Archives of Computational Methods in Engineering (2021) 28:3687–3701
https://doi.org/10.1007/s11831-020-09521-2

ORIGINAL PAPER

Selection of Renewable Energy Alternatives for Green Blockchain Investments: A Hybrid IT2-based Fuzzy Modelling

Juan Liu[1] · Jun Lv[2] · Hasan Dinçer[3] · Serhat Yüksel[3] · Hüsne Karakuş[3]

Received: 15 April 2020 / Accepted: 14 December 2020 / Published online: 7 January 2021

Abstract

In this study, it is aimed to determine the most suitable renewable energy alternatives that can be used in blockchain investments. In this context, firstly, a wide literature review is made and 6 different criteria that could have an impact on this decision are determined. The analysis process of the consists of two different stages. Firstly, the significance levels of these criteria are calculated with the help of interval type-2 (IT2F) decision making trial and evaluation laboratory (DEMATEL)-analytical hierarchy process (ANP) (DANP) method. According to the analysis results obtained, it has been determined that continuity in energy supply and legal conditions are the most important criteria. Hence, it is recommended that while choosing among renewable energy alternatives, it is necessary to pay attention to the legal regulations in the country. Another important point is that attention should be paid to this issue in renewable energy sources to be selected in order to have sustainable benefit from energy in blockchain technologies. On the other hand, in the second phase of the analysis process of the study, 5 different renewable energy alternatives are listed according to their suitability in blockchain technology. In this process, the IT2 fuzzy VIšeKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) approach has been taken into consideration. As a result, it is concluded that wind and solar energy are the most suitable energy alternatives for this technology. Considering the results obtained, it is understood that countries that use blockchain technology should pay particular attention to wind and solar investments. In this regard, companies that use wind and solar energy with individuals or institutions using blockchain technology should be in cooperation. Thanks to these renewable energy alternatives, excess energy consumption resulting from the use of blockchain technology can be achieved with environmentally friendly energy sources. In other words, it will be possible to minimize the carbon emission problem that occurs with the use of this technology.

1 Introduction

Blockchain technology has become popular in many areas, especially in recent years. In the most basic way, this technology means that data is recorded in blocks sequentially and these blocks are linked in chains. An updated copy of the database of each computer in the network of this system is located in this chain. In this way, blockchain technology is considered to be quite safe [1]. This is considered to be the main advantage of this technology. Due to this mentioned issue, this technology has started to be used in many different fields such as logistics, supply chain management, health, money transfer, insurance and foreign trade. Also, one of the most important advantages of this technology is that there is no need for an intermediary institution in the transactions. For example, money transfer can be done without a bank [2]. This situation both speeds up the users and reduces the cost of the transactions.

✉ Juan Liu
juanliulj@sina.com

✉ Serhat Yüksel
serhatyuksel@medipol.edu.tr

Jun Lv
jlv@dbm.ecnu.edu.cn

Hasan Dinçer
hdincer@medipol.edu.tr

Hüsne Karakuş
husne.karakus@st.medipol.edu.tr

1 School of Economic and Management, Shanghai Institute of Technology, Shanghai 201418, China

2 Faculty of Economics and Management, East China Normal University, Shanghai 200241, China

3 The School of Business, İstanbul Medipol University, İstanbul, Turkey

On the other hand, it is possible to mention some disadvantages of this system. One of the most important negative aspects of the mentioned system is that it is difficult to change the data. Therefore, it may be necessary to leave the chain when data needs to be changed. In addition, users have private keys in the blockchain system. This allows users to have their own cryptocurrencies. However, if these private keys are lost, it is not possible to obtain them again [3]. This situation causes users to lose their money. Another disadvantage of the blockchain system is that data mining application is inefficient. Data miners are trying to encrypt transactions while doing serious effort. However, there is considerable competition in this process and only one data miner is able to encrypt this process [4]. Therefore, the work of data miners who are not successful is wasted.

One of the major disadvantages of blockchain technologies is that the energy used is very high. In this technology, serious data mining studies are carried out for transfers to be valid. As a result of this study, the data miner who can provide the transfer is awarded [5]. Due to this mentioned issue, many people compete at the same time. In other words, due to the large number of computers competing in data mining at the same time, a large amount of energy consumption occurs. Bitcoin energy consumption was estimated to be around 52.06 terawatt hours per year in 2018 [6]. It is obvious that this value is much greated than the energy consumotion of many different countries. As can be understood from this situation, due to the use of blockchain technology, a significant amount of carbon is released into the atmosphere, which increases environmental pollution.

Since the high amount of energy used in blockchain technology both increases costs and damages the environment, some precautions must be taken for the solution of this problem. In this framework, emphasis is placed on the development of a new product that will consume less energy while data mining [7]. On the other hand, the issue of using renewable energies in the use of blockchain technology has become popular especially in recent years. Renewable energy alternatives can be defined as the type of energy obtained from natural sources. Wind, solar, biomass, geothermal and hydroelectric energy are among the most known renewable energy types [8]. These energies are considered to be cleaner compared to other energy types since they reduce air and water pollution. Considering that a lot of energy is consumed in blockchain technology, providing this energy from renewable energy sources will significantly decrease carbon emission.

The important issue in this process is to determine which type of renewable energy is more suitable for blockchain technology. There are many criteria to be considered in this process. For example, since energy is used frequently and intensively in this technology, the continuity of the energy to be obtained is also very important [9]. In addition to the mentioned issue, it is important that the location of the facility is suitable for renewable energy projects. In this context, the climatic conditions of the region also play an important role in the selection of renewable energy to be used. On the other hand, the legal conditions in the country should be taken into consideration in the selection of these energy alternatives. In addition, the cost of the energy to be obtained and the technological competence required for this type of energy are the criteria that determine which type of renewable energy to choose.

In this study, it is aimed to determine which renewable energy alternatives are suitable for the use of blockchain energy. In this process, firstly, 6 different criteria to be taken into consideration while determining this selection are determined as a result of the literature review. The analysis process of the study consists of two different stages. In the first stage, it is determined which of the 6 different criteria mentioned are more important for blockchain technology. In this process, IT2 DANP method is taken into account. Using DEMATEL methodology provides to make relationship analysis between the criteria. Additionally, with the help of ANP approach, inner dependency situation between the items can be taken into account. On the other hand, in the second stage of the analysis part of the study, by considering these weighted criteria, it will be determined which renewable energy source will be more suitable for blockchain technology. In this process, renewable energy alternatives will be ranked according to their importance by IT2 VIKOR method. The main advantages of this approach is flexibility and ease of use in the analysis process.

It is possible to talk about the difference of this study due to many different aspects. Firstly, in this study, it is tried to develop a solution proposal for the solution of excessive energy consumption problem, which is an important issue in the use of blockchain technologies. In this process, considering the alternative energy alternatives increases the originality of the study. Moreover, the list of criteria to be considered in order to reduce energy consumption in blockchain technology has been determined. This list is considered to guide blockchain investors. On the other hand, IT2 DANP and IT2 VIKOR methods have been taken into consideration for the first time in the literature for energy use in blockchain technologies. It was concluded that this was an application that made the study different from the others. Moreover, attitude of decision maker taken into consideration by changing the factors.

This study includes 5 different sections. First, information was given on topics such as blockchain technology and renewable energy use. The second part of the study includes a literature review. In this framework, studies examining the factors to be considered for the selection of energy types to be used in blockchain technology have been analyzed. In the third part of the study, detailed information about IT2 DANP and IT2 VIKOR methods are shared. On the other hand, in the fourth part of the study, the details of the analysis are given. In addition, in the last section, strategy suggestions based on the results of the analysis are presented.

