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Turkey's 2023 Energy Strategies and Investment Opportunities for Renewable Energy Sources: Site Selection Based on ELECTRE

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Abstract: In Turkey, current energy generations are not sufficient for the existing energy needs and besides, energy demand is expected to increase by 4–6 percent annually until 2023. Therefore, the government aims to increase the ratio of renewable energy resources (RES) in total installed capacity to 30 percent by 2023. By this date, total energy investments are expected to be approximately $110 billion. Turkey is the fastest growing energy market among the OECD countries. Therefore, Turkey is an attractive market for energy companies and investors. At this stage, site selection and deciding appropriate RES are the most important feasibility parameters for investment. In this study, "Site Selection in Turkey" issue for RES (solar, wind, hydroelectric, geothermal, biomass) is evaluated by the ELECTRE which is one of the Multi Criteria Decision Making (MCDM) methods. In addition, the reasons for choosing this method are explained according to the literature. The study emphasizes the importance of energy generation from renewable and sustainable sources and is concerned with improving the position of the country. The Turkish government offers many purchasing guarantees and high incentives, especially in the renewable energy sector. As a result of the analysis, the most suitable energy sources are presented according to the geography and energy potential of the regions. The study aims to inform energy firms and everyone related with RES about Turkey's RES opportunities.

Keywords: renewable energy sources; multi criteria decision making; site selection; ELECTRE; Turkey

1. Introduction

Energy may be described as the strength to do a job and it is necessary for life. Primary sources are harvested from natural resources and can be utilized directly. Energy sources named oil, natural gas, coal, and nuclear energy are described as fossil energy sources. On the other hand, wind, solar, biomass, hydraulic, geothermal, and wave energy named as renewable energy Şengül, et al. [1]. Renewable energy generates less greenhouse gas emission and renews itself continuously; it depends on the natural climatic conditions and characteristics of an area. The use of fossil fuels causes adverse effects on the ecosystem as well as on the economy, such as the foreign trade deficit. If nations continue to supply their energy demands by import, energy supply safety will run into danger. Furthermore, increases in costs of oil and natural gas may compromise national manufacturing of the importing countries, and cause an expansion in the foreign trade deficit. The most well-known instance is the oil crisis in October 1973, where increase in energy costs led to an increase in generation costs, which resulted in energy supply inflation and degeneration of macroeconomic stability in many countries. According to insurers, economic losses due to environmental problems have tripled since 1980 [2].

Fuels are used for heating and other energy requirement. Therefore, energy generation based on fossil fuels is the main reason for environmental pollution. Flue gases, exhaust gases, sulphur dioxide

(SO_2), nitrogen oxides (NO_X), hydrocarbons, and particulate from industrial facilities are the most common pollutants. Those pollutants hang in the air for 2–7 days and transform into acid after uniting with humidity and rain water, causing soil pollution as a result of acid rain. Likewise, poisonous industrial wastes such as heavy metals (Hg, Cd, Al) can react with humidity and acid rain causing toxic effects on plants, animals, and people via the food chain and drinking water [3–6]. Environmental problems threaten the future of mankind through water, air, and soil pollution. The greatest cause of environmental problems is industrial activities, especially energy consumption based on fossil fuels which account for 49% of the effect on global warming [3]. Policy makers have been informed by the Intergovernmental Panel on Climate Change that there is a remarkable danger of catastrophic climate change. The well-known agreement established in Paris in December 2015 drafts a global commitment to try to restrict global temperature increase to 1.5 °C. Under the contract, each country will perform its individual climate performance program that will be evaluated every five years [7]. However, Turkey is still among the countries that refused to sign the agreement. According to 2017 data, Turkey consumes 289 billion kWh of electricity per year, so it is among the world's top 20 energy-consuming countries. Emission levels were increased from 75 million metric tons of carbon dioxide in 1980 to 350 million metric tons of carbon dioxide in 2014. As can be understood from the rates, Turkey should take the necessary measures for a sustainable economy and environment and planning should be done in this context. Any installations that convert a renewable resource into energy needs a great amount of initial capital investment, so installing generation plants for renewable energy sources is quite expensive for both government and private investors. Therefore, making the right decision for investment is very important. However, once you pay the initial expense, costs of energy will be less than the costs of energy generated from fossil fuels [8]. Moreover, choosing the appropriate region for an energy source is a multi-criteria decision making (MCDM) problem and requires an evaluation in terms of many contradictory criteria. Decision making is an act of making a choice among alternative behavior types in order to reach to the target and achieve the purpose [9,10]. If the MCDM methods are classified according to their different expectations; Analytical Hierarchy Process (AHP), Analytic Network Process (ANP), MAUT, UTA, MACBETH, PROMETHEE, ELECTRE I, TOPSIS, Objective Programming, and Data Envelopment Analysis are used to select from among the options; AHP, ANP, MAUT, UTA, MACBETH, PROMETHEE, ELECTRE III, and TOPSIS are used for rating; AHP Sort, UTADIS, Flow Sort, ELECTRE-Tri, are used for classification; methods such as GAIA and FS-Gaia are recommended when identification is desired [11]. It is understood that different approaches can be used to select the appropriate location of an RES site. According to the type of the problem, appropriate MCDM methods have been decided on as a result of the experiments carried out over the years. Therefore, ELECTRE method has been proposed which takes into account concordance and discordance for site selection of energy sources. Furthermore, ELECTRE and PROMETHEE are especially popular for sustainable renewable energy development fields [12]. ELECTRE has been particularly preferred in energy planning. Decision makers use them due to the large perspective supplies for the problem explanation and they can observe all the computations. Therefore, this technique is more favorable in practices based on energy demand allocation [13].

In this study, MCDM is used to make decisions on the basis of geographical regions for renewable energy facilities and it suggests a renewable energy roadmap. Therefore, the proposed method (ELECTRE) evaluates the allocation of renewable energy sources with respect to seven geographical regions of Turkey through taking into account different geographical and local potentials. The evaluated suitable renewable energy sources (RES) for electricity generation in Turkey are solar, hydroelectric, wind, biomass, and geothermal power. Because of the importance of energy for sustainable development, multi criteria decision making methods are utilized to plan energy policies in many countries such as Iran, Greece, India, Spain, and China. The study informs energy firms and everyone related to RES about convenient RES potential according to the geographical regions in Turkey. Therefore, it aims to offer the most suitable RES alternatives for each geographic region in order to reach Turkey's 2023 RES targets.

