Which renewable energy consumption is more efficient by fuzzy EDAS method based on PESTLE dimensions?

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Abstract

The facilities that energy delivers to social life and economic activities render it indispensable. Hence, it is equally critical that the energy cycle must have a sustainable structure. Therefore, it is an indisputable fact that developing and performing correct and consistent energy policies is vitally necessary. Energy consumption planning includes a continuous process to reassess existing and potential alternative energy approaches and strategies. The public and private decision-makers in charge of planning and managing energy consumption policies must adapt their strategies to novel and superior alternative resources according to sustainability and efficiency criteria. In this paper, the fuzzy EDAS method is used to address the best renewable energy consumption by taking political, economic, social, technological, legal, and environmental (PESTLE) dimensions into account. The analysis of the paper indicates the most efficient renewable energy consumption is sourced by geothermal, solar, wind, hydroelectricity, and biomass, respectively. By further investigation, it is concluded that the most optimum renewable energy consumption alternatives based on PESTLE dimensions are geothermal and solar energies.

Keywords Renewable energy consumption · Energy planning · Analytical hierarchy process · PESTLE · Fuzzy-EDAS

Introduction

Energy resources are an important part of the development of countries and it is important in the environment, social, and political aspects and now it has become one of the most highlighted and discussed global issues (Bhattacharya et al. 2016; World Energy Council 2010; Dornan and Shah 2016; Ozturk 2017; Usman et al. 2020). With the advancement of technology and the emergence of industrialization in the

world, the need for energy sources has been increased with the passage of time. But the energy reserves and the number of reserves available in very country differ because the energy sources depend on the topography of the country. And due to this unequal distribution of energy sources, some major environmental concerns have arisen, some serious political conflicts have been raised between different countries, and also the unavoidable dependency of the economy and the social issues (Jenkins et al. 2016). These conflicting situations allow

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people to find alternative sources of energy for future consumption. But these current and future conflicts of the governments and the environment will lead to a negative consequence and the countries will try to move towards the energy sources that are renewable. To restore and utilize the energy in this aspect, the energy has become an answer for the planning of the sustainable energy. (Begic and Afgan 2007; Lund 2009; Asumadu-Sarkodie 2016)

This research paper has several unique contributions to the energy literature in different aspects. First of all, the paper is providing a practical model for the selection of renewable energy sources on a broader scale by means of PESTLE analysis. Besides this novel approach, this study also employs the fuzzy EDAS method for the first time in the context of energy optimization criteria. Combining multi-criteria inventory classification and PESTLE technique, this paper satisfies the lack of tools faced by decision makers and stakeholders in the selection of the best renewable energy sources. This research paper, reinforced by the power of mathematics and the macro-environmental perspectives, provides a distinctive contribution and a solid framework on energy selection procedure which is vital for sustainability. The usefulness of a tool also requires a high level of flexibility under various conditions. From this point of view, the study shows an adaptive nature depending on the PESTLE conditions of any region concerned. Apart from the literature, we employ an analytical hierarchy process (APH) to see the best energy resources by taking political, economic, social, technological, legal, and environmental dimensions into account.

Sustainable development is also known as the consistent development which means that without the loss of the future generations we can meet the needs of the present generation (Ouedraogo 2017). In other words, sustainable development is to maintain a balance between the growth of the economy and to preserve the environment (Gaffney 2014). By balancing both the things, we can achieve sustainable development. But when we discuss about the sustainable development and the preservation of the environment, energy is the main factor in this discussion.

To meet the needs and the requirements of the people of the country in a considerable manner is called Energy Planning (Ulutas 2005; Hiremath et al. 2007; Ozgur 2008; Demirtas 2014). But energy planning decision has other aspects as well, as it involves the process in which balancing of the social and economic aspects and the preservation of the environment and the use of the technology over the space and the time is an important factor. This balance is necessary for the survival of nature. It was observed and estimated that the consumption of the electricity in the world will reach to an extent by the year 2020 to 24,400 billion kWh. And if we want to select the important parameters of the energy sources and its consumption, the main aspects to look upon these resources are the economy and the environment, since it has been seen that 85% of the emission of the

greenhouse gases are the result of the energy sources of today.

The renewable energy sources that are clean and are cost-effective have become a priority but none of these energy sources alternatively can meet the demands and requirements of the world at its own (Edenhofer et al. 2011). So for the proper consumption of the resources, energy policies should be developed and this problem can be seen as a multiple criteria decision-making (MCDM) problem and this is a time-consuming and a strategic process (Pohekar and Ramachandran 2004; Cereska 2016; Aziz 2016).

In the decision-making process, different factors are considered as the qualitative and the quantitative factors (Saaty 1980; Samouilidis and Mitropoulos 1982; Chang 1992, 1996; Cox et al. 2000; Soma 2003; Kahraman et al. 2004; Wang et al. 2006; Kone and Buke 2007). As we find difficulty and complexity while making any decision, this difficulty has become a major problem for the decision-makers while they take decisions to find an alternative solution for the problems of fulfilling the needs of the present generation. But when the energy evaluation process is conducted, it must deal with the difficult characteristics and attributes to define and also the components of nature including both the factors qualitative and quantitative (Albayrak and Erensal 2004). These evaluations should overcome the problems related to the economy, environment, and technology because these things are not identifiable easily and also has to overcome the socio-economic problems that has affected various groups of the interests and the stakeholders that are needed. To view and solve the difficulties, the AHP method is used to define the difficult assessment procedures (Aziz 2016).