2 Literature Review

Energy is significantly consumed in blockchain investments. This mentioned problem has been emphasized in the literature by many researchers. This technology has been criticized mainly on two issues, since it consumes energy in a very serious way. Primarily, this high amount of energy spent increases the cost of using this technology [10]. This increased cost will make the use of blockchain meaningless after a certain point [11]. In other words, the cost of energy in the use of this technology will start to be much higher than the potential income to be obtained after a certain point. In his study, Truby [12] focused on high energy consumption in blockchain technology. According to the results obtained, high energy consumption both increases the cost and seriously damages the environment. Plaza et al. [13] carried out a similar study on this subject. In this study, it is emphasized that the blockchain system is very costly due to excess energy consumption.

In addition to them, some studies in the literature are particularly focused on the environmental damage of blockchain technology. In these studies, the source of the high amount of energy generally used in this technology was questioned. The biggest criticism in the use of this technology is on the use of non-renewable energies [14, 15]. These energy types release high amounts of carbon dioxide into the atmosphere. This stated condition pollutes the air significantly [16]. As a result, important health problems arise. Many environmental organizations have emphasized the importance of this issue on different platforms. Imbault et al. [17] highlighted the harm caused by the high energy consumed in the blockchain system to the environment. Therefore, it has been argued that the use of renewable energy sources should be made compulsory. On the other hand, Park et al. [18] also focused on the environmental damage caused by high energy usage in blockchain technology. In order to solve this problem, he proposed the use of solar energy.

The studies on the high energy problem consumed by blockchain technology are summarized above. In order to solve this problem, a number of factors should be taken into consideration. However, there are a limited number of studies in the literature that suggest solutions to the high energy use problem of blockchain technology. Therefore, some studies on these factors will be explained independently from the blockchain technology literature. For example, the issue of continuity in energy stands out in this context. Since blockchain technology is a constantly used application, a sustainable energy source is needed [19, 20]. Therefore, it is essential to take this issue into account in solving the specified problem. Kumar et al. [21] emphasized the importance of a similar subject in his study on developing countries. Also, Al-Hamamre et al. [8] did a similar study for Jordan and underlined the issue of continuity in energy.

Another important feature in the literature to develop an alternative model to energy used in blockchain technology is physical conditions. In this context, a significant part of the studies emphasized that physical conditions should be considered in the choice of renewable energy [22]. For example, Bjørnebye et al. [23] conducted a study on renewable energy use in Norway. As a result, it was stated that great attention should be paid to the selection of location in order to minimize investment costs. Similarly, Diemuodeke et al. [24] conducted an investigation for Nigeria using the TOPSIS method and expressed the importance of the same issue. In addition to the physical conditions, some of the studies have also indicated the importance of the climate constraint. In this context, Kardooni et al. [25] carried out a study for renewable energy investments in Malaysia. In this study, in which the survey method was used, it was stated that the climate constraint should be taken into consideration while choosing the type of renewable energy. On the other hand, Owusu and Asumadu-Sarkodie [26] and Buonocore et al. [27] are other example studies investigating this issue in the literature.

Another important issue in the literature in this context is the importance of legal regulations. Governments may have limitations or incentives for renewable energy use. These issues will also affect the preference of renewable energy. Therefore, this issue should be considered in alternative energy sources to be preferred in blockchain technologies. Husein and Chung [28] conducted an investigation to increase renewable energy projects in South Korea. In this study, it is stated that legal regulations play a very important role in this regard. Also, Aquila et al. [29] and Zhao et al. [30] also examined different countries and reached similar results in their studies. On the other hand, cost issue has been examined by many researchers within this framework. In his study, Scholz [31] focused on the use of renewable energy in European countries and emphasized that cost is the most important issue. Also, Kuik et al. [32] and Hussain et al. [33] conducted an investigation on wind and solar energy. As a result, it is stated that low cost will increase competitiveness.

Another point that stands out in the renewable energy choice is whether the technological infrastructure is sufficient. Blockchain technology is preferred by people and institutions in many areas. Therefore, problems encountered in this application will decrease the effectiveness of the system and as a result, unhappiness will occur on the part of the user. Therefore, it is essential to pay attention to the technological infrastructure in the energy selection of this application. A renewable energy alternative to be selected even though the technology is not sufficient causes the system to not operate effectively. Holdmann et al. [34] also evaluated Alaska as an example in this regard. In this study, it is emphasized that renewable energy investment should not be made due to the poor technological infrastructure of Alaska. Chel and Kaushik [35] and Noailly and Shestalova [36] also discussed different countries and country groups and identified that the technological infrastructure is important.

According to the results of the literature review, blockchain technology has become very popular among researchers, especially in recent years. In these studies, energy consumption in blockchain technology is concentrated. Furthermore, basic energy consumption and negative effects on the environment were emphasized. As a result, it is found that there are few studies on how these problems can be solved. Therefore, it is believed that a new study that takes into account different factors to solve this problem will contribute significantly to the literature. In this study, renewable energy alternatives for energy consumption in blockchain investments are proposed. In this context, 6 different criteria are taken into account. On the other hand, IT2 DANP and IT2 VIKOR methods are also considered and it is aimed to provide uniqueness in a methodological sense. Hence, it is thought that this analysis will complete what is thought to be deficient in the literature.

3 Methodology

In this part of the study, theoretical information related to the methods used in the analysis process is given. In this context, firstly, IT2 fuzzy sets are explained. After that, the calculation process of IT2 fuzzy DANP methodology is identified. In the final part, IT2 fuzzy VIKOR methodology is defined as well.

3.1 IT2 Fuzzy Sets

A type 2 fuzzy set is represented by $\tilde{A}$. Additionally, $\mu_{\tilde{A}(x,u)}$ gives information about the type-2 membership function [37]. This situation is expressed in the Eq. (1).

$$\left\{\left((x,u),\mu_{\tilde{A}(x,u)}\right)|\forall_x \in X, \forall_u \in J_x \subseteq [0,1]\right\} \text{or } \tilde{A} = \int_{x\in X}\int_{u\in J_x} \mu_{\tilde{A}}(x,u)/(x,u)J_x \subseteq [0,1], \tag{1}$$

This membership function can take value between 0 and 1. On the other side, for discrete universes of discourse, $\int$ can be replaced with Σ. When the membership function equals to 1, the type-2 fuzzy set can be identified as the Eq. (2).

$$\tilde{A} = \int_{x\in X}\int_{u\in J_x} 1/(x,u)J_x \subseteq [0,1] \tag{2}$$

The upper and lower trapezoidal membership functions $(\tilde{A}_i^U, \tilde{A}_i^L)$ are explained in the Eq. (3). In this equation, $a_{i1}^U, .., a_{i4}^L$ explain the reference values of $\tilde{A}_i$. Additionally, $H_j\left(\tilde{A}_i^U\right)$ gives information about the membership values [38].

$$\tilde{A}_i = (\tilde{A}_i^U, \tilde{A}_i^L) = \left(\left(a_{i1}^U, a_{i2}^U, a_{i3}^U, a_{i4}^U; H_1(\tilde{A}_i^U), H_2(\tilde{A}_i^U)\right), \left(a_{i1}^L, a_{i2}^L, a_{i3}^L, a_{i4}^L; H_1(\tilde{A}_i^L), H_2(\tilde{A}_i^L)\right)\right) \tag{3}$$