The rest of the study is organized as follows: Section 2 gives some information about renewable energy alternatives and presents a literature review for renewable energy decision problems. Section 3 explains all the steps of the proposed MCDM method. Section 4 presents obtained results. Section 5 presents discussions and Section 6 presents the conclusion.

2. Renewable Energy Sources

Turkey is located between 26–45 degrees eastern longitude with 36–42 degrees north latitude in the Northern Hemisphere. Therefore, the country is closer to Ecuador than the North Pole and it is in the temperate zone. With an area of 785,350 km^2, it is one of the largest countries of Europe and the Middle East. Its total electric energy consumption is 213.20 billion kWh per year. The per capita average energy consumption is approximately 2640 kWh [14]. More than half of Turkey's electrical energy is generated from fossil fuels. As a significant part of the energy sources are imported, it is necessary to reduce dependence on foreign sources, because this situation negatively affects the country's economy and current account deficit. In terms of the sustainability of the country's economy, efficient and diversified energy sources should be sought. Also, the cost of RES should be at an affordable level. Renewable energy is a great opportunity for Turkey because it has a significant geographical location in terms of its renewable energy capacity. Besides, Turkey can use almost all known renewable energy sources, such as solar, wind, geothermal, hydro, wave, and biomass. Today, renewable sources compose almost 45 percent of the whole energy producing capacity in Turkey. Hydropower has the preponderance of this generation. Energy generation with renewable sources is increasing globally. By the year 2030, Turkey's energy demands are expected to increase more than 100 percent compared to today. Thus, Turkey's passionate 2023 vision, declares especially attractive goals for the renewable energy sector. For this reason, the Ministry of Energy and National Resources (MENR) encourages to increase the share of RES in electricity generation and it is striving to improve the whole capacity of renewables to 61,000 MW by 2023. 34,000 MW of this total installed generation will be composed of hydropower; 20,000 MW of wind power, 1000 MW of geothermal, 5000 MW of solar, and 1000 MW of biomass energy. The total estimated cost of this object is almost 60 billion dollars. Table 1 shows the estimated resource-based electricity generation rates in the 2023 MENR strategic plan [15].

Table 1. The estimated resource-based electricity generation amounts in the 2023 MENR strategic plan [15].

Renewable Energy Sources	2015	2017	2019	2023
Hydropower	25,526	28,763	32,000	34,000
Wind	5660	9549	13,308	20,000
Geothermal	412	559	706	1000
Solar	300	1800	3000	5000
Biomass	377	530	683	1000
Total	32,275	41,241	49,697	61,000

In 2015, investments in the field of renewable energy were equal to 1.9 billion dollars in Turkey and this quantity has been growing continuously. In 2002, Turkey's installed renewable energy generation was 31,846 MW, and it grew to 85,200 MW in 2017.

Figure 1 shows the comparison of installed capacity share (%) in 2002 and 2017.

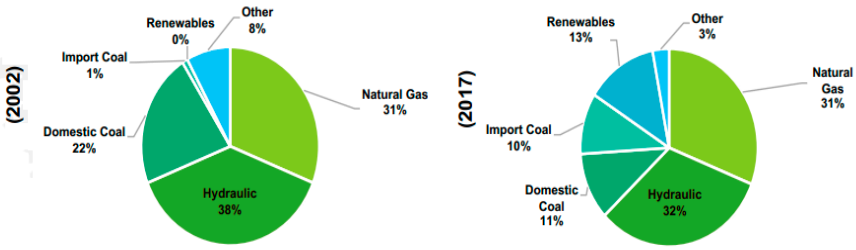

Figure 1. Comparison of installed capacity shares (%) in 2002 and 2017 [16].

As seen in Figure 1, the total share of renewable energy and hydraulic energy in installed capacity increased from 38% to 45% in 15 years. The rate of renewable energy rose from 0% to 13%. Besides, renewable energy sources (RES) have played a great role in reducing global warming and climate change concerns. The only way to reduce greenhouse gases that result from the energy production process of fossil fuels and cause climate change and pollutant emissions is RES. Besides, with increasing population, there is a growing energy demand in every region of the world. Current energy sources are not sufficient to meet this energy need. Therefore, more economical and clean energy source options should be found and preferred. Sources such as oil, natural gas, coal, and nuclear energy are considered fossil energy sources, while wind, sun, biomass, hydraulics, geothermal, wave, and hydrogen energy are described as RES [1]. At this point, RES can be offered as a solution to this energy demand. Turkey's national action plan for energy contains significant topics such as energy supply safety, diversified energy sources, usage of local energy resources to supply extra worth to economy, independent energy markets, and high energy yield. Therefore, priority is given to the use of local and RES. Growing urbanization, favorable demographic propensities, economic enlargement, and increasing per capita GDP are main determinants of energy necessity. Turkey is the world's 17th and Europe's 6th largest economy and with an ever-increasing demand for energy. The sum of investments demanded to encounter the energy necessities in Turkey by 2023 is forecasted to be approximately USD 110 billion, greater than twice as much as the total investments in the last 10 years. Because of the present improvement in the renewable energy sector and the investor supporter opportunities such as the feed-in tariffs in the many renewable energy subsectors, can be attractive for the local or foreign firms, industries and other companies related with renewable energy. Turkey's energy market is Europe's fastest-growing market. The energy market has a growth rate of 5.1% since 2002 and has a higher growth rate than countries such as Brazil, Mexico, Iran, and South Korea. Figure 2 shows the share of energy resources at installed capacity as of the end of 2017 [15].

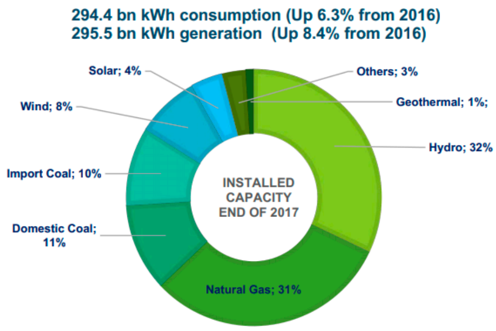

Figure 2. The share of energy resources at installed capacity as of the end of 2017 [15].