Some criteria in the MCDM are set for the evaluation of the energy issues. These criteria are the economical investment cost, operation, and maintenance cost, fuel cost, net present value, payback period, service life, equivalent annual cost, etc.); technical (efficiency, primary energy ratio, safety, reliability, maturity, etc.); environmental CO₂ emission, NO_x emission, SO₂ emission, particles emission, land use, noise, etc.); and the social (social acceptability, job creation, social benefits, etc.) (Kaya and Kahraman 2010; Kumar et al. 2017).

For the consistent and sustainable development of the country, at both the global and the national levels, different alternatives including the long term and the short term that enable increasing the sources of the energy variations and also decrease the dependence of the country on the foreign supply is a factor that must be considered. The renewable sources of the country must be evaluated and observed in a very distinctive and sensitive way and these resources must be evaluated to promote the environment. The main objective and aim of this study is to define the best energy resources for the country for the planning of sustainable energy. To achieve our goals and aims, we used a methodology called the APH to make criteria for the selection of the alternative sources of energy (Cinelli et al. 2014).

Energy phenomenon is directly or indirectly associated with every aspect of human life. In this regard, in this paper, the renewable energy selection criteria are investigated taking into account PESTLE dimensions. For instance, the electricity consumption level is one of the important antecedents of economic growth, and FDI (foreign direct investment) inflows into the energy field boost low-income and emerging economies' development (Chandio et al. 2020). Besides the consumption of electricity, CO₂ emission (carbon-dioxide) and renewable energy production have a positive influence on GDP (gross domestic product) (Rehman et al. 2019). Electric power intensity results in urbanization and it creates water-based polluting emissions. As a result of this cycle, various levels of regional growth have been observed depending on the different regional scales (Ahmad et al. 2020). All these empirical investigations reveal the strategic role of energy as a triggering tool of the social and economic prosperity of countries.

This article is further categorized into four main sections. In the first section, we will generate a literature review regarding sustainable and renewable energy sources. In the second section, the methodology of the research is discussed in detail. In the third section, analysis of the data collected during the field study will be presented along with the results discussed in relation to the literature review. In the last section, the strengths and the weakness of the research and the implications and future recommendations will be given.

Literature review

PESTLE analysis

PESTLE (political, economic, social, technological, legal, and environmental) analysis allows comprehensive investigation of the problems that most influence the development of business activities or projects that they need to promote (Espinoza et al. 2019). This strategic planning foundation goes beyond the SWOT (strengths, weaknesses, opportunities, and threats) analysis and provides a broad perspective including social and environmental dimensions that are highly valued by today's societies and non-profit organizations. Therefore, the renewable energy industry also requires macro-level environmental scanning (Grant 2016) more than other sectors to be consistent with its nature. In this context, the multi-dimensional PESTLE technique employs a robust conceptual framework to secure the sustainable development of renewable energy planning (Koshesh and Jafari 2019; Zalengera et al. 2014)

Energy and sustainability

According to Bishop et al. (2010), the chief purpose of sustainable energy systems is to provide cost-effective services along with improving the quality of life. These energy

resources are supposed to be very potent as well. The term sustainability is basically an environment-friendly and cost-effective way to provide resources which can be backed up by the institutional structure of the country. A lot of factors such as cost-effectiveness, industrial and commercial profits, improving the quality of life overall, and eliminating poverty are taken into consideration when thinking about the sustainable resources and their services (WCED 1987; Owusu and Asumadu-Sarkodie 2016; IAEA et al. 2005; Houck and Rickerson 2009). This is known as assessing the most proper renewable energy alternative regarding sustainable energy development. While taking all these into account, a very key factor should be focused upon and that is providing the resources for the overall well-being of the population and not over-consume the resources. They should be planned and used wisely (Ellabban et al. 2014). If this is taken care of along with easy and diverse access to the energy resources, the system will be successfully sustainable.

Sustainability indicators for energy

The systems of energies are groundworks for supplying all the chief indicators to build a sustainable environment (Moldan et al. 2012). There are a number of factors that have to be considered while evaluating the energy use and a correlation between sustainability and human activities is seen. Once the indicators are sorted out, other areas can be looked into. These include the environment, social, technical, and financial components (Ellabban et al. 2014). By putting all these together, monitoring, design, and development are worked upon. These indicators play an essential role in giving us a whole picture of how each and everything are interlinked. A system has sub-systems and they all interact with each other. Since this is a big network, every minute detail of energy use and its after-effects are evaluated and presented by the help of these indicators, be it short term or long term (International Atomic Energy Agency (IAEA) 2005). Such a complex structure has to be well-linked and translated because without this, nothing will be of use and there will be stunted growth of the sustainable environment system (Evans et al. 2009). The work altogether converges to translate energy-related problems and for encouraging institutional dialogue.

An abundance of investigations and studies have been carried out regarding the sustainability indicators (see Table 1). They play a tremendous part in the evaluation of development strategies and planning ahead. After so much work, it was concluded that the energy sources have been categorized into six PESTLE dimensions (Zalengera et al. 2014). A number of researchers put together their work towards the cause. Despite all that literature, very scarce proof comprising mathematical models for energy sustainability is there. Here are a few examples of what each researcher concluded. Zhou et al. (2006) highlighted that the multifold criteria decision making and