Moreover, the details of the calculation process are given in the Eqs. (4)–(8).

$$\tilde{A}_1 \oplus \tilde{A}_2 = \left(\tilde{A}_1^U, \tilde{A}_1^L\right) \oplus \left(\tilde{A}_2^U, \tilde{A}_2^L\right) = \left(\left(a_{11}^U + a_{21}^U, a_{12}^U + a_{22}^U, a_{13}^U + a_{23}^U, a_{14}^U + a_{24}^U; min\left(H_1\left(\tilde{A}_1^U\right), H_1\left(\tilde{A}_2^U\right)\right), min\left(H_2\left(\tilde{A}_1^U\right), H_2\left(\tilde{A}_2^U\right)\right)\right), \left(a_{11}^L + a_{21}^L, a_{12}^L + a_{22}^L, a_{13}^L + a_{23}^L, a_{14}^L + a_{24}^L; min\left(H_1\left(\tilde{A}_1^L\right), H_1\left(\tilde{A}_2^L\right)\right), min\left(H_2\left(\tilde{A}_1^L\right), H_2\left(\tilde{A}_2^L\right)\right)\right)\right) \tag{4}$$

$$\tilde{A}_1 \ominus \tilde{A}_2 = \left(\tilde{A}_1^U, \tilde{A}_1^L\right) \ominus \left(\tilde{A}_2^U, \tilde{A}_2^L\right) = \left(\left(a_{11}^U - a_{24}^U, a_{12}^U - a_{23}^U, a_{13}^U - a_{22}^U, a_{14}^U - a_{21}^U; min\left(H_1\left(\tilde{A}_1^U\right), H_1\left(\tilde{A}_2^U\right)\right), min\left(H_2\left(\tilde{A}_1^U\right), H_2\left(\tilde{A}_2^U\right)\right)\right), \left(a_{11}^L - a_{24}^L, a_{12}^L - a_{23}^L, a_{13}^L - a_{22}^L, a_{14}^L - a_{21}^L; min\left(H_1\left(\tilde{A}_1^L\right), H_1\left(\tilde{A}_2^L\right)\right), min\left(H_2\left(\tilde{A}_1^L\right), H_2\left(\tilde{A}_2^L\right)\right)\right)\right) \tag{5}$$

$$\tilde{A}_1 \otimes \tilde{A}_2 = \left(\tilde{A}_1^U, \tilde{A}_1^L\right) \otimes \left(\tilde{A}_2^U, \tilde{A}_2^L\right) = \left(\left(a_{11}^U \times a_{21}^U, a_{12}^U \times a_{22}^U, a_{13}^U \times a_{23}^U, a_{14}^U \times a_{24}^U; min\left(H_1\left(\tilde{A}_1^U\right), H_1\left(\tilde{A}_2^U\right)\right), min\left(H_2\left(\tilde{A}_1^U\right), H_2\left(\tilde{A}_2^U\right)\right)\right), \left(a_{11}^L \times a_{21}^L, a_{12}^L \times a_{22}^L, a_{13}^L \times a_{23}^L, a_{14}^L \times a_{24}^L; min\left(H_1\left(\tilde{A}_1^L\right), H_1\left(\tilde{A}_2^L\right)\right), min\left(H_2\left(\tilde{A}_1^L\right), H_2\left(\tilde{A}_2^L\right)\right)\right)\right) \tag{6}$$

$$k\tilde{A}_1 = \left(k \times a_{11}^U, k \times a_{12}^U, k \times a_{13}^U, k \times a_{14}^U; H_1\left(\tilde{A}_1^U\right), H_2\left(\tilde{A}_1^U\right)\right), \left(k \times a_{11}^L, k \times a_{12}^L, k \times a_{13}^L, k \times a_{14}^L; H_1\left(\tilde{A}_1^L\right), H_2\left(\tilde{A}_1^L\right)\right) \tag{7}$$

$$\frac{\tilde{A}_1}{k} = \left(\frac{1}{k} \times a_{11}^U, \frac{1}{k} \times a_{12}^U, \frac{1}{k} \times a_{13}^U, \frac{1}{k} \times a_{14}^U; H_1\left(\tilde{A}_1^U\right), H_2\left(\tilde{A}_1^U\right)\right), \left(\frac{1}{k} \times a_{11}^L, \frac{1}{k} \times a_{12}^L, \frac{1}{k} \times a_{13}^L, \frac{1}{k} \times a_{14}^L; H_1\left(\tilde{A}_1^L\right), H_2\left(\tilde{A}_1^L\right)\right) \tag{8}$$

3.2 IT2 Fuzzy DANP

DANP methodology is the combination of both DEMATEL and ANP approach. Hence, it is obvious that this approach is considered to find the significance of different criteria. With this combination, it is aimed to get the advantages of both methods [39]. In this context, by using DEMATEL methodology, the causality analysis between the criteria can be performed. Additionally, impact relation map for the factors can be generated. In the first step of the calculation process, direct relation matrix is developed while considering the evaluations of the experts [40]. The second step is related to the generation of the initial influence matrix (A) that is given in the Eq. (9).

$$A = \begin{bmatrix} a_{11} & a_{21} & a_{13} & \cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & a_{n3} & \cdots & a_{nn} \end{bmatrix} \tag{9}$$

$$s = max\left[\begin{matrix} max \\ 1 \le i \le n \end{matrix} \sum_{J=1}^{n} a_{ij}, \begin{matrix} max \\ 1 \le j \le n \end{matrix} \sum_{i=1}^{n} a_{ij}\right] \tag{11}$$

Additionally, the total influence matrix (T) is developed in the fourth step by Eq. (12).

$$T = N + N^2 + N^2 + \ldots + N^h = N\left(I + N + N^2 + \ldots + N^{h-1}\right)(I - N)(I - N)^{-1}$$

$$T = N\left(I - N^h\right)(I - N)^{-1} = N(I - N)^{-1}, \text{when} \lim_{h \to \infty} N^h = [0]_{n \times n} \tag{12}$$

The fifth step is related to the defuzzification process. For this situation, Eq. (13) is taken into account. In this equation, α and β explain the maximum membership degrees of the lower membership function. On the other hand, the largest and the least possible value of the upper membership functions are given as u_U and l_U. Additionally, with respect to the upper membership function, the second and third parameters are defined as m_{1U} and m_{2U}. However, regarding the lower membership function, u_L gives information about the largest possible value, l_L explains the least possible value and the second and third parameters are identified as m_{1L} and m_{2L}.

$$Def_T = \frac{\frac{(u_U - l_U) + (\beta_U \times m_{1U} - l_U) + (\alpha_U \times m_{2U} - l_U)}{4} + l_U + \left[\frac{(u_L - l_L) + (\beta_L \times m_{1L} - l_L) + (\alpha_L \times m_{2L} - l_L)}{4} + l_L\right]}{2} \tag{13}$$

On the other side, the third step includes the normalization of this matrix. With the help of the Eqs. (10) and (11), the normalized direct effect matrix (N) is created.

$$N = A/s \tag{10}$$

The sixth step includes the creation of the influential network relation map with the Eqs. (14)–(16).

$$T = \left[t_{ij}\right]_{n \times n}, i, j = 1, 2, \ldots, n \tag{14}$$

$$r = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} = \left(r_i\right)_{n\times 1} = \left(r_1, \dots, r_i, \dots, r_n\right) \tag{15}$$

$$y = \left[\sum_{i=1}^{n} t_{ij}\right]'_{1\times n} = \left(y_j\right)'_{1\times n} = \left(y_1, \dots, y_i, \dots, y_n\right) \tag{16}$$