Energy consumption in 2017 increased by 5% compared to 2016. In 2017, there was an increase of 6.3% with 294.4 bn kWh energy consumption compared to 2016. Also, there was an increase of 8.4% with 295.5 bn kWh energy generation compared to 2016.

Table 2 shows the energy demand projection (MW) of geographic regions for years 2017–2024 [17]. By the year 2024, Turkey's energy demands are expected to increase more than 45 percent compared to today.

Table 2. Energy demand projection (MW) of geographic regions for years 2017–2024 [17].

Region	2017	2018	2019	2020	2021	2022	2023	2024
South Eastern Anatolia	2,836,159	2,998,808	3,171,119	3,351,502	3,527,482	3,709,637	3,898,641	4,096,695
Mediterranean	6,882,584	7,277,290	7,695,442	8,133,181	8,560,235	9,002,277	9,460,938	994,156
Eastern Anatolia	154,867	1,637,484	1,731,573	183,007	1,926,163	2,025,628	2,128,833	2,236,979
Central Anatolia	6,459,915	6,830,381	7,222,853	763,371	8,034,539	8,449,434	8,879,928	9,331,034
Aegean	7,522,593	7,954,003	8,411,038	8,889,482	9,356,248	9,839,395	1,034,071	1,086,602
Marmara	1,746,127	18,462,650	19,523,510	2,063,406	2,171,751	2,283,898	2,400,261	2,522,196
Black Sea	3,671,808	3,882,380	4,105,461	4,338,992	4,566,822	4,802,648	5,047,341	5,303,749

Brief descriptions of renewable energy alternatives are as follows:

2.1. Solar Energy

Solar energy is a clean source of energy that is generated directly from sunlight without any harmful gas emissions. Some of the energy generated by the reactions in the sun is the radiation that reaches the earth. The process of converting this radiation into electrical energy by panels defines the solar energy system. The energy is used for cooling, lighting, heating, and other energy requirements [18]. The amount of annual insolation time is 2.737 h (a total of 7.5 h per day). Besides, the amount of solar energy generated annually is 1.527 kWh/m^2 per year (total 4.2 kWh/m^2 per day). The average solar radiation amount is 1500 kW/m^2-year [15]. When analyzed on a regional basis, the Black Sea region is the most inefficient region, while Southeast Anatolia is the most productive region. The second most efficient region in the production of solar energy is the Mediterranean Region. Photovoltaic generators are convenient for all regions apart from the Eastern Black Sea Region. Turkey is among the largest developing solar markets. By the year 2018, the amount of installed solar collector area in Turkey is calculated as almost 20,200.000 m^2. By using solar collectors in 2018, heat energy which is equivalent to approximately 876,720 TEP tons of petroleum was generated. About 600,000 TEP of heat energy was used in dwellings and 276,000 TEP was used for industrial aims. By the end of September 2018, the energy amount of 5868 solar energy plants was calculated as 5063 MW in December 2018. The share of total electricity production in Turkey increased to 2.5% with 7.477.3 GWh. Construction of a 1000 MWe capacity solar power plant in Konya-Karapınar that will be one of the world's largest solar power plants is underway [16].

2.2. Wind Energy

Wind energy is a natural, renewable, clean, and endless power and its source is the sun. It is derived from the collision of air masses with distinct temperatures and electricity is generated by wind turbines [1]. Turkey's wind energy capability is forecasted as 48,000 MW. The entire area suitable to this capacity is approximately % 1.3 of Turkey's area. Besides, wind energy generation amount was calculated as 19,882 GWh in 2018 and the established potential of active wind energy plants has been determined as 7005 MW [16]. An 11GW reserve is estimated from the present projects. In addition, Turkey aims to reach a 20 GW wind energy potential in 2023 [19].

2.3. Geothermal Energy

Geothermal energy is the internal temperature of the earth. This temperature spreads out from the central torrid zone towards the earth surface. Steam and warm water reservoirs beneath the Earth's surface have huge potential as a renewable energy source (RES) [20]. Turkey is also among the top five countries in the world in the use of these resources directly. Despite obtaining an unsatisfactory amount of electricity production from geothermal energy, Turkey has the second largest geothermal energy capacity in Europe. The country is the third largest geothermal energy market in Europe.

The top 5 countries in geothermal heat and thermal water services are the USA, Philippines, Indonesia, Turkey, and New Zealand. The nations with the highest amounts of geothermal energy-producing potential in 2016 were the United States (3.6 GW), the Philippines (1.9 GW), Indonesia (1.6 GW), New Zealand (1.0 GW), Mexico (0.9 GW), Italy (0.8 GW), Turkey (0.8 GW), Iceland (0.7 GW), Kenya (0.6 GW), and Japan (0.5 GW) [21]. Theoretically, Turkey's geothermal potential is 31,500 MW. 78% of these geothermal areas are located in Western Anatolia, 9% in Central Anatolia, 7% in the Marmara Region, 5% in Eastern Anatolia and 1% in the other regions. 90% of geothermal sources are low and moderate temperature and are convenient for heating, thermal tourism, minerals production, etc. and 10% is appropriate for electric energy generation. 55% of the geothermal fields in Turkey are appropriate for heating applications. Geothermal energy potential grew five times in five years. The 165 MW Kizildere geothermal energy plant was established in 2017. Turkey has 2 GWe potential in 25 reserves. By June 2015, a total of 28 plants with a potential of 654.67 MW were licensed and 431 MW was under process. After Turkey had opened 10 plants in 2015, the country constructed at least extra 10 new geothermal power plants in 2016, increasing the capacity by approximately 200 MW for a total of 821 MW. Turkey has maintained a fast increase in electricity produced from geothermal energy; production grew 25% in 2016 alone, to 4.21 TWh [22]. Also, the installed capacity of geothermal energy was 14.06 GWe in 2017 [16].

2.4. Hydroelectric Energy

The power of flowing water is converted into electrical energy by hydroelectric power plants. Hydroelectric power plants are considered positively because they are environmentally friendly and have low risk potentials. Turkey has 1% of the world theoretical hydroelectric potential, and its economic potential is 16% of Europe. Furthermore, Turkey has 433 billion kWh hydroelectric RES potential and technically its consumable potential is 216 kWh. Also, the economic potential is 140 billion kWh/year. By the end of 2013, there were 467 hydroelectric power plant with a total power of 22.289 MW. This corresponds to 34.8% of the total potential [23]. The hydropower capacity grew over 0.8 GW in 2016, so the total installed capacity was 26.7 GW. After an obvious improvement in production in 2015, hydropower amount remained stable in 2016, at 66.9 TWh. [24]. In 2017, Turkish hydropower consumption was equivalent to roughly 13.2 million metric tons of oil, Turkey was the eighth most rapidly developing hydro market in 2017 with 0.6 GW installations, and the country surpassed Japan and France [16].

