with a rapid impact assessment matrix (RIAM) [10]. Up to now, this model is the most important quantitative model for assessing SD in term of the environmental aspects. Mukhopadhyay suggested a framework by integrating three analytical approaches to plan models for SD including economic analysis, decision analysis, and system analysis [11]. A diagnostic methodology to the path of (un)sustainable economic development was developed in this framework. Czaplicka-Kolarz and others identified factors of underground coal gasification influencing balanced Life Cycle Assessment; they attempted to assess the effect of underground coal gasification technology on the indicators of SD in Poland [12]. Burchart-Korol and others have developed algorithms for assessment of the aspects of SD for hard coal mines, the environmental and cost efficiency of mining production processes. They presented an equation for coal mine environmental assessment. Afterward, the socio-economic analysis was performed using cost-benefit analysis (CBA), and an equation was presented for this purpose. Finally, on the foundation of previous equations, a SD indicator was developed. Their study was done in the Poland's hard coal industry as a case study [13]. Uddin and others have investigated the cooperation of methane coal mine projects under the clean development mechanism (CDM) with SD in China. Moreover, they compared it with six similar projects implemented with CMD in other developed countries [14].

Based upon the literature review, it was concluded that there were two important points in the previous studies: providing a model for evaluating SD in coal mining, general assessment of SD in a case study. Although these efforts have provided significant contributions to the sustainability development concept in mining, however, there is no analytical study about the aspect and impacting factor of SD in terms of their inter-relationships. Therefore, this paper describes the structure of SD components as well as impacting factors for underground coal mining from a causal structural viewpoint. Furthermore, their importance according to the influence that each exert or receive from others was analyzed. To do so, the decision-making trial and evaluation laboratory (DEMATEL) method that is a technique for inter-relationships in a system was used.

2. SD in coal industry

The sustainable development (SD) was defined in 1987 by World Commission on Environment and Development at United Nations as [1]. **"SD is a development that meets the needs of the pre-sent without compromising the ability of the future generations to meet their own needs".**

The implementation of SD means the integration of activities in the following three key areas (Figure 1) [15]:

- technical and economic activities, ensuring economic growth;
- ecological, ensuring the protection of natural resources and the environment;
- social, meaning care for the employee at the workplace and community development in the area of the mining environment.

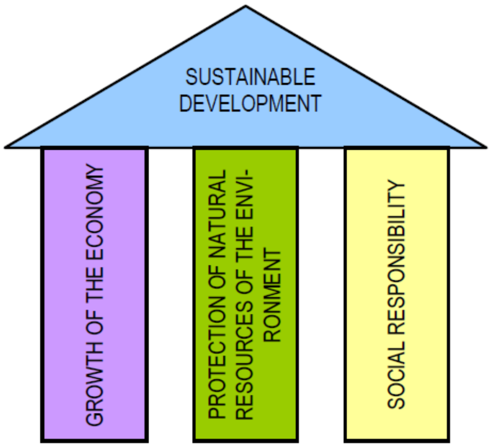

Figure 1. Key elements of SD [15].

Challenges of SD are reflected in the strategies and action plans of the coal mining industry as an energy source and a key component of an important industry such as steel and cement manufacturing. These issues play an important role in setting aims and priorities associated with the long-term development of coal industries and its ability to follow the rules of SD. As a result, due to the lack of paying attention to any aspects of SD in coal mining, this industry not only will grow but also will follow harmful effects. The three main aspects of a SD can be divided into the impacting factors. Therefore, based upon the literature, recommendations of the experts, and our knowledge, the related factors were classified as shown in Figure 2.

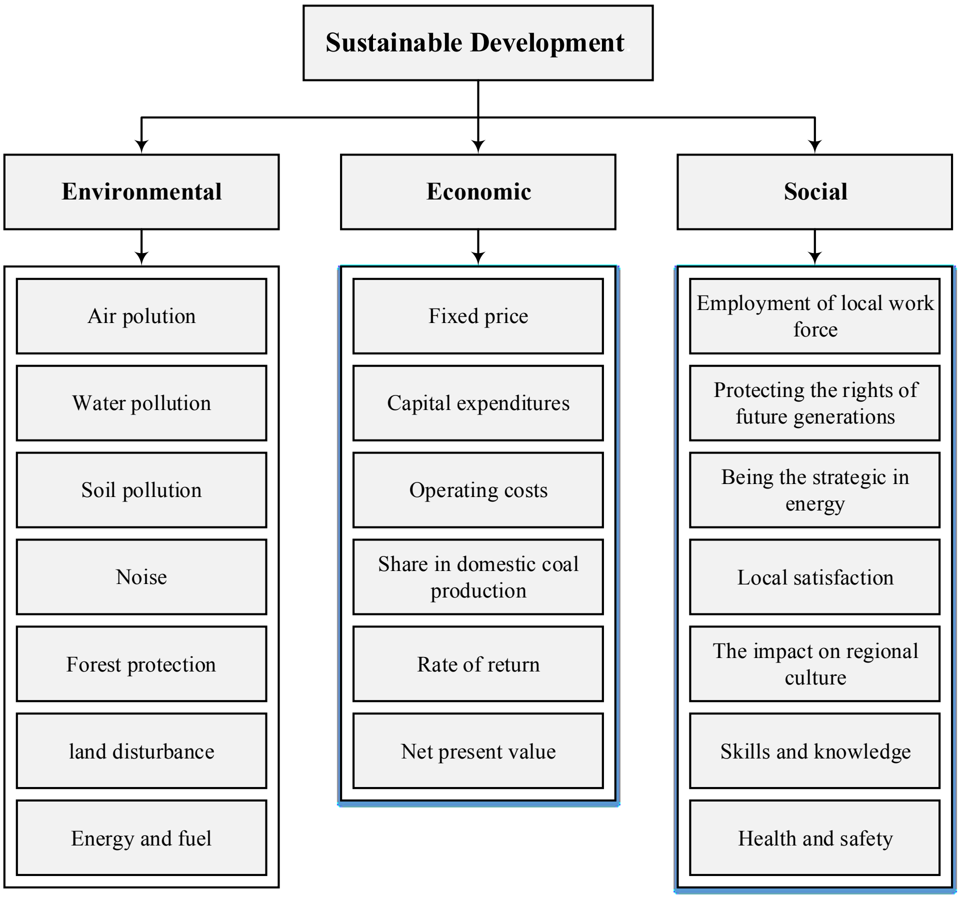

Figure 2. Factors involved for a SD.