Additionally, the unweighted super-matrix (W) is created in the seventh step by using the Eqs. (17)–(21).

$$\begin{array}{ccc} & & \begin{array}{ccccc} D_1 & \cdots & D_j & \cdots & D_n \end{array} \\ & & \begin{array}{cccccccc} c_{11}c_{12} & \cdots & c_{1m1} & \cdots & c_{n1}c_{n2} & \cdots & c_{nm_n} \end{array} \\ T_c = & \begin{array}{cc} D_1 & \begin{array}{c} c_{11} \\ c_{12} \\ \vdots \\ c_{1m1} \end{array} \\ \vdots & \vdots \\ D_i & \\ \vdots & \\ D_n & \begin{array}{c} c_{n1} \\ \vdots \\ c_{nm_n} \end{array} \end{array} & \begin{bmatrix} T_c^{11} & \dots & T_c^{1j} & \dots & T_c^{1n} \\ \vdots & & \vdots & & \vdots \\ T_c^{i1} & \dots & T_c^{ij} & \dots & T_c^{in} \\ \vdots & & \vdots & & \vdots \\ T_c^{n1} & \dots & T_c^{nj} & \dots & T_c^{nn} \end{bmatrix} \end{array} \tag{17}$$

$$\begin{array}{ccc} & & \begin{array}{ccccc} D_1 & \cdots & D_j & \cdots & D_n \end{array} \\ & & \begin{array}{cccccccc} c_{11}c_{12} & \cdots & c_{1m1} & \cdots & c_{n1}c_{n2} & \cdots & c_{nm_n} \end{array} \\ T_c^{\beta} = & \begin{array}{cc} D_1 & \begin{array}{c} c_{11} \\ c_{12} \\ \vdots \\ c_{1m1} \end{array} \\ \vdots & \vdots \\ D_i & \\ \vdots & \\ D_n & \begin{array}{c} c_{n1} \\ \vdots \\ c_{nm_n} \end{array} \end{array} & \begin{bmatrix} T_c^{\beta 11} & \dots & T_c^{\beta 1j} & \dots & T_c^{\beta 1n} \\ \vdots & & \vdots & & \vdots \\ T_c^{\beta i1} & \dots & T_c^{\beta ij} & \dots & T_c^{\beta in} \\ \vdots & & \vdots & & \vdots \\ T_c^{\beta n1} & \dots & T_c^{\beta nj} & \dots & T_c^{\beta nn} \end{bmatrix} \end{array} \tag{18}$$

$$d_i^{11} = \sum_{j=1}^{m_1} t_{c^{ij}}^{11}, i = 1, 2, \dots, m_1 \tag{19}$$

$$T_c^{\beta 11} = \begin{bmatrix} t_{c^{11}}^{11} \big/ d_1^{11} & \cdots & t_{c^{1j}}^{11} \big/ d_1^{11} & \cdots & t_{c^{1m_1}}^{11} \big/ d_1^{11} \\ \vdots & & \vdots & & \vdots \\ t_{c^{i1}}^{11} \big/ d_i^{11} & \cdots & t_{c^{ij}}^{11} \big/ d_i^{11} & \cdots & t_{c^{im_1}}^{11} \big/ d_i^{11} \\ \vdots & & \vdots & & \vdots \\ t_{c^{m1}1}^{11} \big/ d_{m_1}^{11} & \cdots & t_{c^{m1j}}^{11} \big/ d_{m_1}^{11} & \cdots & t_{c^{m1m1}}^{11} \big/ d_{m_1}^{11} \end{bmatrix}$$

$$= \begin{bmatrix} t_{c^{11}}^{\beta 11} & \cdots & t_{c^{1j}}^{\beta 11} & \cdots & t_{c^{1m_1}}^{\beta 11} \\ \vdots & & \vdots & & \vdots \\ t_{c^{i1}}^{\beta 11} & \cdots & t_{c^{ij}}^{\beta 11} & \cdots & t_{c^{im_1}}^{\beta 11} \\ \vdots & & \vdots & & \vdots \\ t_{c^{m1}1}^{\beta 11} & \cdots & t_{c^{m1j}}^{\beta 11} & \cdots & t_{c^{m1m1}}^{\beta 11} \end{bmatrix} \tag{20}$$

$$\begin{array}{ccc} & & \begin{array}{ccccc} D_1 & \cdots & D_i & \cdots & D_n \end{array} \\ & & \begin{array}{cccccccc} c_{11} & c_{12} & \cdots & c_{1m1} & \cdots & c_{n1} & c_{n2} & \cdots & c_{nm_n} \end{array} \\ W = (T_c^{\beta})' = & \begin{array}{cc} D_1 & \begin{array}{c} c_{11} \\ c_{12} \\ \vdots \\ c_{1m1} \end{array} \\ \vdots & \vdots \\ D_j & \begin{array}{c} c_{n1} \\ c_{n2} \\ \vdots \end{array} \\ \vdots & \\ D_n & c_{nm_n} \end{array} & \begin{bmatrix} W_{11} & \dots & W_{i1} & \dots & W_{n1} \\ \vdots & & \vdots & & \vdots \\ W_{1j} & \dots & W_{ij} & \dots & W_{nj} \\ \vdots & & \vdots & & \vdots \\ W_{1n} & \dots & W_{in} & \dots & W_{nn} \end{bmatrix} \end{array} \tag{21}$$

The weighted super-matrix (W^{β}) is calculated in the eight step by using the Eq. (22). Moreover, Eq. (23) gives information about the normalization of the total influence matrix.

$$= \begin{bmatrix} t_{11}^{D_{11}} & \cdots & t_{1j}^{D_{1j}} & \cdots & t_{1m}^{D_{1m}} \\ \vdots & & \vdots & & \vdots \\ t_{i1}^{D_{i1}} & \cdots & t_{ij}^{D_{ij}} & \cdots & t_{im}^{D_{im}} \\ \vdots & & \vdots & & \vdots \\ t_{m1}^{D_{m1}} & \cdots & t_{mj}^{D_{mj}} & \cdots & t_{mm}^{D_{mm}} \end{bmatrix} \tag{22}$$

$$d_i = \sum_{j=1}^{m} t_{ij}^{D_{ij}}, i = 1, 2, \dots, m \tag{23}$$

T_D^{β} is calculated by normalizing T_D in Eq. (24).

$$= \begin{bmatrix} t_{11}^{D_{11}}/d_1 & \cdots & t_{1j}^{D_{1j}}/d_1 & \cdots & t_{1m}^{D_{1m}}/d_1 \\ \vdots & & \vdots & & \vdots \\ t_{i1}^{D_{i1}}/d_i & \cdots & t_{ij}^{D_{ij}}/d_i & \cdots & t_{im}^{D_{im}}/d_i \\ \vdots & & \vdots & & \vdots \\ t_{m1}^{D_{m1}}/d_m & \cdots & t_{mj}^{D_{mj}}/d_m & \cdots & t_{mm}^{D_{mm}}/d_m \end{bmatrix} = \begin{bmatrix} t_{11}^{\beta_{11}} & \cdots & t_{1j}^{\beta_{1j}} & \cdots & t_{1m}^{\beta_{1m}} \\ \vdots & & \vdots & & \vdots \\ t_{i1}^{\beta_{i1}} & \cdots & t_{ij}^{\beta_{ij}} & \cdots & t_{im}^{\beta_{im}} \\ \vdots & & \vdots & & \vdots \\ t_{m1}^{\beta_{m1}} & \cdots & t_{mj}^{\beta_{mj}} & \cdots & t_{mm}^{\beta_{mm}} \end{bmatrix} \quad (24)$$