Table 1 Assessment criteria for sustainable energy planning

Dimensions	Criteria
Political	Governmental support Political stability Corruption
Economic	Investment cost Operation and maintenance cost Service life Payback period
Social	Social benefits Social acceptability Support for renewable energy
Technological	Energy production capacity Technological maturity Reliability Safety
Legal	Environmental regulations Compliance with EU laws Antitrust law
Environmental	Weather and climate Pressures from NGOs Natural disaster risks

energy-associated environmental studies have arisen since 1995. On another occasion, numerical values were given to specific energy systems in accordance with the indicators and evaluated these under weighting conditions. A comparative study was done by Burton and Hubacek (2007) where their main focus was the cost difference in the small-scale energy technology vs the larger substitutes. This was done by keeping the abovementioned four categories in mind. Similarly, fuzzy AHP and VIKOR methodology played a major role in the planning of renewable energy, by Kumar et al. (2010). A selection of a renewable energy analysis was done by Wang et al. (2017) by using fuzzy VIKOR approach and it revealed that the best renewable energy alternatives are wind energy and biomass energy types. On doing some research, Afgan et al. (2007) gauged the usage of natural gas in the energy industry. Axiomatic design (AD) and AHP were put into use to filter out the options of the top renewable energy substitute under fuzzy conditions by Kahraman et al. (2009). For some time, the manufacturing industry was facing a problem regarding the energy resource selection; this was solved by Onut et al. (2008) by putting analytic network process (ANP), into use.

After a lot of research by various bodies, various indicators have been set up to get a proper knowledge of cause and effect on the energy system. For instance, the economic indicators tell us about the effects of the production mechanism of

energy and the advantages the services provided on overall economy and its progress. Similarly, the technical indicators are used to evaluate if the institutional structure is fit to provide an effective and efficient energy system. Likewise, different energy systems have distinctive influence on the environment as a whole; the environment indicators are useful to evaluate these effects. The pros and cons of the effects in land, air, and water (fresh and marine) are also investigated through these. Lastly, the social indicators keep tags on the effects on employment opportunities, poverty, community development, culture, pollution, health, and demographic transition (Reddy et al. 2000). In conclusion, these indicators evaluate the effects of energy systems on the nourishment of mankind.

Renewable energy sources

According to Colak and Kaya (2017); Kahraman et al. (2009); Krukanont and Tezuka (2007); Ozkale et al. (2017); Tsoutsos et al. (2009), various forms of top renewable energy resources are wind energy, hydropower energy, solar energy, geothermal energy, and biomass. Mostly, the issue faced in energy sources planning is preference from different energy resources and the mechanics to be advocated.

According to Kruger (2006), geothermal energy is the form of energy which is located and found in the upper part of earth's crust which is 10 km deep. Mostly, it comes in formation of volcanoes, hot springs, and fumaroles. Logically, this energy form has a lot of potential since it is basically the heat of the earth beneath its surface. It is mainly found in the outermost layer of the earth, i.e., the earth's crust, with an average temperature range of between 20 and 30 °C/km depth.

Solar is the other source for energy production. According to Aman et al. (2015) and Lehman and Nierderle (2006), this form of energy is the cleanest if environment is taken into consideration. The sun is our chief source of solar energy and it has immense potential, logically. Various forms can be derived from it, e.g., the solar radiation (thermal) which is dispersed through the clouds cannot be converged but its secondary forms are transitioned further into biomass and thus used for energy production. Hydropower and wind energy can also be generated. On the other side, the direct beam radiation (thermal) can definitely be converged and collected according to Kruger (2006). The amount of energy used globally in a year is much lesser than the solar radiation intercepted by the earth. Solar energy functions as a fusion reactor emanating energy all through the solar system. According to Assmann et al. (2006); Noorollahi et al. (2016), the amount of radiation received in any space depends upon the available area, geographic location, and the weather situation.

Another resource of energy production is the wind. This comes with its pros and cons, e.g., when electricity is generated, CO₂, NO_x, SO₂, mercury, air pollutants, and particulate matter are filtered out in comparison to any other conventional power

station. On the upside, most investors and firms also agree on the fact that this form of energy has the lowest hazard and is a sub-category of the green energy (Saygin and Çetin 2010; Sen and Ganguly 2017). Another reason that it became famous within the investment inflow sector is the green signal from the large offshore wind farms, financially (Cristobal 2011; Kunneke et al. 2015). BP Statistical Review of World Energy (2010) also confirms that wind energy is one of the profitable and successful resources considering how most countries of the world are suffering from a financial crisis. Keeping all these information into account, the statistics show wind to be playing an essential role in the production of energy (Kaplan 2015).

As time passes, the increase in production and usage of renewable energy is excelling due to various reasons. Hydropower energy is counted as one of the top resources compared to fossil fuel resources. Even the finest fossil fuel plants can provide up to 50% efficacy, whereas the smaller sized but modern turbines can generate up to 90% of the energy into electricity. Hydropower is becoming famous for a reason. It has approximately 94% production rate of renewable energy, but 20% overall energy generation. Nowadays, there are a number of reasons why mega projects cannot be set up; e.g., the sites are not available easily and issues regarding the environment have to be considered; it is because of those high-powered hydroelectric stations which were built approximately a century ago that we are able to make use of this resource. These generated hundreds of megawatts compared to the small-scale hydropower stations. These have immense potential also because the need and usage of renewable energy and generation of electricity are booming (Ansel and Robyns 2006; Korkovelos et al. 2018; Manders et al. 2016). According to Yuksek et al. (2006); Bilgili et al. (2018), if the hydroresources are used wisely and successfully, they can help countries be self-sufficient and not be dependent on fossil fuel resources.

According to Van de Velden et al. (2008) and Toklu (2017), biomass will have all its resources from the waste products of various industries, such as agriculture and forestry. All of these cost-effective products also are easy accessible which make them a desirable resource. These organic products, e.g., crops and organic wastes, are re-usable and play an essential role in energy production. Statistics tell us that 14% of the chief energy is produced from biomass usage, as a resource. These come in all forms, i.e., solid (wood chips and straw), liquid (slurry tanks and vegetable oils), and gas (biogas). The liquids can be transitioned into biogas also (Herbert and Krishnan 2016). Biomass is mostly a result of agricultural, municipal, and forest waste along with a few crops which can specifically be further used as a resource for fuel.