3. Decision-making trial and evaluation laboratory (DEMATEL) technique

DEMATEL is one of the MCDM methods based upon graph theory, which was introduced for the first time in the late 1971 in Geneva research center by Fontela and Gabus for the study of very complex structure systems [16-19]. This method uses the principles of graph theory based on experts' opinions on various issues in the form of graphs showing a directional and hierarchical structure. Moreover, DEMATEL demonstrates the inter-relations among criteria and discovers the central criteria to represent the effectiveness of factors. This method has been applied in many situations such as safety problems [20], E-learning [21], supply chain management [22], business process management [23], and risk assessment [24]. In order to implement this method, 7 steps must be carried out as what follow [21, 25-27].

Step 1: Determining effective factors in system. In this step, it is necessary to identify the main components and their impacting factors. For this purpose, the brain strom method (recommendation of experts and exprimental judgement) and reviewing the literature can be used.

Step 2: Establishing pairwise comparison matrix. For this aim, a square matrix is established, in which the effective factors are put in row and column. Then the experts are asked to indicate the direct influence that each factor exerts on the others according to an integer scale ranging in Table 1. The element of comparison matrix is noted by $x_{ij}^{(k)}$, which shows the direct influence of factor (i) on factor (j), given by expert (k).

Table 1. Numerical values for exert and received influence.

Classification	No influence	Very low influence	Low influence	High influence	Very high influence
Score	0	1	2	3	4

Step 3: Calculating average matrix. This matrix is the average of pairwise comparison matrix, denoted by A. The (i, j) element of matrix A is a_{ij}, calculated as follows:

$$a_{ij} = \frac{1}{h}\sum_{k=1}^{h} x_{ij}^{k} \quad (1)$$

where *h* is the number of experts.

Step 4: Calculating initial direct influence matrix. The initial direct influence matrix D is obtained through normalizing matrix A, which can be gained from Equations (2) and (3).

$$D = \frac{A}{s} \quad (2)$$

where s is a constant, which can be calculated as follows:

$$s = \max\left(\max_{1\le i\le n}\sum_{j=1}^{n} a_{ij}, \max_{1\le j\le n}\sum_{i=1}^{n} a_{ij}\right) \quad (3)$$

Step 5: Calculating total relation matrix. Based upon the graph theory, the sum of direct and indirect influences that vertices of a graph exert on each other, considering all feedbacks, is the sum of the terms of an infinite geometric series. Therefore, the total relation matrix T shows the total indirect and direct relations calculated as follows:

$$T = \sum_{m=1}^{\infty} D^{i} = D\left(1-D\right)^{-1} \quad (4)$$

By letting t_{ij} to be the (i, j) element of matrix T, the sum of the i-th row and the sum of the j-th column, r_i and c_j, are obtained, respectively, as follow:

$$\left[r_i\right]_{n\times 1} = \left(\sum_{j=1}^{n} t_{ij}\right)_{n\times 1} \quad (5)$$

$$\left[c_j\right]_{n\times 1} = \left(\sum_{i=1}^{n} t_{ij}\right)_{n\times 1} \quad (6)$$

where r_i represents the total direct and indirect influences of factor i on the other factors, and c_j denotes the sum of the direct and indirect influences, received by factor j from the other factors. Therefore, when j = i, $(c_i + r_i)$ provides an index of the strength of influences given and received, in other words, $(c_i + r_i)$ shows the degree that factor i plays in the problem. If $(c_i - r_i)$ is positive, then factor i affects the other factors, and if $(c_i - r_i)$ is negative, then factor i is influenced by the other factors.

Step 6: Impact-relation map. At this stage, a Cartesian coordinate system is drawn with the values of r+c and r-c represented on the x-axis and the y-axis, respectively.

Step 7: Setting a threshold value and showing causal relation. In order to describe the structural relationship between the factors involved, a threshold value must be considered to filter some negligible effects in matrix T. While each factor of matrix T provides information on how one factor affects another, the decision-maker must set a threshold value in order to reduce the complexity of the structural relation model implied by matrix T. Only some factors whose effects in matrix T is greater than the threshold value, should be chosen and shown in the impact-relation map. In fact, the causal relation shows the network relation, and it can be plotted in the impact-relation map or separately. If it shows as individual, it is called the network relation map.

4. Implementing DEMATEL for SD

For implementation of the DEMATEL method to assess SD in underground coal mining, at first, questionnaires were designed in order to collect the necessary data, and then distributed among the experts. These questionnaires consist of four parts: components and their impacting factors according to Figure 2. Therefore, the experts were asked to evaluate the direct influence of factors located in the rows on the factors located in columns, as shown in Table 2. Finally, 15 questionnaires were received. In the following, the implementation of the DEMATEL method for each one of the components and their impacting factors are described in separate sections.

4.1. Implementation of DEMATEL method for components

The matrix shown in Table 2 is used in order to gather expert judgments in which EN, EC, and S represent the environmental, economic, and social components, respectively.

Table 2. Matrix for components.