2.5. Biomass Energy

Biomass may be interpreted as the entire quantity of existing organisms that belongs to a society makes up of species. Biomass is described as an organic carbon. Active biodiesel potential is 160,000 tons in Turkey. Total waste from forests is 4,800,000 Tons (1.5 MTOE-600 MW) and from agriculture is 15,000,000 Tons (300 PJ). The amount of biomass capacity in Turkey is equivalent to approximately 8.6 million tons of petrol (MTEP). Also, biogas amounts that may be generated from biomass are 1.5-2 MTEP. In 2018, 3216 GWh electricity was produced from biomass energy plants with a whole installed capacity of 811 MW [16]. It is forecasted that there is almost 1.2 million tons/year biodiesel generation potential and 0.7 million tons/year bioethanol as considering potential 2.7 million hectares of agricultural land. The country has 1.5–2 MTOE biogas capacity. Also, 20 installed biogas plants have approximately 180 million m^3/year biogas generation potential. Moreover, agricultural crops, municipal solid waste, animal manure, and urban waste water treatment sludge are the other biomass resources in Turkey. Agricultural products are recommended for energy production when compared with others [25].

There are many studies using MCDM methods to assess the location of renewable energy resources. Some of the studies are summarized as follows: Tasri and Susilawati [26] introduced a decision approach based on fuzzy AHP to decide the most convenient renewable energy alternative for electricity generation in Indonesia. Cannistraro, et al. [27] shows some examples of a smart island that proposes the use of RES for sustainable development. Sozen et al. [28] used TOPSIS technique for solar plant location by planting analysis. Akkas, et al. [29] proposed an AHP approach to select suitable sites for solar power plants. Also, Akkaş, et al. [30] developed a methodology that included AHP, ELECTRE, TOPSIS, and VIKOR techniques for solar power plant site selection in five provinces of Central Anatolia. Nigim, et al. [31] applied two MCDM techniques to support societies in the pre-feasibility ranking of regional renewable energy sources. They respectively applied analytic hierarchy process (AHP) and sequential interactive model for urban sustainability (SIMUS) methods. Haralambopoulos and Polatidis [32] used an appropriate group decision-making structure to sustain multi-criteria analysis in renewable energy plans and also used PROMETHEE II method for ranking. Ayag [33] proposed an AHP-based approach to the study of solar power plant site alternatives. Sözen, et al. [34] proposed a hybrid method that includes data enveloping and TOPSIS techniques were used in the research on selection of location for wind power plants. Beccali, et al. [35] introduced an application of multicriteria decision-making methodology (MCDM) which used to estimate an action strategy for the diffusion of renewable energy technologies at a regional scale. Then, they studied a case for Sardinia Island and ranked three separate situations with the ELECTRE III method. On the other hand, Cetinay, et al. [36] proposed a wind speed model and linear optimization critics to determine the optimum location of wind farms. Kaya and Kahraman [37] used a hybrid fuzzy AHP-VIKOR technique to decide the best renewable energy alternative for Istanbul. After that, they tried to select among different energy generation sites in İstanbul through the same technique. Cetinay [38] used optimization method in the determining the wind energy potential and optimal wind farm located in Turkey. Madlener, et al. [39] defined the contribution of renewable energy sources in heat and electricity generation as a national and international scope for sustainable growth. They used PROMETHEE technique as a MCDM method and assessed five renewable energy situations in Austria for 2020. Adhikary, et al. [40] offered a MCDM proposal including TOPSIS and VIKOR methods to rank renewable energy options for a site in the Himalayan Region. Arnette and Zobel [41] proposed a multi-objective linear programming (MOLP) model to define the optimal mix of RES and existing fossil fuel plants on a regional basis. Aplak and Sogut [42] introduced a mixed methodology of fuzzy decision-making and game theory in energy management decision-making. Chen, et al. [43] combined interval linear programming and integer linear programming technique for regional optimization of energy systems. There are many studies on energy resources in Turkey. A large part of these papers related to RE technologies. Kahraman, et al. [44] practiced the Choquet integral methodology to select the best energy option for Turkey; in accordance with their result, wind energy is the best alternative. Ertay, et al. [45] proposed MACBETH and AHP-based multicriteria methods for the estimation of renewable energy alternatives in Turkey under fuzziness. Özcan and Erol [46] used a multiobjective mixed-integer linear programming model to select the best energy resources utilized for electricity production in Turkey. Uz and Baskak [47] used a benchmarking model to compare solar and wind energy through the Mediterranean, Aegean, and Marmara regions in Turkey. Kabak and Dağdeviren [18] used the analytic network process to determine Turkey's energy profile and prioritize alternative renewable energy sources; they emphasized that hydropower is the optimal renewable energy in Turkey. Şengül, Eren, Shiraz, Gezder and Şengül [1] used an MCDM support structure for ranking renewable energy supply systems in Turkey; they applied the Interval Shannon's Entropy methodology to define the weights of the criteria and practiced the fuzzy TOPSIS method to decide the most renewable energy systems for Turkey and determined that the best option was hydropower for Turkey. Balin and Baraçli [48] used AHP and TOPSIS techniques to decide the best renewable energy alternative in Turkey. According to their model, wind energy is the best for Turkey followed by solar, hydraulic, biomass, and geothermal respectively. Kuleli Pak, et al. [49] proposed a renewable energy approach with Analytic Network Process (ANP) and TOPSIS techniques for Turkey. Büyüközkan and Güleryüz [50] used a hybrid structure based on DEMATEL and Analytic Network Process that considered the technical, economic, political, and social criteria to select the most appropriate renewable energy in Turkey through an investor focused perspective. Ishizaka, et al. [51]

applied a visualization technique with AHP to help policymakers with gaining insights into energy planning problems. Ren, et al. [52] proposed a multi-criteria decision analysis structure to make a comprehensive ranking of groundwater management strategies. Karakaş and Yıldıran [53] evaluated renewable energy alternatives for Turkey via modified fuzzy AHP. The obtained results indicate that the best alternatives are solar and wind respectively. Çolak and Kaya [54] used a hybrid technique based on type-2 fuzzy sets AHP method and hesitant fuzzy TOPSIS to assess renewable energy sources in Turkey. According to their model, wind energy is the best renewable energy source for Turkey. Aksoy [17] proposed an integrated decision-making model for renewable energy planning in Turkey and the paper presents the total supply amount of renewable sources for geographical regions. The model is generated to allocate renewable energy sources to the geographical regions. According to results, the total renewable energy investment was apportioned among the regions and Marmara was the region where the highest investment was allocated.