There is a model below in Fig. 1 for sustainable energy planning in accordance to the abovementioned energy sources, indicators, and criteria.

Methodology

In this paper, we used a fuzzy approach method that is called EDAS in order to select the best renewable energy. Fuzzy set theory was developed by Zadeh (Zadeh 1965) for handling problems in which information is imprecise, vague, and uncertain. The term “fuzzy” is related to the situation that we have no well-defined boundaries of the set of activities or observations. Some of the definitions related to fuzzy sets and fuzzy numbers, which are used in this research to extend the EDAS method, are stated as follows (Ghorabae et al. 2016):

Definition 1 A fuzzy subset A of a universal set X can be defined by its membership function $\mu_A(x)$ as:

$$A = (x, \mu_A(x)) \quad , x \in X \quad (1)$$

where $x \in X$ denotes the elements belonging to the universal set, and $\mu_A(x) : X \rightarrow [0, 1]$.

Definition 2 A fuzzy number is a special case of a convex, normalized fuzzy subset ($\sup \mu_A(x) = 1$) of the real line $R(\mu_A(x) : R \rightarrow [0, 1])$.

Definition 3 A fuzzy number A is a trapezoidal fuzzy number (TFN) if its membership function is:

$$\mu_A(x) = \begin{cases} \frac{x-a_1}{a_2-a_1} & a_1 \leq x \leq a_2 \\ 1 & a_2 \leq x \leq a_3 \\ \frac{a_4-x}{a_4-a_3} & a_3 \leq x \leq a_4 \end{cases} \quad \text{and} \quad 0 \text{ otherwise} \quad (2)$$

This fuzzy number can also be defined by a quadruplet $A = (a_1, a_2, a_3, a_4)$. An example of this type of fuzzy numbers is shown in Fig. 2.

Definition 4 A crisp number k can be represented by a trapezoidal fuzzy number $k = (k, k, k, k)$.

Definition 5 Suppose that $A = (a_1, a_2, a_3, a_4)$ and $B = (b_1, b_2, b_3, b_4)$ be two positive trapezoidal fuzzy numbers ($a_1 \geq 0$ ve $b_1 > 0$) and k is a crisp number. The arithmetic operations with these fuzzy numbers are defined as follows:

- Addition:

$$A \oplus B = (a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4) \quad (3)$$

$$A + k = (a_1 + k, a_2 + k, a_3 + k, a_4 + k) \quad (4)$$

Fig. 1 The model for sustainable energy planning

- Subtraction:

$$A \ominus B = (a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1) \quad (5)$$

$$A - k = (a_1 - k, a_2 - k, a_3 - k, a_4 - k) \quad (6)$$

- Multiplication:

$$A \otimes B = (a_1 \times b_1, a_2 \times b_2, a_3 \times b_3, a_4 \times b_4) \quad (7)$$

$$A \times k = \begin{cases} (a_1 \times k, a_2 \times k, a_3 \times k, a_4 \times k) & \text{if } k > 0 \\ (a_4 \times k, a_3 \times k, a_2 \times k, a_1 \times k) & \text{if } k < 0 \end{cases} \quad (8)$$

- Division:

$$A \oslash B = (a_1 / b_4, a_2 / b_3, a_3 / b_2, a_4 / b_1) \quad (9)$$

$$A \div k = \begin{cases} (a_1 / k, a_2 / k, a_3 / k, a_4 / k) & \text{if } k > 0 \\ (a_4 / k, a_3 / k, a_2 / k, a_1 / k) & \text{if } k < 0 \end{cases} \quad (10)$$

Definition 6 Let $A = (a_1, a_2, a_3, a_4)$ be a trapezoidal fuzzy number. Then, the defuzzified (crisp) value of this fuzzy number can be defined as follows:

$$k(A) = \frac{1}{3} \left(a_1 + a_2 + a_3 + a_4 - \frac{a_3 a_4 - a_1 a_2}{(a_3 + a_4) - (a_1 + a_2)} \right) \quad (11)$$

Definition 7 Suppose that $A = (a_1, a_2, a_3, a_4)$ be a trapezoidal fuzzy number. A function, called psi (ψ), is defined in the following to find the maximum between a trapezoidal fuzzy number and 0.

$$\psi(A) = \begin{cases} A & \text{if } k(A) > 0 \\ 0 & \text{if } k(A) < 0 \end{cases} \quad (12)$$

Where $0 = (0, 0, 0, 0)$

Fig. 2 A trapezoidal fuzzy number

EDAS method

As previously stated, the EDAS method was developed by Keshavarz Ghorabae et al. (2015) for multi-criteria inventory classification. It was also demonstrated that the EDAS method is an efficient method to handle MCDM problems. In this section, an extended version of the EDAS method is proposed to deal with multi-criteria group decision-making problems in the fuzzy environment. In this study, the decision-makers express the weights of criteria and the rating of alternatives with respect to each criterion by linguistic terms. These linguistic terms are quantified by positive trapezoidal fuzzy numbers. Therefore, the concepts and arithmetic operations of the trapezoidal fuzzy numbers are utilized for extending the EDAS method. Suppose that we have a set of n alternatives ($A = \{A_1, A_2, \dots, A_n\}$), a set of m criteria ($C = \{c_1, c_2, \dots, c_m\}$), and k decision-makers ($D = \{D_1, D_2, \dots, D_k\}$). The steps of the extended fuzzy EDAS method are presented as follows (Ghorabae et al. 2016):

Step 1. Construct the average decision matrix (X), shown as follows:

$$X = [x_{ij}]_{m \times n} \quad (13)$$

$$x_{ij} = \frac{1}{k} \bigoplus_{p=1}^k x_{ij}^p \quad (14)$$

where x_{ij}^p denotes the performance value of alternative A_i ($1 \leq i \leq n$) with respect to criterion c_j ($1 \leq j \leq m$) assigned by the p th decision-maker ($1 \leq p \leq k$).