	EN	EC	S
EN	0		
EC		0	
S			0

By undertaking steps 1-3 in the DEMATEL technique, matrix A was calculated as follows. This matrix shows the initial direct effects that a factor exerts and receives from the other factors.

$$\begin{array}{cc} & \begin{array}{ccc} EN & EC & S \end{array} \\ \begin{array}{r} EN \\ A = EC \\ S \end{array} & \begin{bmatrix} 0.000 & 3.500 & 3.875 \\ 3.000 & 0.000 & 3.313 \\ 2.875 & 3.250 & 0.000 \end{bmatrix} \end{array}$$

By implementation of steps 4 and 5 of the DEMATEL method, vectors of (r), (c), (r-c), and (r+c) were calculated for components, and the results obtained were tabulated in Table 3. Vector (r) indicates the total exert influence on the others, (c) is a vector that shows the total influence received from the others, (r-c) is relation, and (r+c) is impact. Then the impact-relation map of SD was drawn and illustrated in Figure 3.

Table 3. Results of total relationships matrix for components.

Components	r	c	r + c	r - c
Environmental	8.902	7.607	16.509	1.295
Economic	7.989	8.374	16.363	-0.385
Social	7.822	8.732	16.554	-0.91

As it can be seen in Table 3, ‘environmental’ is the most total exerted influence component with an (r) value of 8.902, whereas ‘social’ is the least total exerted influence component with (r) value of 7.822. Mining activities influence the environment in different ways in the area that coal mines are located. When a mining area concerns with the environmental problems, it causes social troubles, loss of life, people immigration, and unemployment. These are examples of the effects of the environmental component. It is quite natural that this component is the most total exerted influence. On the other hand, values for the social component are determined by the other components. It is the least total exerted influence component compared with the others. Thus social components are the most total received influence, and the environmental components are the least total received influence that the result confirms this point. Therefore, nowadays many countries need a comprehensive planning for social management in order to gain environmental, social, and economical benefits at the same time. Due to the presence of internal relationships among environmental, economic, and social components, the total exerted influence and the total received influence values are close together.

As it can be seen in Figure 3, the economic and social components are in the relation group, with negative (r-c) values of -0.385 and -0.91, respectively, and the environmental component is in the relation group with a positive (r-c) value of 1.295. The social component has the most impact, and hence, is the most important among these components, whereas the economic component has the least impact, and hence, is the least important component.

As described earlier, the value for r-s shows the net effect that a factor shares with the system. Accordingly, although EC and S have the negative value of (r-c), and thus are the effective components, EC has a more exerted effect on the system. In fact, the graph shows that the economic component is more in relation with the system compared with the social component.

Ultimately, in order to draw a network relationship map based on the information of total relationship matrix, a threshold value was calculated by arithmetic averaging of T matrix, which was equal to 2.746. Therefore, in drawing a network relationship map, any relationship is only displayed whose amount in matrix T is more than the threshold value. This map is illustrated in Figure 4. The network relationship map shows that the economic and social components have more total received influence than the environmental component. On the other hand, the environmental component is not influenced by any other components. In this structure, the economic and social components are in a two-way communication with each other.

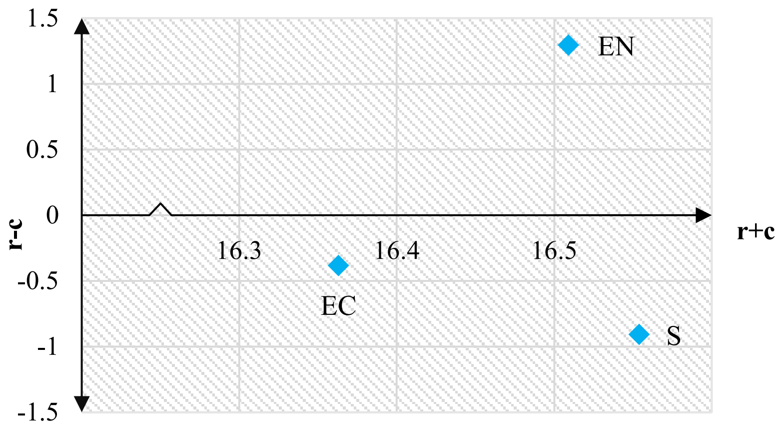

Figure 3. Impact-relations map for components.

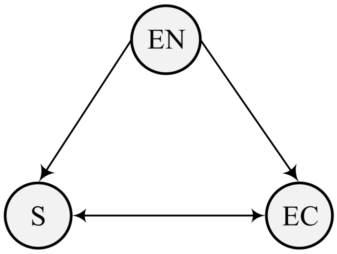

Figure 4. Structure of network relationships map.

4.2. Implementation of DEMATEL method for environmental impacting factors

To collect the expert views, the matrix shown in Table 4 was used, in which AP, WP, SP, N, FP, DL, and EF indicate the impacting factors of air pollution, water pollution, soil pollution, noise, forest protection, land disturbance, energy, and fuel respectively.

Table 4. Matrix for environmental impacting factors.

	AP	WP	SP	N	FP	LD	EF
AP	0						
WP		0					
SP			0				
N				0			
FP					0		
LD						0	
EF							0

Through undertaking steps 1-3 in the DEMATEL method, matrix A is calculated as follows. This matrix shows the initial direct effects that a factor exerts on and receives from the other factors.

$$
A = \begin{array}{c} \\ AP \\ WP \\ SP \\ N \\ FP \\ LD \\ EF \end{array}
\begin{array}{c}
\begin{array}{ccccccc} AP & WP & SP & N & FP & LD & EF \end{array} \\
\begin{bmatrix}
0.000 & 1.933 & 1.867 & 0.867 & 2.133 & 1.400 & 1.143 \\
1.867 & 0.000 & 2.667 & 0.600 & 2.400 & 1.867 & 1.143 \\
2.000 & 2.733 & 0.000 & 0.800 & 2.867 & 2.000 & 1.143 \\
1.400 & 0.800 & 0.800 & 0.000 & 1.200 & 1.133 & 0.928 \\
2.933 & 2.643 & 2.733 & 1.467 & 0.000 & 2.667 & 1.285 \\
1.600 & 1.933 & 2.000 & 0.800 & 2.133 & 0.000 & 1.071 \\
2.200 & 2.200 & 1.867 & 1.533 & 1.867 & 1.267 & 0.000
\end{bmatrix}
\end{array}
$$

By execution of steps 4 and 5 of the DEMATEL method, vectors of total exert influence (r), total received influence (c), relation (r-c), and impact (r+c) were calculated for environmental impacting factors, and the results obtained were tabulated in Table 5. Then the causal diagram of SD was drawn and shown in Figure 5. In addition, the network relationships map was demonstrated in Figure 6.