When the literature is analyzed, it is seen that several MCDM approaches are used with this subject. Kumar, Sah, Singh, Deng, He, Kumar and Bansal [12] presented an extensive literature review about MCDM methods that utilized in renewable energy studies. Mardani, et al. [55] presented a paper on MCDM methods that indicates the studied areas of applications between 2000 and 2014 years. Fifty-five studies (13.45%) have utilized MCDM methods in the fields of energy, environment, and sustainability. MCDM is considered the fastest growing branch of operational research in our day [56]. Figure 3 reveals that the number of multi criteria decision making method studies made in the energy field increase year over year. Most of the studies have been written in the last 10 years.

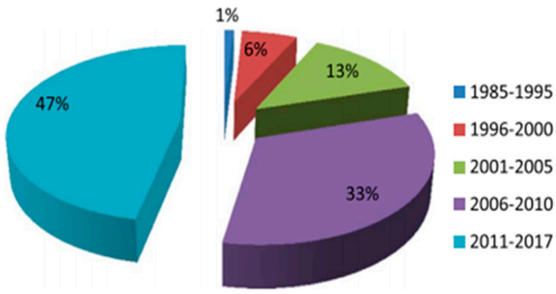

Figure 3. Classification of MCDM papers based on years (1985–2017) [54].

Figure 4 shows the percentages of MCDM methods in energy decision making problems. The figure presents that the Analytic Hierarchy Process (AHP) is the most popular multi-criteria decision-making method in energy studies. The method is followed by PROMETHEE, ELECTRE, TOPSIS, and ANP methods respectively [12].

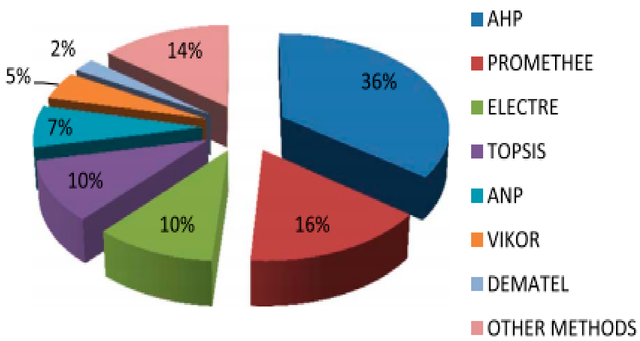

Figure 4. Percentages of MCDM methods in energy decision making problems [54].

AHP mostly is applied to calculate the weights of criteria. AHP has achieved popularity because of its simplicity in process. However, ELECTRE and PROMETHEE which are described as outranking techniques also are popular for energy planning and sustainable development fields [12].

These techniques are more preferred in practices based on the allocation of renewable energy sources with respect to regions [13]. Some of the related papers are summarized as follows: Devi and Yadav [57] proposed a methodological approach to select the most suitable plant location through using ELECTRE. Sánchez-Lozano, et al. [58] implemented the ELECTRE III method in the selection of GIS-based photovoltaic solar farm sites for Torre Pacheco, Murcia, and the Southeastern region of Spain. Agrebi, et al. [59] used ELECTRE technique to assess the location selection of distribution centers. Ray, et al. [60] applied four complete and one partial ranking method (TOPSIS, SAW, GRA, and MOORA) to determine the potential facility location alternative, but the methods gave conflicting outcomes. Then, they primarily tried to eliminate the variation. For this purpose, they preferred ELECTRE-I. Therefore, the final ranking system based on ELECTRE-I method has been suggested by the authors to simplify the decision-making operation. Ghoseiri and Lessan [61] proposed the site selection for waste disposal with AHP and ELECTRE techniques. Using the ELECTRE method provides that a very poor criterion value of an alternative may not be defused by greater values on other alternative criteria. Another benefit of ELECTRE was that an important weak criterion value of an alternative might not directly be defused by other better criteria values. Govindan, et al. [62] indicated that the selected application fields are dominated by AHP and TOPSIS so far. However, the disadvantages of these methods may be overcome by applying the outranking method (ELECTRE). Jun, et al. [63] handled the macro site selection of wind and solar hybrid power station via ELECTRE-II. When they compared other extensive assessment methods with ELECTRE, the risk level was apparent for the decision makers. The ELECTRE method does not only present the actual values but also supplies the decision makers with more reliable outcomes. Besides, ELECTRE utilizes the data in the decision-making matrix and apply the concordance and non-concordance test. Hence, the sorting outcome becomes more efficient. They emphasized that results were consistent with the related research findings and had better correctness, and the conclusions were proving the feasibility and effectiveness of the method. Fetanat and Khorasaninejad [64] proposed a novel hybrid MCDM approach for offshore wind farm site selection with a case study of Iran. They used the ELECTRE method for selection part of the case study. Azzopardi, et al. [65] proposed a decision support system for ranking photovoltaic technologies via ELECTRE that leads a mathematical analysis that could assist photovoltaic (PV) system owners, bureaucrats, and business societies about PV technologies, financial support methods and business plans. Wu, et al. [66] presented a decision structure for selecting offshore wind power location with ELECTRE. Peng, et al. [67] proposed an integrated decision support model based on regret theory and ELECTRE III to evaluate investment risk for new energy resources. The study demonstrates that the method effectively support new energy investment decision-making and it performs better than other existing methods.