Additionally, the weighted super-matrix W^β is calculated as in the Eq. (25).

$$= \begin{bmatrix} t_{11}^{\beta_{11}} \times W_{11} & \cdots & t_{i1}^{\beta_{i1}} \times W_{i1} & \cdots & t_{m1}^{\beta_{m1}} \times W_{n1} \\ \vdots & & \vdots & & \vdots \\ t_{1j}^{\beta_{1j}} \times W_{1j} & \cdots & t_{ij}^{\beta_{ij}} \times W_{ij} & \cdots & t_{mj}^{\beta_{mj}} \times W_{nj} \\ \vdots & & \vdots & & \vdots \\ t_{1m}^{\beta_{1m}} \times W_{1n} & \cdots & t_{im}^{\beta_{im}} \times W_{in} & \cdots & t_{mm}^{\beta_{mm}} \times W_{nn} \end{bmatrix} \quad (25)$$

In the final step, the limit super-matrix is defined.

3.3 IT2 Fuzzy VIKOR

VIKOR approach is a significant MCDM mode that aims to find the best alternative when there are many different opportunities. In the evaluation process, the best and worst values of fuzzy numbers with the maximum group utility are taken into account [41]. The main advantages of this approach is flexibility and ease of use in the analysis process. In the first step, decision matrix is created. For this situation, the evaluations of different decision makers are obtained. The decision matrix (X_{ij}) is demonstrated in the Eq. (26).

C1 C2 C3 … Cn

$$\text{Xij} = \begin{matrix} A_1 \\ A_2 \\ A_3 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} x_{11} & x_{12} & x_{13} & & \cdots & x_{1n} \\ x_{21} & x_{22} & x_{23} & & \cdots & x_{2n} \\ x_{31} & x_{32} & x_{33} & & \cdots & x_{3n} \\ \vdots & \vdots & \vdots & \ddots & & \vdots \\ x_{m1} & x_{m2} & x_{m3} & & \cdots & x_{mn} \end{bmatrix} \quad (26)$$

In this equation, A represents alternatives whereas C indicates different criteria. Additionally, xij explains the rating of this alternative regarding the criterion [42]. In this process, average value of different decision makers is considered as in the Eq. (27).

$$x_{ij} = \frac{1}{k}\left[\sum_{e=1}^{n} x_{ij}^{e}\right], i = 1, 2, \ldots, m \quad (27)$$

In the second step, the defuzzified values are computed. For this purpose, Eqs. (28)-(31) are taken into account. In these equations, $S_q\left(\overset{\sim j}{A_i}\right)$ demonstrates the standard deviation of the elements.

$$\begin{aligned} Def\left(x_{ij}\right) = Rank(\tilde{x}_{ij})_{m\times n} = M_1\left(\overset{\sim U}{A_i}\right) + M_1\left(\overset{\sim L}{A_i}\right) \\ + M_2\left(\overset{\sim U}{A_i}\right) + M_2\left(\overset{\sim L}{A_i}\right) + M_3\left(\overset{\sim U}{A_i}\right) \\ + M_3\left(\overset{\sim L}{A_i}\right) - \frac{1}{4}\left(S_1\left(\overset{\sim U}{A_i}\right) + S_1\left(\overset{\sim L}{A_i}\right)\right. \\ + S_2\left(\overset{\sim U}{A_i}\right) + S_2\left(\overset{\sim L}{A_i}\right) + S_3\left(\overset{\sim U}{A_i}\right) \\ \left. + S_3\left(\overset{\sim L}{A_i}\right) + S_4\left(\overset{\sim U}{A_i}\right) + S_4\left(\overset{\sim L}{A_i}\right)\right) \\ + H_1\left(\overset{\sim U}{A_i}\right) + H_1\left(\overset{\sim L}{A_i}\right) + H_2\left(\overset{\sim U}{A_i}\right) + H_2\left(\overset{\sim L}{A_i}\right) \end{aligned} \quad (28)$$

$$M_p\left(\tilde{A}_i^j\right) = \left(a_{ip}^j + a_{i(p+1)}^j\right)/2 \quad (29)$$

$$S_q\left(\tilde{A}_i^j\right) = \sqrt{\frac{1}{2}\sum_{k=q}^{q+1}\left(a_{ik}^j - \frac{1}{2}\sum_{k=q}^{q+1} a_{ik}^j\right)^2} \quad (30)$$

$$S_4\left(\tilde{A}_i^j\right) = \sqrt{\frac{1}{4}\sum_{k=1}^{4}\left(a_{ik}^j - \frac{1}{4}\sum_{k=1}^{4} a_{ik}^j\right)^2} \quad (31)$$

After that, the fuzzy best and worst values (fj^*, f_J^-) are calculated as in the Eq. (32).

$$f_J^* = \underset{i}{max}\, x_{ij} and f_J^- = \underset{i}{min}\, x_{ij} \quad (32)$$

Just then, the values of S_i, R_i and Q_i are computed by the formulas (33)–(35).

$$S_i = \sum_{i=1}^{n} w_j \frac{\left(\left|f_j^* - x_{ij}\right|\right)}{\left(\left|f_j^* - f_j^-\right|\right)} \quad (33)$$

$$R_i = maxj\left[w_j \frac{\left(\left|f_j^* - x_{ij}\right|\right)}{\left(\left|f_j^* - f_j^-\right|\right)}\right] \quad (34)$$

Table 1 The List of Criteria

Dimensions	Criteria	Supported literature
Environmental factors (D1)	Sustainable energy transfer (C1)	Fontes and Freires [16],Vidadili et al. [38]
	Physical conditions (C2)	Bjørnebye et al. [5],Diemuodeke et al. [11]
	Climatic constraint (C3)	Kardooni et al. [25],Asumadu-Sarkodie (2016)
Operational factors (D2)	Legal regulations (C4)	Husein and Chung [20],Aquila et al. [2]
	Energy supply cost (C5)	Kuik et al. [26],Hussain et al. [21]
	Technological infrastructure (C6)	Holdmann et al. [19],Chel and Kaushik [8]

Table 2 Linguistic and fuzzy scales for criteria and dimensions

Linguistic scales	Interval type 2 fuzzy numbers
Very very low (VVL)	((0,0.1,0.1,0.2;1,1), (0.05,0.1,0.1,0.15;0.9,0.9))
Very low (VL)	((0.1,0.2,0.2,0.35;1,1), (0.15,0.2,0.2,0.3;0.9,0.9))
Low (L)	((0.2,0.35,0.35,0.5;1,1), (0.25,0.35,0.35,0.45;0.9,0.9))
Medium (M)	((0.35,0.5,0.5,0.65;1,1), (0.4,0.5,0.5,0.6;0.9,0.9))
High (H)	((0.5,0.65,0.65,0.8;1,1), (0.55,0.65,0.65,0.75;0.9,0.9))
Very high (VH)	((0.65,0.8,0.8,0.9;1,1), (0.7,0.8,0.8,0.85;0.9,0.9))
Very very high (VVH)	((0.8,0.9,0.9,1;1,1), (0.85,0.9,0.9,0.95;0.9,0.9))