Table 5. Results of total relationships matrix for environmental impacting factors.

Impacting factors	r	c	r+c	r-c
Air pollution	3.048	3.75	6.798	-0.702
Water pollution	3.43	3.885	7.315	-0.455
Soil pollution	3.699	3.826	7.525	-0.127
Noise	2.036	1.937	3.973	0.099
Forest protection	4.189	3.969	8.158	0.22
Land disturbance	3.108	3.355	6.463	-0.247
Energy and fuel	3.421	2.207	5.628	1.214

As it can be seen in Table 5, the forest protection is the most exerted influence among the impacting factors with the largest (r) value of 4.189, whereas noise is the least total exerted influence with the smallest (r) value of 2.036. Mining is one of the most activities in every country for SD. However, an increase in the mines causes an increase in the mining area that has many environmental problems. One of the most important outcomes of mining that would happen at the same time or after destruction of vegetation in the forests. For example, in the non-mechanized or semi-mechanized coal mines, wooden pillars are used for support in underground mines. This issue is effective on the other environmental impacting factors. Destruction of forests causes land disturbance, air pollution (not sufficient oxygen), and soil erosion (of heavy metals) that result in water pollution. On the other hand, it is quite natural that noise is the least total exerted influence factor since it does not increase or decrease any impacting factors. According to the calculations, forest protection is the most received influence with the largest (c) value of 3.969, whereas noise is the least received influence with the smallest (c) value of 1.937. The total exerted influence and total received influence values of air pollution, water pollution, soil pollution, and land disturbance due to inter-relationships among them are close together.

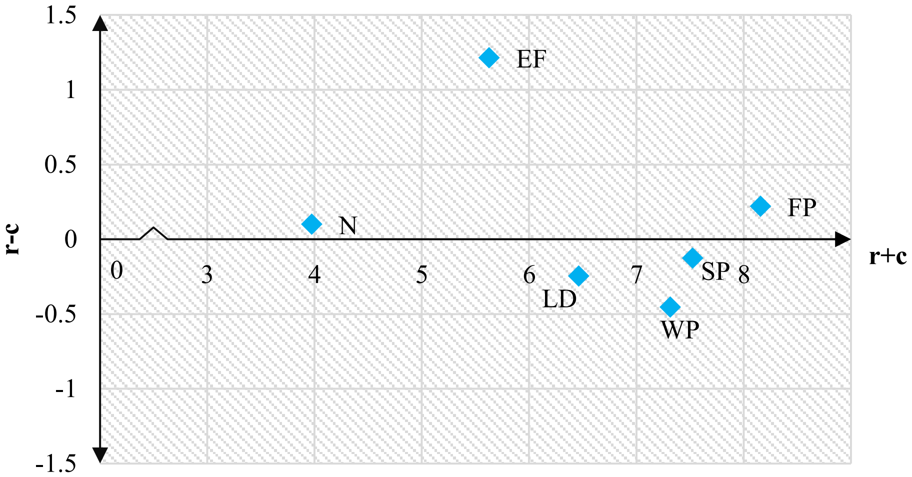

Figure 5. Impact-relations map for environmental impacting factors.

As it can be seen in Figure 5, air pollution, water pollution, soil pollution, and land disturbance are in the relation group, with negative (r-c) values of -0.702, -0.455, -0.127, and -0.247, respectively; and noise, forest protection, and energy and fuel impacting factors are in the relation group with the positive (r-c) values of 0.099, 0.22, and 1.214. This means that factors with negative (r-c) are effective parameters, and the positive (r-c) shows the cause parameters. Forest protection has the most impact, and hence, is the most important among the impacting factors, whereas noise has the least impact, and hence, it is the least important impacting factor.

At the end, in order to draw network relationship maps based on the information of total relationships matrix, a threshold value was calculated by arithmetic averaging T matrix that is equal to 0.468. This map is illustrated in Figure 6. A network relationship map shows that the forest protection, air pollution, and water pollution have more total received influences than the other impacting factors. On the other hand, the energy and fuel impacting factors are not influenced by any other factors. In this structure, air pollution, water pollution, soil pollution, land disturbance, and forest protection are in two-way communication with each other. Soil pollution, forest protection, and water pollution affect themselves.

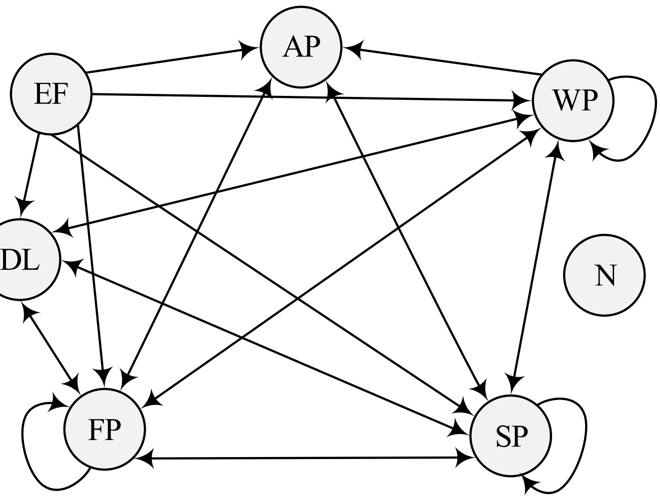

Figure 6. Structure of network relationship map for environmental impacting factors.