Step 2. Construct the matrix of criteria weights, shown as follows:

$$W = [w_j]_{1 \times m} \quad (15)$$

$$w_j = \frac{1}{k} \bigoplus_{p=1}^k w_j^p \quad (16)$$

where w_j^p denotes the weight of criterion c_j ($1 \leq j \leq m$) assigned by the p th decision-maker ($1 \leq p \leq k$).

Table 3 Evaluation of criterion weights by verbal variables by four decision-makers

	KV-1	KV-2	KV-3	KV-4
C1	H	H	VH	H
C2	H	VH	M	M
C3	VH	H	H	H
C4	H	H	VH	VH
C5	VH	H	H	H
C6	H	H	H	H
C7	H	VH	H	H
C8	VH	H	H	E
C9	H	H	M	M
C10	H	H	VH	VH
C11	H	H	H	H
C12	H	H	H	H
C13	VH	VH	H	VH
C14	H	VH	H	H
C15	H	H	H	H
C16	VH	M	M	H
C17	H	M	M	H
C18	VH	H	L	H
C19	H	M	M	M
C20	L	L	L	L

Step 3. Construct the matrix of criteria weights, shown as follows:

$$AV = [av_j]_{1 \times m} \quad (17)$$

$$av_j = \frac{1}{n} \bigoplus_{i=1}^n x_{ij} \quad (18)$$

The elements of this matrix av_j represent the average solutions with respect to each criterion.

Therefore, the dimension of the matrix is equal to the dimension of criteria weights matrix.

Step 4. Suppose that B is the set of beneficial criteria and N is the set of non-beneficial criteria. In this step, the matrices of positive distance from

Table 2 Verbal variables used in evaluation and triangular fuzzy number equivalents

Verbal variables	Triangular fuzzy numbers used in the evaluation of criteria			Triangular fuzzy numbers used to evaluate alternatives		
Very low (VL)	0	0	0,1	0	0	1
Low (L)	0	0,1	0,3	0	1	3
Medium low (ML)	0,1	0,3	0,5	1	3	5
Medium (M)	0,3	0,5	0,7	3	5	7
Medium high (MH)	0,5	0,7	0,9	5	7	9
High (H)	0,7	0,9	1	7	9	1
Very high (VH)	0,9	1	1	9	1	1

Table 4 Evaluation of alternatives by verbal variables by four decision-makers

	KV1					KV2					KV3					KV4				
	E1	E2	E3	E4	E5	E1	E2	E3	E4	E5	E1	E2	E3	E4	E5	E1	E2	E3	E4	E5
C1	VH	H	VH	H	VH	VH	H	H	H	H	VH	H	VH	L	VH	H	H	H	M	H
C2	H	H	L	L	M	VH	VH	L	M	H	VH	H	H	H	H	H	M	L	M	M
C3	VH	H	H	H	L	H	H	H	M	H	H	H	H	H	H	VH	H	H	M	H
C4	H	H	M	H	M	H	H	L	H	H	H	H	H	H	VH	H	M	M	M	H
C5	H	H	H	M	M	H	H	H	L	H	H	VH	H	H	H	H	M	M	M	H
C6	VH	H	H	L	L	H	H	H	H	H	VH	H	VH	M	H	H	H	L	L	L
C7	H	H	L	L	L	H	VH	M	M	H	H	H	H	L	VH	VH	M	M	H	M
C8	H	H	M	L	L	H	H	M	L	H	VH	H	H	M	H	VH	M	H	M	M
C9	H	H	M	M	M	H	H	M	M	M	H	H	H	M	H	H	M	M	M	H
C10	VH	VH	H	H	H	H	H	H	H	M	H	VH	H	H	VH	H	H	H	H	H
C11	VH	H	H	L	H	VH	H	H	M	M	VH	H	H	M	VH	H	H	L	H	H
C12	H	H	H	L	L	H	H	H	L	H	H	H	VH	M	H	VH	H	M	H	H
C13	VH	H	H	L	L	H	VH	M	M	M	H	H	H	M	VH	H	M	M	M	M
C14	H	H	H	L	L	VH	H	M	H	H	VH	H	VH	L	H	H	M	L	L	H
C15	H	H	VH	VH	VH	H	VH	H	M	M	H	H	H	M	VH	H	H	M	H	H
C16	VH	H	H	H	H	VH	H	H	M	M	VH	H	L	H	VH	VH	M	M	H	H
C17	H	H	VH	H	L	H	L	H	M	M	H	M	M	M	H	H	H	H	H	H
C18	H	H	H	H	H	VH	M	M	M	M	H	L	M	H	M	H	H	L	H	M
C19	VH	H	VH	H	H	VH	M	H	H	H	H	H	M	M	H	ÇH	H	M	H	M
C20	H	L	H	H	H	H	H	M	H	M	H	H	H	M	M	H	M	M	M	M

average (*PDA*) and negative distance from average (*NDA*) are calculated according to the type of criteria (beneficial and non-beneficial), shown as follows:

$$PDA = [pda_{ij}]_{n \times m} \quad (19)$$

$$NDA = [nda_{ij}]_{n \times m} \quad (20)$$

$$pda_{ij} = \begin{cases} \frac{\psi(x_{ij} \ominus av_j)}{k(av_j)} \\ \frac{\psi(av_j \ominus x_{ij})}{k(av_j)} \end{cases} \quad (21)$$

$$nda_{ij} = \begin{cases} \frac{\psi(av_j \ominus x_{ij})}{k(av_j)} \\ \frac{\psi(x_{ij} \ominus av_j)}{k(av_j)} \end{cases} \quad (22)$$

where pda_{ij} and nda_{ij} denote the positive and negative distances of performance values of i th alternative from the average solution in terms of j th criterion, respectively.