Table 3 Linguistic evaluations for dimensions

Dimensions	D1			D2		
	DM1	DM2	DM3	DM1	DM2	DM3
Environmental factors (D1)	–	–	–	H	VH	H
Operational factors (D2)	H	M	H	–	–	–

Table 4 Linguistic evaluations for criteria

	C1			C2			C3			C4			C5			C6		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
C1	–	–	–	M	H	M	H	M	VH	VVH	VH	M	M	VH	M	H	M	H
C2	L	M	M	–	–	–	VVL	VVL	VL	VL	VL	VVL	VVL	VVL	L	VL	VL	VVL
C3	VVL	M	VL	L	M	VL	–	–	–	L	L	VL	VVL	VL	VL	VL	VVL	L
C4	L	M	M	VL	M	VVL	L	L	M	–	–	–	L	L	VVL	L	L	VVL
C5	L	M	VL	M	VL	L	VVL	M	M	L	L	VL	–	–	–	L	L	VVL
C6	L	VVL	VL	VVL	VL	L	VVL	VL	L	L	VVL	M	L	VVL	M	–	–	–

$$\tilde{Q}_i = \frac{v\left(S_i - S^*\right)}{\left(S^- - S^*\right)} + (1 - v)\frac{\left(R_i - R^*\right)}{\left(R^- - R^*\right)} \tag{35}$$

In these equations, v shows the maximum group utility. In VIKOR methodology, two conditions should be satisfied for the acceptable advantage and stability. These issues are given on the Eqs. (36)–(37). In this process, $A^{(1)}$ is the best while $A^{(2)}$ is the second rank of the alternatives.

$$Q\left(A^{(2)}\right) - Q\left(A^{(1)}\right) \geq 1/(j-1) \tag{36}$$

$$Q\left(A^{(M)}\right) - Q\left(A^{(1)}\right) < \frac{1}{(j-1)} \tag{37}$$

4 An Analysis for Selection of Renewable Energy Alternatives for Green Blockchain Investments

This study aims to find the best renewable energy alternatives for blockchain technology to minimize environmental pollution. For this purpose, the analysis process has two different steps. First of all, selected criteria are defined and weighted with IT2 fuzzy DANP approach. In the second part, renewable energy alternatives are ranked by using IT2 fuzzy VIKOR.

4.1 Defining the Weights of Criteria

Firstly, the criteria, which can affect the selection of renewable energy alternatives for blockchain technology, are selected. In this context, the literature is reviewed in a detailed manner and 6 different criteria are defined. The details of these criteria are given on Table 1.

Table 1 indicates that sustainable energy is very important for blockchain technology. The main reason is that a continuous energy source is needed to perform transactions in blockchain technology. Physical conditions also play a very key role in renewable energy selection because blockchain technology can be used in different areas. Hence, the selected renewable energy alternative should be appropriate for these different locations. The climate is also essential for renewable energy alternatives so that it should be taken into account to decide the energy source of blockchain technology. On the other side, there may be some legal regulations which promoting or preventing renewable energy usage. This situation should also be analyzed in this decision process. Moreover, the cost of energy supply is also significant because in blockchain technology, there is very high amount of energy consumption. Another important indicator for this situation is the technological infrastructure because renewable energy projects need important engineering knowledge. IT2 fuzzy DANP method is used for weighting the dimensions and criteria of green blockchain investments. The decision makers provide the linguistic scores for the criteria and dimensions by using the scales in Table 2.

The linguistic evaluations of criteria and dimensions from the experts are given in Tables 3 and4.

The computation process of IT2F DANP is employed and the results are presented in the Appendix Tables 9, 10, 11, 12, 13, 14, 15 and 16 respectively. The weights of the criteria are given on the limit supermatrix as in Table 5.

According to the analysis results made with IT2 Fuzzy DANP method, it has been identified that legal regulations (C4) have the highest importance on the effectiveness of energy use in blockchain technologies. On the other side, it is also determined that sustainable energy transfer (C1) has a significant impact on energy use in blockchain technologies. Another important result is that physical conditions (C2) and climatic constraint (C3) have the lowest weights.

4.2 Selecting the Appropriate Renewable Energy Alternatives for Blockchain Investments

In the second part of the analysis, renewable energy alternatives are ranked by using IT2 Fuzzy VIKOR methodology. For this situation, 5 different renewable energy alternatives are taken into account that are wind (A1), solar (A2), biomass (A3), geothermal (A4) and hydroelectric (A5). All of these renewable energies have advantages and disadvantages. With respect to the wind energy, installation areas of wind power plants take up less space than others. Also, since wind can be both day and night, there is no shortage of time in the production of wind energy. However, the initial setup costs of wind power plants are higher than other renewable energy sources. In addition to the wind energy, solar energy has some advantages as well. For instance, solar panels do

Table 6 Linguistic and fuzzy scales for alternatives

Linguistic scales	Interval type 2 fuzzy numbers
Very low (VL)	((0,0,0,0.1;1,1), (0,0,0,0.05;0.9,0.9))
Low (L)	((0,0.1,0.1,0.3;1,1), (0.05,0.1,0.1,0.2;0.9,0.9))
Medium low (ML)	((0.1,0.3,0.3,0.5;1,1), (0.2,0.3,0.3,0.4;0.9,0.9))
Medium (M)	((0.3,0.5,0.5,0.7;1,1), (0.4,0.5,0.5,0.6;0.9,0.9))
Medium high (MH)	((0.5,0.7,0.7,0.9;1,1), (0.6,0.7,0.7,0.8;0.9,0.9))
High (H)	((0.7,0.9,0.9,1;1,1), (0.8,0.9,0.9,0.95;0.9,0.9))
Very high (VH)	((0.9,1,1,1;1,1), (0.95,1,1,1;0.9,0.9))

Table 5 Limit supermatrix

	C1	C2	C3	C4	C5	C6
C1	0.170	0.170	0.170	0.170	0.170	0.170
C2	0.158	0.158	0.158	0.158	0.158	0.158
C3	0.158	0.158	0.158	0.158	0.158	0.158
C4	0.189	0.189	0.189	0.189	0.189	0.189
C5	0.164	0.164	0.164	0.164	0.164	0.164
C6	0.162	0.162	0.162	0.162	0.162	0.162

Table 7 Linguistic evaluations for alternatives

	A1 (Wind)			A2 (Solar)			A3 (Biomass)			A4 (Geothermal)			A5 (Hydroelectric)		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
C1	VH	VH	H	H	H	H	H	H	M	VH	H	H	H	H	H
C2	VH	VH	H	VH	H	VH	M	M	MH	M	MH	M	VH	VH	H
C3	VH	H	H	VH	VH	H	VH	M	H	M	MH	MH	H	MH	MH
C4	VH	VH	H	H	H	VH	H	M	MH	VH	VH	H	H	H	MH
C5	VH	VH	H	VH	VH	H	MH	M	MH	MH	M	MH	VH	VH	H
C6	H	MH	MH	MH	H	MH	M	M	M	MH	MH	M	VH	VH	H

Table 8 Ranking Results of Alternatives

Alternatives	Si	Ri	Qi	Ranking
Wind (A1)	0.088	0.070	0.000	1
Solar (A2)	0.157	0.070	0.042	2
Biomass (A3)	0.922	0.189	1.000	5
Geothermal (A4)	0.626	0.164	0.718	4
Hydroelectric (A5)	0.254	0.097	0.211	3

not have a significant cost apart from installation financing. In addition, solar energy can be used more easily and spread faster compared to other renewable energy sources. Nevertheless, the solar radiation is low in winter and at night. Therefore, the desired efficiency from solar energy may not be achieved.