3. Proposed Multi Criteria Decision Making Method (ELECTRE)

ELECTRE (ELimination Et Choix Traduisant la REalité) is proposed to evaluate renewable energy alternatives for Turkey and geographical regions are used as alternatives while the RES potentials of these regions are used as criteria. There are seven regions (Black Sea, Aegean, Marmara, Mediterranean, Central Anatolia, Southeastern Anatolia, and Eastern Anatolian Regions) which show great differences in geographical aspect in Turkey. The solar energy map, wind map, hydroelectric, geothermal, and biomass sources are taken into consideration in order to determine renewable energy potentials. The ELECTRE method was first introduced in 1966 by Beneyoun. The acronym ELECTRE stands for ELimination Et Choix Traduisant la REalité (ELimination and Choice Expressing REality) [68]. The method is based on the binary superiority comparisons between alternative decision points for each assessment factor. Subsequently, ELECTRE I, II, III, IV, IS, and TRI were developed [69–72], which are extensions of it. ELECTRE provides reliable elimination and selection to problems which have also qualitative data. It is defined as a method that can transform them into quantitative data [73]. ELECTRE concentrates on dominance relations among the alternatives. It is based on outranking relations and notions of concordance. These outranking relations are built to make it possible to compare alternatives.

The method uses concordance and discordance indexes to analyze the outranking relations among the alternatives. [74,75]. In addition, Marzouk [76] evaluates the use of ELECTRE techniques as follows: The ELECTRE-I method is used in selection problems; ELECTRE II, III, and IV are used in sorting problems and ELECTRE-Tri is proposed for assignment problems. In comparison with ELECTRE, other simple qualitative methods—such as Delphi, Analytic Hierarchy Process (AHP), and Analytic Network Process (ANP)—are too subjective. On the other hand, quantitative techniques such as Gravity, MCLP (Multi Criteria Linear Programming), and 0–1 Integer do not take into account the subjective factors. Using obscure comparisons, Fuzzy AHP (FAHP) creates a fuzzy weight for each criterion in the selection method. However, it is not sufficient. Site selection for renewable energy is a multiple target decision-making problem, therefore, using a good decision-making approach may solve the problem effectively. ELECTRE has an easy and obvious logical relation and considerable interaction that provides the fully using of information in the decision matrix. Based on domestic and international research, authors prefer ELECTRE for site selection to obtain scientific and reasonable results [77]. In the MCDM techniques, the proposal of the appropriate method according to the type of the problem has been decided as a result of the studies over the years. Therefore, the ELECTRE method which considers concordance and discordance has been proposed for energy planning problems. The steps of ELECTRE method are given as follows [78–82].

Step 1. This process converts the elements of the decision matrix into dimensionless comparable elements by applying Equation (1)

$$x_{ij} = \frac{a_{ij}}{\sqrt{\sum\limits_{k=1}^{m} a_{kj}^2}} \tag{1}$$

Thus, the normalized matrix X is shown as

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{2}$$

where m presents the number of alternatives, n shows the number of criteria, and x_{ij} is the normalized preference measure of the i-th alternative with regard to the j-th criterion.

Step 2. Construction of weighted standard decision matrix (Y): The importance of evaluation factors may be different for each decision-maker. In order to reflect these significant differences to the ELECTRE solution, the Y matrix is calculated. The decision-maker must first determine the weights (w_i) of the evaluation factors. $0 \leq w_1, w_2, \ldots, w_n \leq 1$ and the correlation coefficients of normalized interval numbers are between 0 and 1.

$$\sum_{i=1}^{n} w_i = 1 \tag{3}$$

Then the elements in each column of the X matrix are multiplied by the corresponding w_i value to form the Y matrix. Therefore, the weighted matrix which is derived from the normalized matrix is shown in Equation (4):

$$Y_{ij} = \begin{bmatrix} w_1x_{11} & w_2x_{12} & \cdots & w_nx_{1n} \\ w_1x_{21} & w_2x_{22} & \cdots & w_nx_{2n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ w_1x_{m1} & w_2x_{m2} & \cdots & w_nx_{mn} \end{bmatrix} \tag{4}$$

Step 3. Determining the set of concordance (C_{kl}) and discordance (D_{kl}).

The Y matrix is used to determine the fit sets. The decision points are compared with each other in terms of evaluation factors and the sets are determined by the relationship shown in the formula:

$$C_{kl} = \left\{ j, y_{kj} \geq y_{lj} \right\} \tag{5}$$

The formula is based on the comparison of the superiority of the row elements relative to each other. The number of concordance sets in a multiple decision problem is $(m.m - m)$. The $k \neq l$ condition should be provided for k and l indices when creating concordance sets. The number of elements in a set of concordance can be the maximum number of evaluation factors (n).

For example, in order to be able to decide the C concordance set for k = 1 and l = 2, the elements of row 1 and 2 of the Y matrix are mutually compared with each other. When there are four evaluation factors, the C_{12} concordance set will have, at most, four elements. For instance, if the comparison results of rows 1 and 2 are as follows: $y_{11} > y_{21}$, $y_{12} < y_{22}$, $y_{13} < y_{23}$ and $y_{14} = y_{24}$. The condition in formula Equation (5) will fit for the values of j = 1 and j = 4, and the C_{12} concordance set will be defined as $C_{12} = \{1,4\}$. The ELECTRE method has a discordance set (D_{kl}) which is complementary to each concordance set (C_{kl}). In other words, there are as many discordance sets as the number of concordance sets. The discordance set elements consist of j values that do not belong to the complementary concordance set. In the example, concordance set is $C_{12} = \{1,4\}$ therefore discordance set is $D_{12} = \{2,3\}$.

Step 4. Construction of concordance (C) and discordance matrices (D)

Concordance sets are used to create the concordance matrix (C). The matrix C is a mxm matrix and does not have a value for $k = l$. The concordance index c_{kl} is the sum of the weights related with the criteria included in the concordance set. The elements of the C matrix are calculated by the relationship shown in the formula

$$c_{kl} = \sum_{j \in C_{kl}} w_j \text{ for } j = 1,\ 2,\ 3,\ \ldots,\ n. \tag{6}$$

The concordance index shows the relative significance of alternative A_k with regard to alternative A_l. Obviously, $0 \leq c_{kl} \leq 1$. For example, if $C_{12} = \{1,4\}$, the value of c_{12} for the C matrix will be $c_{12} = w_1 + w_4$. The concordance matrix (C) is described in Equation (7)

$$C = \begin{bmatrix} - & c_{12} & c_{13} & \cdots & c_{1m} \\ c_{21} & - & c_{23} & \cdots & c_{2m} \\ . & & & & . \\ . & & & & . \\ . & & & & . \\ c_{m1} & c_{m2} & c_{m3} & \cdots & - \end{bmatrix} \tag{7}$$

The discordance matrix (D) shows the degree that a particular alternative A_k is worse than a competing alternative A_l. The elements of the discordance matrix (D) are calculated by Equation (8)

$$d_{kl} = \frac{\max\limits_{j \in D_{kl}} \left| y_{kj} - y_{lj} \right|}{\max\limits_{j} \left| y_{kj} - y_{lj} \right|} \tag{8}$$

As with the C matrix, the D matrix is also a mxm matrix and does not have a value for $k = l$. The discordance matrix is described in Equation (9)

$$D = \begin{bmatrix} - & d_{12} & d_{13} & \dots & d_{1m} \\ d_{21} & - & d_{23} & \dots & d_{2m} \\ . & & & & . \\ . & & & & . \\ . & & & & . \\ d_{m1} & d_{m2} & d_{m3} & \dots & - \end{bmatrix} \quad (9)$$

Moreover, both of these two mxm matrices are not symmetric.