4.3. Implementation of DEMATEL method for economic impacting factors

The matrix in Table 6 shows the expert judgments for economic impacting factors in which FP, CE, OC, SP, ROR, and NPV indicate impacting factors of fixed price, capital expenditures, operating costs, share in domestic coal production, rate of return, and net present value, respectively.

Table 6. Matrix for economic impacting factors.

	FP	CE	OC	SP	ROR	NPV
FP	0					
CE		0				
OC			0			
SP				0		
ROR					0	
NPV						0

The matrix of initial direct effects (A) is calculated as follows:

$$A = \begin{array}{c} \\ FP \\ CE \\ OC \\ SP \\ ROR \\ NPV \end{array} \begin{array}{c} \begin{array}{cccccc} FP & CE & OC & SP & ROR & NPV \end{array} \\ \begin{bmatrix} 0.000 & 2.067 & 2.867 & 2.667 & 3.267 & 3.200 \\ 2.733 & 0.000 & 2.667 & 2.400 & 2.867 & 2.867 \\ 3.400 & 2.067 & 0.000 & 2.933 & 3.133 & 3.067 \\ 2.867 & 2.467 & 2.733 & 0.000 & 2.467 & 2.467 \\ 2.933 & 2.067 & 2.533 & 2.4 & 0.000 & 3.000 \\ 2.667 & 2.667 & 2.467 & 2.333 & 3.000 & 0.000 \end{bmatrix} \end{array}$$

Table 7 demonstrates the values for total exert influence (r), total received influence (c), relation (r-c), and impact (r+c) vectors for the economic impacting factors. In addition, Figure 7 shows the causal diagram for these factors.

As it can be seen in Table 7, the operating costs have the most total exerted influence among the impacting factors with the largest (r) value of 12.087, whereas the rate of return has the least total exerted influence with the smallest (r) value of 10.91. When the operating costs increase or decrease, other economic impacting factors will be changed. For instance, when salary increases, the fixed price and share in domestic coal production will also increase. On the other hand, rate of return must have necessary conditions for selection as the most economic project. According to the problems existing in coal mines, it is quite natural that this impacting factors has the least total exerted influence. For the same reason, the rate of return has the most total received influence, and the results also confirm this point. Capital expenditure includes exploration, drilling, and geotechnical costs that depend on the existing condition in underground coal mine, having the least total received influence.

Table 7. Results of total relationships matrix for economic impacting factors.

Impacting factors	r	c	r+c	r-c
Fixed price	11.703	12.088	23.791	-0.385
Capital expenditure	11.338	9.737	21.075	1.601
Operating costs	12.087	11.141	23.228	0.946
Share in domestic coal production	10.976	10.765	21.741	0.211
Rate of return	10.91	12.214	23.124	-1.304
Net present value	11.046	12.119	23.165	-1.073

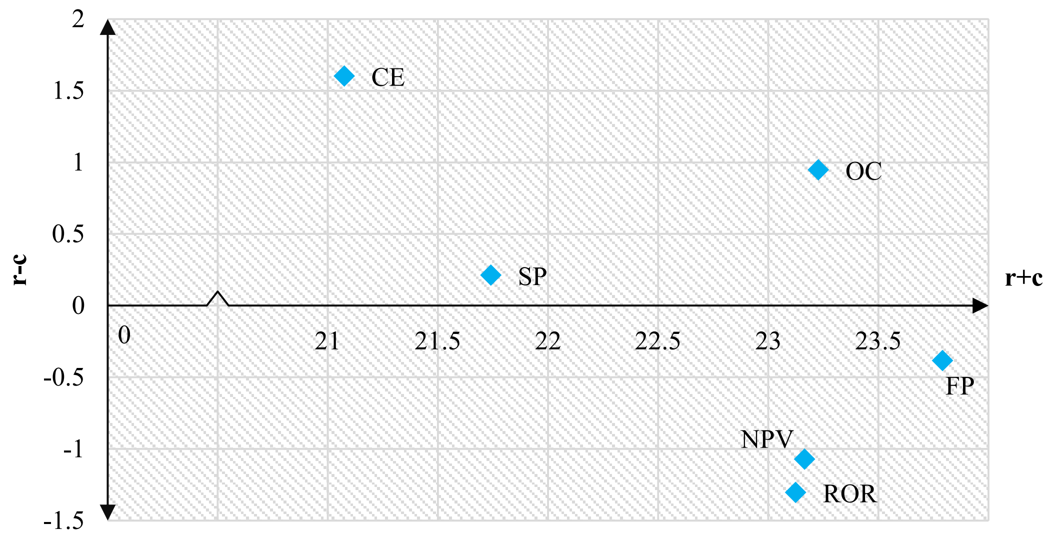

Figure 7. Impact-relations map for economic impacting factors.

As it can be seen in Figure 7, fixed price, rate of return, and net present value are in the relation group, with the negative (r-c) values of -0.385, -1.304, and -1.073, respectively; and capital expenditure, operating costs, and share in domestic coal production are in the relation group with the positive (r-c) values of 1.601, 0.946, and 0.211, respectively. Fixed price has the most impact, and hence, is the most important among the impacting factors, whereas capital expenditure criterion has the least impact, and hence, is the least important factor.

Again a threshold value of 1.890 is used to draw the network relationship map. This map is illustrated in Figure 8. The network relationship map shows that the rate of return and net present value have a total received influence more than the other impacting factors. On the other hand, the capital expenditure is not influenced by any other factors. In this structure, shares in domestic coal production, fixed price, and operating costs are in two-way communication with each other. A fixed price affects itself.