Moreover, storage of biomass energy is much easier than other types of energy. However, this energy type also has some disadvantages. As an example, large areas are needed to utilize biomass energy. In addition, since this energy is obtained from living organisms, it takes a long time to cultivate, grow and transfer it to nature. Moreover, the biggest advantage of geothermal energy is that it is not affected by climatic conditions. Furthermore, these facilities take up little space as they are underground. On the other hand, secondary liquids used to decompose harmful substances in steam and liquid are very costly. Regarding hydroelectric energy, the costs arising in the installation of the facility are less compared to other renewable energy sources. This situation can be regarded as one of the most important advantages of this type of energy. However, the negative impact of the ecological order in the region where the power plant is built is one of the prominent disadvantages of hydroelectric energy. IT2 FVIKOR is used for measuring the performance of renewable energy alternatives. For this situation, the experts select their evaluations by considering the scores in Table 6.

The linguistic evaluations for decision matrix are given in Table 7.

The calculation details of IT2 FVIKOR are provided in the Appendix part Tables 17 and 18. The ranking results of the renewable energy alternatives are given on Table 8.

Table 8 indicates that wind (A1) and solar energy (A2) are the most appropriate renewable energy alternatives for the blockchain technology. On the other side, biomass (A3) and geothermal (A4) take on the last place. This explains that they are not suitable for the blockchain technology.

5 Discussion and Conclusion

Especially in recent years, blockchain technology became very popular in different areas. However, the most important disadvantage of blockchain investments is that it consumes a lot of energy. This situation creates problems both economically and environmentally. The main reason for this is that excessive energy causes carbon emission in the atmosphere. The purpose of this study is to identify renewable energy alternatives that should be used for blockchain investments. Therefore, the most important hypothesis of this study is that this problem in blockchain technologies can be solved thanks to environmentally friendly renewable energy alternatives. For this purpose, firstly, the literature is examined in detail and 6 different criteria, which are thought to be effective on the effectiveness of blockchain technologies, are identified. An analysis is made with the IT2 Fuzzy DANP method to determine which of the mentioned criteria are more important. In the second part of the analysis process of the study, 5 different renewable energy alternatives (solar, wind, geothermal, hydroelectric, biomass) are chosen as alternatives. In order to determine which of these renewable energy alternatives are suitable for blockchain technology, an investigation is made with IT2 Fuzzy VIKOR approach.

According to the analysis results made with IT2 Fuzzy DANP method, it has been determined that legal regulations have the highest importance on the effectiveness of energy use in blockchain technologies. As can be understood from here, the state needs to make some legal arrangements both to create a safe area for investors and to increase the effectiveness of blockchain technology. This should definitely be done for excess energy consumption in these technologies. In other words, the state must first control the energy spent on blockchain technology. For example, since excess energy consumption causes environmental pollution, the state should prevent this pollution with legal regulations. In this case, it will contribute to the use of renewable energy alternatives in the use of blockchain technology. On the other hand, the laws of the state will be decisive in the type of renewable energy to be chosen. In this context, while making this choice, attention should be paid to the details of legal regulations in the country. There are some obstacles in the use of some renewable energy sources in the details of these regulations.

The importance of this issue has been emphasized by many studies in the literature. As an example, Husein and Chung [28] conducted a review on renewable energy use in South Korea. In this study, microgrid planning model has been taken into consideration. As a result, it is stated that while choosing among renewable energy alternatives, it is necessary to pay attention to the legal regulations in the country. In this context, it is concluded that government incentives such as tax breaks have an important role in these elections. In parallel with this study, Aquila et al. [29] focused on renewable energy investments in Brazil. In this study, it has been determined that there are some obstacles to the use of renewable energy in this country. It is stated that this situation has an important role in the selection of renewable energy alternatives. On the other hand, Zhao et al. [30] did a similar study for China. In this study, it has been determined that tax incentives are very important in the selection of renewable energy alternatives.

Another result obtained from the analysis is that sustainable energy transfer has an impact on energy use in blockchain technologies. A lot of energy is consumed in blockchain technology. Therefore, the energy used to increase the effectiveness of blockchain technology must be continuous. Attention should be paid to this issue in renewable energy sources to be selected in order to have sustainable benefit from energy in blockchain technologies. Accordingly, the renewable energy source suitable for use in blockchain technology should be determined. It is important to take the necessary actions to increase the investments in this determined energy source. Otherwise, there may be some problems in the implementation of blockchain technology. This may result in financial losses in many different areas.

Similarly, the importance of this issue has been stated in many different studies in the literature. For example, Kumar et al. [21] emphasized the importance of continuity in energy. As a result, it was determined that developing countries should invest in renewable energy in order to ensure continuity in energy. Vidadili et al. [20] carried out a similar study for Azerbaijan. It has been determined that Azerbaijan needs to invest in renewable energy sources both to meet the increasing energy demand and to maintain renewable energy sources. In addition, Fontes and Freires [19] stated in their study that since blockchain technology is an application that is constantly used, a continuous energy source is needed. Al-Hamamre et al. [8] did a similar study for Jordan and underlined that the issue of continuity in energy is important.

According to the results of the analysis made with IT2 Fuzzy VIKOR method, it is determined that one of the renewable energy alternatives, solar energy is suitable for blockchain technology. Accordingly, efforts should be made to apply solar energy to blockchain technology. For this, it is necessary to cooperate with companies producing solar energy and individual or corporate investors using blockchain technology. In addition to the aforementioned issue, individual or corporate investors benefiting from blockchain technology should be given training on the use of solar energy. On the other hand, it is important to increase technological infrastructure investments in order to make solar power generation systems applicable to blockchain technology. Solar panels are installed in large areas to take advantage of energy density. This is a problem for individual or corporate investors using blockchain technology. Therefore, it would be appropriate to reduce the solar panels. In order to achieve the stated purpose, engineering studies on the subject should be increased.

Another result of the analysis is that wind energy is suitable for blockchain technology. Thanks to the electrical energy produced by wind energy, the energy needs of individuals or institutions using blockchain technology can be met. Therefore, wind power generation systems must be suitable for blockchain technology. In this regard, companies that use wind energy and individuals or institutions using blockchain technology should be in cooperation. Individuals or institutions using blockchain technology should be given training on wind power generation. Wind power plants are installed in an area away from the network as they are noisy. For this reason, individuals or institutions using blockchain technology should aim to benefit only from the energy produced by these plants. For this, companies producing wind energy should carry out this transfer by considering the area of institutional investors who use blockchain technology while transmitting electricity. Institutional investors who use this energy should develop a system to store the remaining energy.

In this study, renewable energy sources are proposed for blockchain technologies that have a lot of energy consumption. As a result of the analysis, the most suitable type of renewable energy for this technology has been determined.

Therefore, it is aimed to prevent environmental pollution caused by excessive energy consumption. One of the most important limitations in this study is to consider only 5 types of renewable energy. Other types of renewable energy, such as wave energy, can also be considered in new studies. On the other hand, another limitation of the study is related to the methodology. In this study, DANP and VIKOR, which are MCDM methods, are taken into consideration. Other methods such as AHP, TOPSIS and MOORA can also be used in new studies. In this way, it will be possible to make a comparative analysis. In addition, it is thought that addressing more technical studies on the use of renewable energy sources in blockchain technologies will have an important contribution to the literature.

Acknowledgements This work was sponsored in part by Shanghai Pujiang Program (Grant No. 18PJC031).