Step 5. Determine the concordance and discordance dominance matrices. The concordance dominance matrix (F) is a mxm matrix and the elements of the matrix are obtained from the comparison of the concordance threshold ($\underline{c}$) with the elements (c_{kl}) of the concordance matrix. The concordance threshold value ($\underline{c}$) is obtained by the formula

$$\underline{c} = \frac{1}{m(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} c_{kl} \quad (10)$$

m shows the number of decision points in the formula. More specifically, the value of $\underline{c}$ is equal to the product of the total value of the elements of C matrix and $\frac{1}{m(m-1)}$.

Based on the threshold value, the elements of the concordance dominance matrix F are decided by

$$c_{kl} \geq \underline{c} \Rightarrow f_{kl} = 1,\ c_{kl} < \underline{c} \Rightarrow f_{kl} = 0$$

it also shows the same decision points on the diagonal of the matrix, so it has no value.

In a similar way, the discordance dominance matrix G is described by using a threshold value d, where d could be explained as

$$\underline{d} = \frac{1}{m(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} d_{kl} \quad (11)$$

$$d_{kl} \geq \underline{d} \Rightarrow g_{kl} = 1,\ d_{kl} < \underline{d} \Rightarrow g_{kl} = 0$$

Step 6. Construction of the aggregate dominance matrix (E). Here, the E is a mxm matrix depending on the C and D matrices and it consists of 1 or 0 values.

$$e_{kl} = f_{kl} \times g_{kl} \quad (12)$$

Step 7. Determining the order of importance for decision points. The rows and columns of the E matrix represent the decision points. For example, if the matrix E is calculated as

$$E = \begin{bmatrix} - & 0 & 0 \\ 1 & - & 0 \\ 1 & 1 & - \end{bmatrix}$$

$$e_{21} = 1,\ e_{31} = 1 \text{ and } e_{32} = 1$$

This indicates that the second alternative is preferred to the first alternative, the third alternative is preferred to the first alternative, and the third alternative is preferred to the second alternative by using both the concordance and discordance criteria. In this case, if the decision points are expressed with the symbol A_i ($i = 1, 2, \dots, m$) the order of importance for the decision points will be in the form of A_3, A_2, and A_1.

4. Results

After determining the criteria in Table 3, the results of the assessments made by the three experts have been reduced to a single value in order to determine the preferences of the criteria. In addition, according to experts' evaluations, the renewable energy sources in Turkey were considered as priority criteria (r_i).

Table 3. Table created by the experts.

Alternatives	Criteria				
	Solar Energy	Wind Energy	Hydroelectricity	Geothermal Energy	Biomass
Black Sea Region	45	50	7	6	5
Aegean Region	60	60	6	6	5
Marmara Region	50	65	5	7	6
Mediterranean Region	100	68	8	6	6
Central Anatolia Region	70	60	6	6	7
Southeastern Anatolia Region	80	50	6	5	5
East Anatolia Region	50	40	5	4	5
r_j	1	2	3	4	5

Table 4 shows the weights of the criteria. In the table, it is seen that solar energy has the highest weight with 0.4386 and biomass has the lowest weight with 0.0877. The criteria have different units. Therefore, vector normalization is applied. Because it allows the criteria to be studied together with different units. Table 5 shows the values which were obtained after vector normalization.

Table 4. Weights of the criteria.

Alternatives	Criteria				
	Solar	Wind	Hydroelectric	Geothermal	Biomass
Black Sea Region	45	50	7	6	5
Aegean Region	60	60	6	6	5
Marmara Region	50	65	5	7	6
Mediterranean Region	100	68	8	6	6
Central Anatolia Region	70	60	6	6	7
Southeastern Anatolia Region	80	50	6	5	5
East Anatolia Region	50	40	5	4	5
r_j	1	2	3	4	5
Weights (w_j)	0.4386	0.2193	0.1447	0.1097	0.0877

Table 5. Values which were obtained after vector normalization.

	Alternatives	Criteria				
		Solar (1)	Wind (2)	Hydroelectric (3)	Geothermal (4)	Biomass (5)
A	Black Sea Region	0.2518	0.3322	0.4253	0.3922	0.3365
B	Aegean Region	0.3358	0.3937	0.3645	0.3922	0.3365
C	Marmara Region	0.2798	0.4319	0.3012	0.4575	0.4038
D	Mediterranean Region	0.5596	0.4518	0.4860	0.3922	0.4038
E	Central Anatolia Region	0.3918	0.3987	0.3645	0.3922	0.4711
F	Southeastern Anatolia Region	0.4477	0.3322	0.3645	0.3268	0.3365
G	East Anatolia Region	0.2798	0.2658	0.3012	0.2614	0.3365

Table 6 shows weighted normalization matrix.

Table 6. Weighted normalization matrix.

Alternatives		Criteria				
		Solar (1)	Wind (2)	Hydroelectric (3)	Geothermal (4)	Biomass (5)
A	Black Sea Region	0.1104	0.0729	0.0615	0.0430	0.0295
B	Aegean Region	0.1473	0.0874	0.0527	0.0430	0.0295
C	Marmara Region	0.1227	0.0947	0.0436	0.0532	0.0354
D	Mediterranean Region	0.2454	0.0991	0.0703	0.0430	0.0354
E	Central Anatolia Region	0.1718	0.0874	0.0527	0.0430	0.0413
F	Southeastern Anatolia Reg	0.1964	0.0729	0.0527	0.0358	0.0295
G	East Anatolia Region	0.1227	0.0583	0.04360	0.0286	0.0295

After vector normalization, all the elements of the matrix are multiplied by the weighs to obtain the weighted normalized decision matrix and it is shown in Table 6. Table 7 shows the construction of concordance and discordance sets. Concordance and discordance clusters are created by using the data in the weighted normalized decision matrix in Table 6. In order to create the clusters shown in Table 7, pairwise comparisons are made between the row elements. As a result of the comparisons, when the high and equal values constitute a concordance set (*C*), the low values constitute a discordance set (*D*).