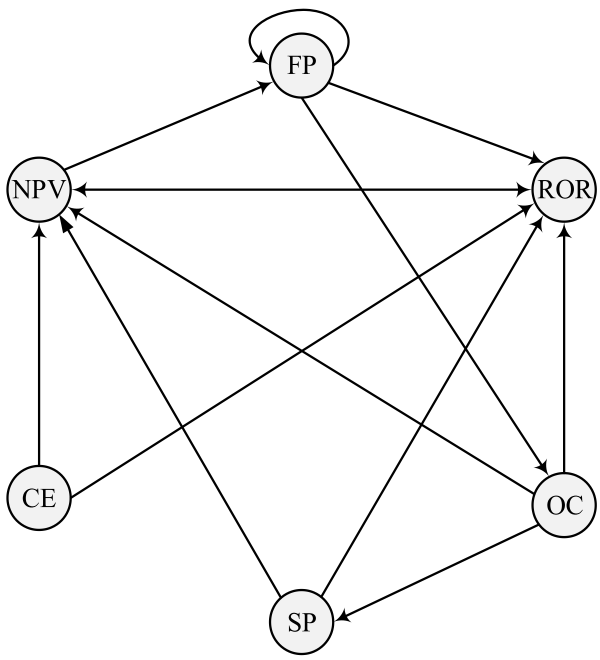

Figure 8. Structure of network relationships map for economic impacting factors.

4.4. Implementation of DEMATEL method for social impacting factors

The matrix in Table 8 demonstrates the expert judgments for social impacting factors, in which ELF, PRG, BSE, LS, TRC, SAK, and HAS point to impacting factors of employment of local work force, protecting the rights of future generations, being strategic in energy, local satisfaction, the impact on the regional culture, skills and knowledge of health, and safety value, respectively.

Table 8. Matrix for social impacting factors.

	ELF	PRG	BSE	LS	TRC	SAK	HAS
ELF	0						
PRG		0					
BSE			0				
LS				0			
TRC					0		
SAK						0	
HAS							0

The matrix of initial direct effects (A) is calculated as follows:

$$A = \begin{array}{c} \\ ELF \\ PRG \\ BSE \\ LS \\ TRC \\ SAK \\ HAS \end{array} \begin{array}{c} \begin{array}{ccccccc} ELF & PRG & BSE & LS & TRC & SAK & HAS \end{array} \\ \begin{bmatrix} 0.000 & 2.357 & 1.643 & 3.357 & 3.143 & 3.357 & 2.357 \\ 1.714 & 0.000 & 1.857 & 2.357 & 2.071 & 1.714 & 1.500 \\ 1.785 & 2.571 & 0.000 & 2.214 & 1.785 & 1.714 & 1.500 \\ 2.285 & 2.143 & 0.928 & 0.000 & 2.428 & 1.785 & 2.214 \\ 1.928 & 2.143 & 1.214 & 2.643 & 0.000 & 2.000 & 2.143 \\ 2.785 & 2.000 & 1.571 & 1.928 & 2.428 & 0.000 & 2.357 \\ 2.285 & 2.000 & 1.500 & 2.071 & 2.643 & 2.143 & 0.000 \end{bmatrix} \end{array}$$

The values for the total exert influence (r), total received influence (c), relation (r-c), and impact (r+c) vectors for the social impacting factors are demonstrated in Table 9. Then the causal diagram for these factors were drawn and shown in Figure 9.

As it can be seen in Table 9, the employment of local work force has the most total exerted influence among the impacting factors with the largest (r) value of 4.445, whereas protecting the rights of the future generations has the least total exerted influence with the smallest (r) value of 3.187. Culture and community in every town is in direct relation with resident people and employment structure in that town. It is quite natural that employment of local work force has the most total exerted influence. On the other hand, since protecting the rights of the future generations are determined based on other factors, it has the least total exerted influence relative to other impacting factors. The results obtained show that local satisfaction and the impact on the regional culture have the most total received influence impacting factors, whereas being strategic in energy is the least total received influence. Rich mines in different parts of Iran have positive and negative effects on the culture and local satisfaction. This total received influence causes effects on the social life of people where this impact is considerable. Protecting the rights of the future generations, health and safety, and skills and knowledge, they all express characteristic employment of local work force. Due to internal relationships among these factors, their total exerted influence and total received influence values are close together.

As it can be seen in Figure 9, protecting the rights of future generations, local satisfaction, and impact on the regional culture are in the relation group, with negative (r-c) values of -0.497, -0.685, and -0.633, respectively (are effect factors), and employment of local work force, being the strategic in energy, skills and knowledge, and health and safety are in the relation group with the positive (r-c) values of 0.83, 0.741, 0.12, and 0.124, respectively (are cause factors). Employment of local work force has the most impact, and hence, is the most important among the impacting factors, whereas being strategic in energy has the least impact, and hence, is the least important impacting factors.

Once more a threshold value of 0.510 is established to draw a network relationship map. This map is shown in Figure 10. The network relationship map shows that protecting the rights of future generations, local satisfaction, and the impact on the regional culture have a total received influence more than the other impacting factors. In contrast, the being of the strategic in energy is not influenced by the other impacting factors. In this structure, local satisfaction, the impact on the regional culture criteria are in two-way communication with each other. Employment of local work force affect itself.

Table 9. Results of total relationships matrix for social impacting factors.