Compliance with Ethical Standards

Conflict of interest There is no conflict of interest for the authors.

Appendix A

See Tables 9, 10, 11, 12, 13, 14, 15, 16, 17 and 18.

Table 9 Direct relation matrix for dimensions

	D1	D2
D1	((0,0,0,0;1,1), (0,0,0,0;0.90,0.90))	((0.55,0.70,0.70,0.83;1,1), (0.60,0.70,0.70,0.78;0.90,0.90))
D2	((0.45,0.60,0.60,0.75;1,1), (0.50,0.60,0.60,0.70;0.90,0.90))	((0,0,0,0;1,1), (0,0,0,0;0.90,0.90))

Table 10 Normalized direct relation matrix for dimensions

	D1	D2
D1	((0,0,0,0;1,1), (0,0,0,0;0.90,0.90))	((0.66,0.84,0.84,1.00;1,1), (0.72,0.84,0.84,0.94;0.90,0.90))
D2	((0.54,0.72,0.72,0.90;1,1), (0.60,0.72,0.72,0.84;0.90,0.90))	((0,0,0,0;1,1), (0,0,0,0;0.90,0.90))

Table 11 Total relation matrix for dimensions

	D1	D2
D1	((0.55,1.53,1.53,9.00;1,1), (0.76,1.53,1.53,3.75;0.90,0.90))	((1.03,2.13,2.13,10.00;1,1), (1.27,2.13,2.13,4.47;0.90,0.90))
D2	((0.84,1.82,1.82,9.00;1,1), (1.06,1.82,1.82,3.99;0.90,0.90))	((0.55,1.53,1.53,9.00;1,1), (0.76,1.53,1.53,3.75;0.90,0.90))

Table 12 Defuzzified total relation matrix for dimensions

	D1	D2
D1	2.49	3.10
D2	2.73	2.49

Table 13 Unweighted supermatrix for dimensions

	D1	D2
D1	0.44	0.52
D2	0.56	0.48

Table 14 Defuzzified total relation matrix for criteria

	C1	C2	C3	C4	C5	C6
C1	0.13	0.25	0.27	0.29	0.25	0.25
C2	0.16	0.06	0.10	0.11	0.10	0.10
C3	0.13	0.15	0.06	0.14	0.10	0.11
C4	0.18	0.14	0.17	0.08	0.13	0.13
C5	0.16	0.16	0.16	0.15	0.07	0.13
C6	0.12	0.11	0.12	0.14	0.13	0.05

Table 15 Unweighted supermatrix for criteria

	C1	C2	C3	C4	C5	C6
C1	0.20	0.51	0.38	0.36	0.33	0.33
C2	0.38	0.19	0.43	0.29	0.33	0.33
C3	0.42	0.30	0.19	0.35	0.34	0.33
C4	0.37	0.35	0.40	0.24	0.43	0.43
C5	0.31	0.33	0.29	0.38	0.19	0.40
C6	0.31	0.32	0.32	0.38	0.38	0.17

Table 16 Weighted supermatrix

	C1	C2	C3	C4	C5	C6
C1	0.09	0.23	0.17	0.19	0.17	0.17
C2	0.17	0.08	0.19	0.15	0.17	0.17
C3	0.19	0.13	0.08	0.18	0.18	0.18
C4	0.21	0.20	0.22	0.11	0.21	0.20
C5	0.17	0.18	0.16	0.18	0.09	0.19
C6	0.17	0.18	0.18	0.18	0.18	0.08

Table 17 Decision matrix

	A1	A2	A3	A4	A5
C1	((0.83,0.97,0.97,1.00;1,1), (0.90,0.97,0.97,0.98;0.90,0.90))	((0.70,0.90,0.90,1.00;1,1), (0.80,0.90,0.90,0.95;0.90,0.90))	((0.57,0.77,0.77,0.93;1,1), (0.67,0.77,0.77,0.85;0.90,0.90))	((0.77,0.93,0.93,1.00;1,1), (0.85,0.93,0.93,0.97;0.90,0.90))	((0.70,0.90,0.90,1.00;1,1), (0.80,0.90,0.90,0.95;0.90,0.90))
C2	((0.83,0.97,0.97,1.00;1,1), (0.90,0.97,0.97,0.98;0.90,0.90))	((0.83,0.97,0.97,1.00;1,1), (0.90,0.97,0.97,0.98;0.90,0.90))	((0.37,0.57,0.57,0.77;1,1), (0.47,0.57,0.57,0.67;0.90,0.90))	((0.37,0.57,0.57,0.77;1,1), (0.47,0.57,0.57,0.67;0.90,0.90))	((0.83,0.97,0.97,1.00;1,1), (0.90,0.97,0.97,0.98;0.90,0.90))
C3	((0.77,0.93,0.93,1.00;1,1), (0.85,0.93,0.93,0.97;0.90,0.90))	((0.83,0.97,0.97,1.00;1,1), (0.90,0.97,0.97,0.98;0.90,0.90))	((0.63,0.80,0.80,0.90;1,1), (0.72,0.80,0.80,0.85;0.90,0.90))	((0.43,0.63,0.63,0.83;1,1), (0.53,0.63,0.63,0.73;0.90,0.90))	((0.57,0.77,0.77,0.93;1,1), (0.67,0.77,0.77,0.85;0.90,0.90))
C4	((0.83,0.97,0.97,1.00;1,1), (0.90,0.97,0.97,0.98;0.90,0.90))	((0.77,0.93,0.93,1.00;1,1), (0.85,0.93,0.93,0.97;0.90,0.90))	((0.50,0.70,0.70,0.87;1,1), (0.60,0.70,0.70,0.78;0.90,0.90))	((0.83,0.97,0.97,1.00;1,1), (0.90,0.97,0.97,0.98;0.90,0.90))	((0.63,0.80,0.80,0.90;1,1), (0.72,0.80,0.80,0.85;0.90,0.90))
C5	((0.83,0.97,0.97,1.00;1,1), (0.90,0.97,0.97,0.98;0.90,0.90))	((0.83,0.97,0.97,1.00;1,1), (0.90,0.97,0.97,0.98;0.90,0.90))	((0.43,0.63,0.63,0.83;1,1), (0.53,0.63,0.63,0.73;0.90,0.90))	((0.43,0.63,0.63,0.83;1,1), (0.53,0.63,0.63,0.73;0.90,0.90))	((0.83,0.97,0.97,1.00;1,1), (0.90,0.97,0.97,0.98;0.90,0.90))
C6	((0.57,0.77,0.77,0.93;1,1), (0.67,0.77,0.77,0.85;0.90,0.90))	((0.57,0.77,0.77,0.93;1,1), (0.67,0.77,0.77,0.85;0.90,0.90))	((0.30,0.50,0.50,0.70;1,1), (0.40,0.50,0.50,0.60;0.90,0.90))	((0.43,0.63,0.63,0.83;1,1), (0.53,0.63,0.63,0.73;0.90,0.90))	((0.83,0.97,0.97,1.00;1,1), (0.90,0.97,0.97,0.98;0.90,0.90))

Table 18 Defuzzified decision matrix

	A1	A2	A3	A4	A5
C1	9.47	9.03	8.24	9.25	9.03
C2	9.47	9.47	7.07	7.07	9.47
C3	9.25	9.47	8.46	7.47	8.26
C4	9.47	9.25	7.86	9.47	8.64
C5	9.47	9.47	7.47	7.47	9.47
C6	8.26	8.26	6.67	7.47	9.47

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