Table 5 Combined fuzzy criterion weights

Criteria	Criteria weights		
C1	0.75	0.93	0.33
C2	0.55	0.73	0.63
C3	0.75	0.93	0.33
C4	0.80	0.95	0.55
C5	0.75	0.93	0.33
C6	0.70	0.90	0.10
C7	0.75	0.93	0.33
C8	0.65	0.83	0.48
C9	0.50	0.70	0.40
C10	0.80	0.95	0.55
C11	0.70	0.90	0.10
C12	0.70	0.90	0.10
C13	0.85	0.98	0.78
C14	0.75	0.93	0.33
C15	0.70	0.90	0.10
C16	0.55	0.73	0.63
C17	0.50	0.70	0.40
C18	0.58	0.73	0.38
C19	0.40	0.60	0.55
C20	0.00	0.10	0.30

Table 6 Decision matrix

	E1			E2			E3			E4			E5			AV		
C1	8.5	9.75	10	7	9	10	8	9.5	10	4.25	6	7.5	8	9.5	10	7.15	8.75	9.5
C2	8	9.5	10	6.5	8.25	9.25	1.75	3	4.75	3.25	5	6.75	5	7	8.5	4.9	6.55	7.85
C3	8	9.5	10	7	9	10	7	9	10	5	7	8.5	5.25	7	8.25	6.45	8.3	9.35
C4	7	9	10	6	8	9.25	3.25	5	6.75	6	8	9.25	6.5	8.25	9.25	5.75	7.65	8.9
C5	7	9	10	6.5	8.25	9.25	6	8	9.25	3.25	5	6.75	6	8	9.25	5.75	7.65	8.9
C6	8	9.5	10	7	9	10	5.75	7.25	8.25	2.5	4	5.75	3.5	5	6.5	5.35	6.95	8.1
C7	7.5	9.25	10	6.5	8.25	9.25	3.25	5	6.75	2.5	4	5.75	4.75	6.25	7.5	4.9	6.55	7.85
C8	8	9.5	10	6	8	9.25	5	7	8.5	1.5	3	5	4.25	6	7.5	4.95	6.7	8.05
C9	7	9	10	7	9	10	4	6	7.75	3	5	7	5	7	8.5	5.2	7.2	8.65
C10	7.5	9.25	10	8	9.5	10	7	9	10	7	9	10	6.5	8.25	9.25	7.2	9	9.85
C11	8.5	9.75	10	7	9	10	5.25	7	8.25	3.25	5	6.75	6.5	8.25	9.25	6.1	7.8	8.85
C12	7.5	9.25	10	7	9	10	6.5	8.25	9.25	2.5	4	5.75	5.25	7	8.25	5.75	7.5	8.65
C13	7.5	9.25	10	6.5	8.25	9.25	5	7	8.5	2.25	4	6	3.75	5.25	6.75	5	6.75	8.1
C14	8	9.5	10	6	8	9.25	4.75	6.25	7.5	1.75	3	4.75	5.25	7	8.25	5.15	6.75	7.95
C15	7	9	10	7.5	9.25	10	6.5	8.25	9.25	5.5	7.25	8.5	7	8.5	9.25	6.7	8.45	9.4
C16	9	10	10	6	8	9.25	4.25	6	7.5	6	8	9.25	6.5	8.25	9.25	6.35	8.05	9.05
C17	7	9	10	4.25	6	7.5	6.5	8.25	9.25	5	7	8.5	4.25	6	7.5	5.4	7.25	8.55
C18	7.5	9.25	10	4.25	6	7.5	3.25	5	6.75	6	8	9.25	4	6	7.75	5	6.85	8.25
C19	8.5	9.75	10	6	8	9.25	5.5	7.25	8.5	6	8	9.25	6	8	9.25	6.4	8.2	9.25
C20	7	9	10	4.25	6	7.5	5	7	8.5	5	7	8.5	4	6	7.75	5.05	7	8.45