Impacting factors	r	c	r+c	r-c
Employment of local work force	4.445	3.615	8.06	0.83
Protecting the rights of future generations	3.187	3.684	6.871	-0.497
Being the strategic in energy	3.27	2.529	5.799	0.741
Local satisfaction	3.373	4.058	7.431	-0.685
The impact on the regional culture	3.421	4.054	7.475	-0.633
Skills and knowledge	3.714	3.594	7.308	0.12
Health and safety	3.581	3.457	7.038	0.124

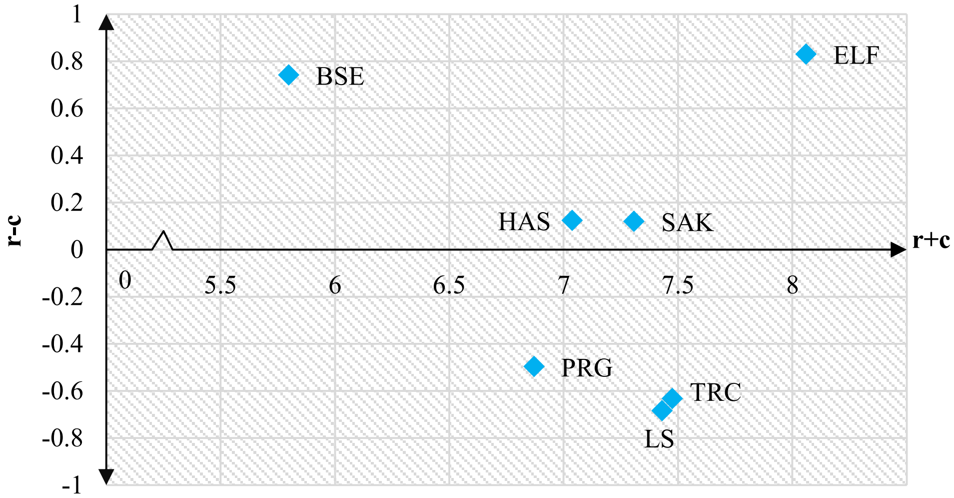

Figure 9. Impact-relations map for social impacting factors.

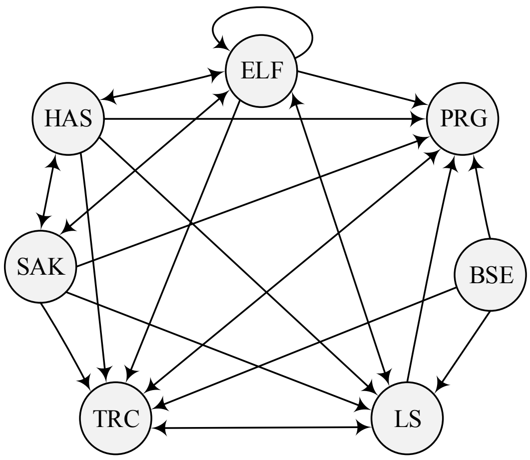

Figure 10. Structure of network relationships map for social impacting factors.

5. Conclusions

Mining activity is one of the most important industries in many countries for economic growth and social welfare. In contrast, many environmental effects of mining such as water and air pollution, soil erosion, various social, and economic problems have led the sustainable development to enter the mining sector. In the modern mining, special attention is paid to the sustainable development. This has led to obtain more welfare and wealth in the industrialized countries. Therefore, this paper evaluates the importance and roles of factors for sustainable development in underground coal mining using the DEMATEL method. For this purpose, three components of SD were divided into the twenty effective impacting factors. The results show that:

- Environmental is the most total exerted influence component, and social is the most received influence. Moreover, the environmental impact is the cause, and the rest are the effect. Most impacts belong to the social component, and hence, it is the most important among components of SD.
- Forest protection has the most total exerted and received influence among the

impacting factors. Noise, forest protection as well as energy and fuel are the cause factors. Furthermore, forest protection has the most impact.

- In the economic component, operating costs exert the most influence on the others, directly and indirectly, while rate of return has the most total received influence. From the causality viewpoint, capital expenditure, operating costs, and share in domestic coal production have the positive relation, and thus they are the cause effects. On the other hand, the most important factor is fixed price with the highest value of impact.
- Employment of local work force has the most exerted influence on the social component, while local satisfaction and impact on the regional culture have received more influence than the other factors. Employment of local work force, being strategic in energy, skills and knowledge, and health and safety are cause, and the remaining parameters are effect. Finally, employment of local work force has the maximum impact and is the most important among the impacting factors.

References

[1]. Brundtland Report. (1987). Our Common Future, Report of the World Commission on Environment and Development United Nations.

[2]. Mining, Minerals, and Sustainable Development (MMSD). (2002). Project, Breaking New Ground: Mining, Minerals, and Sustainable Development, Earthscan for IIED and WBCSD.

[3]. Rankin, W.J. (2011). Minerals, metals and sustainability: meeting future material needs, Collingwood, Vic.: CSIRO Pub.

[4]. Ataei, M., Tajvidi Asr, E., Khalokakaie, R., Ghanbari, K. and Tavakoli Mohammadi, M.R. (2016). Semi-quantitative environmental impact assessment and sustainability level determination of coal mining using a mathematical model. Journal of Mining and Environment. 7 (2): 185-193.

[5]. Sereshki, F. and Saffari, A. Environmental impact assessment and sustainability level determination in cement plants (Case study: Shahrood cement plant). Iranian Journal of Earth Sciences. 8 (2): 90-101.

[6].Chikkatur, A.P., Sagar, A.D. and Sankar, T.L. (2009). Sustainable development of the Indian coal sector. Energy. 34 (8): 942-953.

[7]. Si, H., Bi, H., Li, X. and Yang, C. (2010). Environmental evaluation for sustainable development of coal mining in Qijiang, Western China. International Journal of Coal Geology. 81 (3): 163-168.

[8]. Mitich, M. (2010). Sustainable approaches to a reform of coal mining industry in Serbia. Journal of Sustainable Development. 3 (1): 61.

[9]. Sontamino, P. and Drebenstedt, C. (2011). Decision Support System of Coal Mine Planning Using System Dynamics Model: Introduction and Reviews. 6th Freiberg-St. Petersburg Kolloquium junger Wissenschaftler. Freiberg. Germany.

[10]. Phillips, J. (2012). Applying a mathematical model of sustainability to the Rapid Impact Assessment Matrix evaluation of the coal mining tailings dumps in the Jiului Valley, Romania. Resources, Conservation and Recycling. 63: 17-25.

[11]. Mukhopadhyay, L. (2013). Sustainable Development-A Path Dependent Analysis to the Rat Hole Coal Mining in Jaintia Hills District. India (No. 201306).