Table 7 Positive distance values of all alternatives to average

	E1			E2			E3			E4			E5		
C1	− 0.12	0.12	0.34	0.00	0.00	0.00	− 0.18	0.09	0.34	0.00	0.00	0.00	− 0.18	0.09	0.34
C2	0.02	0.46	0.79	− 0.21	0.26	0.68	0.00	0.00	0.00	0.00	0.00	0.00	− 0.44	0.07	0.56
C3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	− 0.26	0.16	0.54	− 0.22	0.16	0.51
C4	0.00	0.00	0.00	0.00	0.00	0.00	− 0.13	0.36	0.13	0.00	0.00	0.00	0.00	0.00	0.00
C5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	− 0.13	0.36	0.13	0.00	0.00	0.00
C6	− 0.01	0.38	0.68	− 0.16	0.30	0.68	− 0.35	0.04	0.43	0.00	0.00	0.00	0.00	0.00	0.00
C7	− 0.05	0.42	0.79	− 0.21	0.26	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C8	− 0.01	0.43	0.77	− 0.31	0.20	0.65	− 0.46	0.05	0.54	0.00	0.00	0.00	0.00	0.00	0.00
C9	− 0.24	0.26	0.68	− 0.24	0.26	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C10	− 0.27	0.03	0.32	− 0.21	0.06	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C11	− 0.05	0.26	0.51	− 0.24	0.16	0.51	0.00	0.00	0.00	0.00	0.00	0.00	− 0.31	0.06	0.42
C12	− 0.16	0.24	0.58	− 0.23	0.21	0.58	− 0.29	0.10	0.48	0.00	0.00	0.00	0.00	0.00	0.00
C13	− 0.09	0.38	0.76	− 0.24	0.23	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C14	0.01	0.42	0.73	− 0.29	0.19	0.62	0.00	0.00	0.00	0.00	0.00	0.00	− 0.41	0.04	0.47
C15	− 0.29	0.07	0.40	− 0.23	0.10	0.40	0.00	0.00	0.00	0.00	0.00	0.00	− 0.29	0.01	0.31
C16	− 0.01	0.25	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	− 0.33	0.03	0.37
C17	− 0.22	0.25	0.65	0.00	0.00	0.00	− 0.29	0.14	0.54	0.00	0.00	0.00	0.00	0.00	0.00
C18	− 0.11	0.36	0.75	0.00	0.00	0.00	0.00	0.00	0.00	− 0.34	0.17	0.63	0.00	0.00	0.00
C19	− 0.09	0.19	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C20	0.00	0.00	0.00	− 0.36	0.15	0.61	− 0.50	0.00	0.50	− 0.50	0.00	0.50	− 0.40	0.15	0.65

Table 8 Negative distance values of all alternatives to average

	E1		E2		E3		E4		E5							
C1	0.00	0.00	0.00	− 0.34	− 0.03	0.30	0.00	0.00	0.00	− 0.04	0.32	0.62	0.00	0.00	0.00	0.00
C2	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.55	0.95	− 0.29	0.24	0.72	0.00	0.00	0.00	0.00
C3	− 0.17	0.15	0.44	− 0.29	0.09	0.44	− 0.29	0.09	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C4	− 0.26	0.18	0.57	− 0.39	0.05	0.47	0.00	0.00	0.00	− 0.39	0.05	0.47	− 0.32	0.08	0.47	0.47
C5	− 0.26	0.18	0.57	− 0.32	0.08	0.47	− 0.39	0.05	0.47	0.00	0.00	0.00	− 0.39	0.05	0.47	0.47
C6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	− 0.06	0.43	0.82	− 0.17	0.29	0.68	0.68
C7	0.00	0.00	0.00	0.00	0.00	0.00	− 0.29	0.24	0.72	− 0.13	0.40	0.83	− 0.40	0.05	0.48	0.48
C8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	− 0.01	0.56	1.00	− 0.39	0.11	0.58	0.58
C9	0.00	0.00	0.00	0.00	0.00	0.00	− 0.36	0.17	0.66	− 0.26	0.31	0.81	− 0.47	0.03	0.52	0.52
C10	0.00	0.00	0.00	0.00	0.00	0.00	− 0.32	0.00	0.33	− 0.32	0.00	0.33	− 0.24	0.09	0.39	0.39
C11	0.00	0.00	0.00	0.00	0.00	0.00	− 0.28	0.11	0.47	− 0.09	0.37	0.74	0.00	0.00	0.00	0.00
C12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.84	− 0.34	0.07	0.47	0.47
C13	0.00	0.00	0.00	0.00	0.00	0.00	− 0.53	− 0.04	0.47	− 0.15	0.42	0.88	− 0.26	0.23	0.66	0.66
C14	0.00	0.00	0.00	0.00	0.00	0.00	− 0.36	0.08	0.48	0.06	0.57	0.94	0.00	0.00	0.00	0.00
C15	0.00	0.00	0.00	0.00	0.00	0.00	− 0.31	0.02	0.35	− 0.22	0.15	0.48	0.00	0.00	0.00	0.00
C16	0.00	0.00	0.00	− 0.37	0.01	0.39	− 0.15	0.26	0.61	− 0.37	0.01	0.39	0.00	0.00	0.00	0.00
C17	0.00	0.00	0.00	− 0.30	0.18	0.61	0.00	0.00	0.00	− 0.44	0.04	0.50	− 0.30	0.18	0.61	0.61
C18	0.00	0.00	0.00	− 0.37	0.13	0.60	− 0.26	0.28	0.75	0.00	0.00	0.00	− 0.41	0.13	0.63	0.63
C19	0.00	0.00	0.00	− 0.36	0.03	0.41	− 0.26	0.12	0.47	− 0.36	0.03	0.41	− 0.36	0.03	0.41	0.41
C20	− 0.21	0.29	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Step 5. Calculate the weighted sum of positive and negative distances for all alternatives, shown as follows:

$$sp_i = \oplus_{j=1}^m (w_j \otimes pda_{ij}) \quad (23)$$

$$sn_i = \oplus_{j=1}^m (w_j \otimes nda_{ij}) \quad (24)$$

Step 6. The normalized values of spe_i and snf_i for all alternatives are calculated as follows:

$$nsp_i = \frac{sp_i}{\max_i(k(sp_i))} \quad (25)$$

$$nsn_i = 1 - \frac{sn_i}{\max_i(k(sn_i))} \quad (26)$$

Step 7. Calculate the appraisal score (ase_i) for all alternatives, shown as follows:

$$as_i = \frac{1}{2} (nsp_i \oplus nsn_i) \quad (27)$$

Step 8. Rank the alternatives according to the decreasing values of appraisal scores (ase_i). In other words, the alternative with the highest appraisal score is the best choice among the candidate alternatives.

Table 9 Weighted total distances, normalized values, and evaluation results

	spj		snj		nspj		nsnj		asj		Kasj					
E1	− 1.10	3.74	3.80	− 0.53	0.51	0.86	− 0.51	1.74	1.77	1.26	0.75	2.16	0.38	1.25	1.96	1.20
E2	− 1.79	1.94	2.50	− 1.73	0.42	1.59	− 0.83	0.90	1.16	1.86	0.79	1.43	0.51	0.85	1.30	0.89
E3	− 1.13	0.69	0.90	− 2.62	1.48	3.09	− 0.53	0.32	0.42	2.30	0.26	− 0.07	0.89	0.29	0.17	0.45
E4	− 0.49	0.60	0.60	− 1.90	3.84	4.11	− 0.23	0.28	0.28	1.94	− 0.90	− 1.09	0.86	− 0.31	− 0.40	0.05
E5	− 1.45	0.42	1.28	− 2.64	1.15	2.60	− 0.67	0.19	0.59	2.31	0.43	0.42	0.82	0.31	0.51	0.55

Case study of energy selection

In this section, the solution to the energy selection problem is developed with the proposed fuzzy EDAS method. The five energy source alternatives (E1, E2, E3, E4, E5) were evaluated with 4 experts of the field. While doing this, we used 6 criteria and 20 sub-criteria. The evaluation as shown in Table 2 was done according to Chen's (2000) methodology, and the results are given in Table 3. In addition, all of the energy sources were evaluated according to Table 3 results, and we obtained Table 4 results. We used corruption, investment cost, operation and maintenance cost, and natural disaster risks as cost criteria. In addition, the others are used as benefit criteria.

The fuzzy values and the fuzzy criterion weights of the alternatives evaluated by the decision-makers were combined using Eq. 14 and Eq. 16, respectively, and are given in Table 5.

The combined fuzzy values of the alternatives according to each criterion are given in Table 6.

Using the combined decision matrix obtained, the average solution values of alternatives for each criterion were obtained through Eq. 18. Then, we gathered positive distance matrix and negative distance matrices using Eqs. 19 and 20. The positive and negative distances to the mean value for all alternatives were calculated by Eqs. 21 and 22. The obtained results are given in Tables 7 and 8 using function in Eq. 12.

Then, using Eqs. 23 and 24, positive and negative distance values were multiplied by criterion weights and weighted positive and negative distances were calculated. Distance values were normalized using Eqs. 25 and 26. The normalized weighted distance values were calculated using the Eq. 27 evaluation score for each alternative and all these calculated values are presented in Table 9.

According to these results, we obtained a raw for alternatives for the given energy sources as $E1 > E2 > E5 > E3 > E4$. Thus, we can say that the best alternative for this model is E1 (geothermal energy).

Discussion and conclusions

With the development of industry and technology, the essentialness of renewable energy, which has become indispensable in today's society, has been confirmed once again in the COVID-19 (Castán Broto and Kirshner 2020; Hosseini 2020; Pradhan et al. 2020) pandemic period. While energy is a strategic power that all countries firmly embrace, the world is entering a new era in which the cross-border mobility of energy may decrease. With these new settings, it is possible to witness the prevalence of fewer energy transfers and more protectionism. Due to the political-economic, environmental,

health, and other concerns, the energy security and independence (Vanegas Cantarero 2020) issue will continue to stay on the international relations and trade agenda. Therefore, countries and societies need to abandon their comfort zones and get the greatest possible benefit from existing and potential energy alternatives. In this direction, efforts uncovering and transitioning (Vanegas Cantarero 2020) renewable energy technologies and attempting to benefit the best of renewable energy alternatives should continue to increase (Koca and Genc 2020). These efforts may create a major trend in switching non-renewable alternatives to renewable energy options even on an individual scale.

Strategic energy planning issues have been a popular topic in the energy literature. Energy decisions are crucial for both policymakers and governments. Since energy has a potential impact (positive or negative) on many aspects of authority and the country's welfare, governments must be careful to eliminate or mitigate (minimize their impact) the negative costs. Renewable energy generally receives financial, institutional, or educational support from numerous governments from different geographies. A major challenge for governments in the field of renewable energy is policy consistency about which policy should be chosen.

In this paper, which type of renewable energy types is more efficient is analyzed by the fuzzy EDAS method by taking political, economic, social, technological, legal, and environmental dimensions into account. As a result of the analyses, the efficiencies of renewable energy types are listed as follows from the strongest to the weakest: geothermal, solar, biomass, wind, and hydropower.

Strategic energy planning issues have been popular topic in the energy literature. Energy decisions are crucial for both policy makers and governments. Since energy has potential impact (positive or negative) on many aspects of authority and on the country welfare, governments must carefully eliminate or mitigate (minimize their impact) the negative costs. The renewable energy generally receives financial, institutional, or educational support from many governments. A major challenge for governments in the field of renewable energy is policy consistency about which policy should be chosen. In this paper, which type of renewable energy types is more efficient is analyzed by the APH method by taking political, economic, social, technological, legal and environmental dimensions into account. As a result of the APH analysis, the efficiencies of renewable energy types are listed as follows from the strongest to the weakest: geothermal, solar, biomass, wind, and hydropower.

Author contribution AA: writing—original draft, conceptualization. OD and OO: writing—original draft. FZ and OFD: data curation. AA and OD: supervision, project administration

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Declarations

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