[12]. Czaplicka-Kolarz, K., Krawczyk, P. and Burchart-Korol, D. (2013). Metodyka oceny podziemnego zgazowania węgla w aspekcie zrównoważonego rozwoju Polski [Assessment methods of the underground coal gasification process in terms of the sustainable development in Poland]. Przegląd Górniczy. 69 (2): 194-199.

[13]. Burchart-Korol, D., Krawczyk, P., Czaplicka-Kolarz, K., Turek, M. and Borkowski, W. (2014). Development of sustainability assessment method of coal mines. Journal of Sustainable Mining. 13 (4): 5-11.

[14]. Uddin, N., Blommerde, M., Taplin, R. and Laurence, D. (2015). Sustainable development outcomes of coal mine methane clean development mechanism Projects in China. Renewable and Sustainable Energy Reviews. 45: 1-9.

[15]. Dubiński, J. (2013). Sustainable development of mining mineral resources. Journal of Sustainable Mining. 12 (1): 1-6.

[16]. Fontela, E. and Gabus, A. (1972). World Problems an Invitation to Further Thought within the Framework of DEMATEL. Battelle Geneva Research Centre. Switzerland. Geneva.

[17]. Fontela, E. and Gabus A. (1974). DEMATEL, innovative methods. Report No. 2. Structural analysis of the world problematique. Battelle Geneva Research Institute.

[18]. Fontela, E. and Gabus A. (1976). The DEMATEL observer. Battelle Institute. Geneva Research Center.

[19]. Gabus, A. and Fontela, E. (1973). Perceptions of the world problematique: communication procedure, communicating with those bearing collective responsibility (DEMATEL Report no.1). Battelle Geneva Research Centre. Geneva. Switzerland.

[20]. Liou, J.J.H., Yen, L. and Tzeng, G.H. (2008). Building an effective safety management system for airlines. J. Air Transp. Manage. 14: 20-26.

[21]. Tzeng, G.H., Chiang, C.H. and Li, C.W. (2007). Evaluating intertwined effects in e-learning programs: A novel hybrid MCDM model based on factor analysis and DEMATEL. Expert systems with Applications. 32 (4): 1028-1044.

[22]. Chang, B., Chang, C.W. and Wuc, C.H. (2011). Fuzzy DEMATEL method for developing supplier selection criteria. Expert Systems with Applications. 38: 1850-1858.

[23]. Bai, C. and Sarkis, J. (2013). A grey-based DEMATEL model for evaluating business process management critical success factors. Int. J. Production Economics. 146 (1): 281-292.

[24]. Mentes, A., Akyildiz, H., Yetkin, M. and Turkoglu, N. (2015). A FSA based fuzzy DEMATEL approach for risk assessment of cargo ships at coasts and open seas of Turkey. Safety Science. 79: 1-10.

[25]. Lin, C.L. and Tzeng, G.H. (2009). A value-created system of science (technology) park by using DEMATEL. Expert systems with applications. 36 (6): 9683-9697.

[26]. Wang, Y.L. and Tzeng, G.H. (2012). Brand marketing for creating brand value based on a MCDM model combining DEMATEL with ANP and VIKOR methods. Expert Systems with Applications. 39 (5): 5600-5615.

[27]. Lee, H.S., Tzeng, G.H., Yeih, W., Wang, Y.J. and Yang, S.C. (2013). Revised DEMATEL: resolving the infeasibility of DEMATEL. Applied Mathematical Modelling. 37 (10): 6746-6757.

تحلیل ساختاری فاکتورهای مؤثر بر توسعه پایدار در معدنکاری زیرزمینی زغال‌سنگ با استفاده از روش دیمتل

راضیه نوروزی مصیر*، رضا خالو کاکائی، محمد عطائی و سجاد محمدی

دانشکده مهندسی معدن، نفت و ژئوفیزیک، دانشگاه صنعتی شاهرود، ایران

ارسال ۲۰۱۷/۱/۱۲، پذیرش ۲۰۱۷/۶/۱۲

* نویسنده مسئول مکاتبات: raziye_norouzi@shahroout.ac.ir

چکیده:

توجه و به کارگیری جنبه‌های اقتصادی، زیست‌محیطی و اجتماعی در کل عملیات معدنکاری می‌تواند موجب توسعه پایدار این صنعت شود. در این بین، معدنکاری زغال‌سنگ نیازمند توجهی جدی به این جنبه‌ها است؛ بنابراین، در این پژوهش با مد نظر قرار دادن عوامل مؤثر بر توسعه پایدار در معدنکاری زیرزمینی زغال‌سنگ، ساختار حاکم میان آن‌ها مورد تحلیل و ارزیابی قرار گرفته است. برای این منظور، از روش مبتنی بر نظریه گراف آزمایشگاه ارزیابی و آزمون تصمیم‌گیری (DEMATEL) استفاده شده است. در این راستا پس از تعیین بیست عامل مؤثر مؤلفه‌های توسعه پایدار در این زمینه، ساختار سلسله مراتبی و نظام‌مند تأثیرگذاری یا تأثیرپذیری عوامل نسبت به یکدیگر (روابط علّی) با بهره‌گیری از روش DEMATEL ارائه شده است. نتایج کلی حاصل، بیانگر اهمیت بیشتر جنبه‌های زیست‌محیطی و اجتماعی نسبت به مسائل اقتصادی است. این پژوهش نشان می‌دهد که روش مورد استفاده، رویکردی مناسب برای ارزیابی توسعه پایدار از دیدگاه عوامل مؤثر بر آن و همچنین ارتباطات و وابستگی‌های میان آن‌ها است.

کلمات کلیدی: توسعه پایدار، معدنکاری زیرزمینی، زغال‌سنگ، روش آزمایشگاه ارزیابی و آزمون تصمیم‌گیری.