Table 7. Construction of concordance and discordance sets.

Concordance Set	Discordance Set
C (A,B) = (3,4,5)	D (A,B) = (1,2)
C (A,C) = (3)	D (A,C) = (1,2,4,5)
C (A,D) = (4)	D (A,D) = (1,2,3,5)
C (A,E) = (3,4)	D (A,E) = (1,2,5)
C (A,F) = (2,3,4,5)	D (A,F) = (1)
C (A,G) = (2,3,4,5)	D (A,G) = (1)
C (B,A) = (1,2,4,5)	D (B,A) = (3)
C (B;C) = (1,3)	D (B;C) = (2,4,5)
C (B,D) = (4)	D (B;D) = (1,2,3,5)
C (B,E) = (2,3,4)	D (B,E) = (1,5)
C (B,F) = (2,3,4,5)	D (B,F) = (1)
C(B,G) = (1,2,3,4,5)	D (B,G) = (0)
C (C,A) = (1,2,4,5)	D (C,A) = (3)
C (C,B) = (2,4,5)	D (C,B) = (1,3)
C (C;D) = (4,5)	D (C;D) = (1,2,3)
C (C,E) = (2,4)	D (C,E) = (1,3,5)
C (C,F) = (2,4,5)	D (C,F) = (1,3)
C(C,G) = (1,2,3,4,5)	D (C,G) = (0)
C(D,A) = (1,2,3,4,5)	D (D,A) = (0)
C(D,B) = (1,2,3,4,5)	D (D,B) = (0)
C (D,C) = (1,2,3,5)	D (D,C) = (4)
C (D,E) = (1,2,3,4)	D (D,E) = (5)
C(D,F) = (1,2,3,4,5)	D(D,F) = (0)
C (D,G) = (1,2,3,4,5)	D (D,G) = (0)
C (E,A) = (1,2,4,5)	D (E,A) = (3)
C(E,B) = (1,2,3,4,5)	D (E,B) = (0)
C (E,C) = (1,5)	D (E,C) = (2,3,4)
C (E,D) = (4,5)	D (E,D) = (1,2,3)
C (E,F) = (3,4,5)	D (E,F) = (1,2)
C(E,G) = (1,2,3,4,5)	D (E,G) = (0)

Table 7. *Cont.*

Concordance Set	Discordance Set
C(F,A) = (1,2,5)	D (F,A) = (3,4)
C (F,B) = (1,3,5)	D (F,B) = (2,4)
C (F,C) = (1,3)	D (F,C) = (2,4,5)
C(F,D) = (0)	D (F,D) = (1,2,3,4,5)
C (F,E) = (1,3)	D (F,E) = (2,4,5)
C (F,G) = (1,2,3,4,5)	D (F,G) = (0)
C (G,A) = (1,5)	D (G,A) = (2,3,4)
C (G,B) = (5)	D (G,B) = (1,2,3,4)
C (G,C) = (1,3)	D (G,C) = (2,4,5)
C (G,D) = (0)	D (G,D) = (1,2,3,4,5)
C (G,E) = (0)	D (G,E) = (1,2,3,4,5)
C (G,F) = (5)	D (G,F) = (1,2,3,4)

For example, C (A, B) = (3,4,5) shows that, according to Table 6, the Black Sea Region (A) has equal or greater values than Aegean Region (B) in terms of hydroelectric (3), geothermal (4), and biomass (5). Also, D (A, B) = (1,2) shows that, according to Table 6, the Black Sea Region (A) has less values than Aegean Region (B) in terms of solar (1) and wind (2).

On the other hand, C (B,A) = (1,2,4,5) shows that according to the Table 6 Aegean Region (B) has equal or greater values than Black Sea Region (A) in terms of solar (1), wind (2), geothermal (4), and biomass (5). Besides, D (B,A) = (3) shows that according to the Table 6 Aegean Region (B) has less values than Black Sea Region (A) in terms of hydroelectric (3).

Table 8 shows the calculation results of the concordance and discordance indices:

Table 8. Calculation results of concordance and discordance indices.

Concordance Indices	Discordance Indices
C (A,B) = 0.3421	D (A,B) = 0.6529
C (A,C) = 0.1447	D (A,C) = 0.8503
C (A,D) = 0.1097	D (A,D) = 0.8903
C (A,E) = 0.2544	D (A,E) = 0.7456
C (A,F) = 0.5614	D (A,F) = 0.4386
C (A,G) = 0.5414	D (A,G) = 0.4386
C (B,A) = 0.8553	D (B,A) = 0.1447
C (B,C) = 0.5833	D (B,C) = 0.4167
C (B,D) = 0.1097	D (B;D) = 0.8903
C (B,E) = 0.4737	D (B,E) = 0.5263
C (B,F) = 0.5614	D (B,F) = 0.4386
C (B,G) = 1.00	D (B,G) = 0.00
C (C,A) = 0.8553	D (C,A) = 0.1447
C (C,B) = 0.4167	D (C,B) = 0.5833
C (C;D) = 0.1974	D (C;D) = 0.8026
C (C,E) = 0.3290	D (C,E) = 0.6710
C (C,F) = 0.4167	D (C,F) = 0.5833
C (C,G) = 1.00	D (C,G) = 0.00
C (D,A) = 1.00	D (D,A) = 0.00
C (D,B) = 1.00	D (D,B) = 0.00

Table 8. *Cont.*

Concordance Indices	Discordance Indices
C (D,C) = 0.8903	D (D,C) = 0.1097
C (D,E) = 0.9123	D (D,E) = 0.0877
C (D,F) = 1.00	D (D,F) = 0.00
C (D,G) = 1.00	D (D,G) = 0.00
C (E,A) = 0.8563	D (E,A) = 0.1447
C (E,B) = 1.00	D (E,B) = 0.00
C (E,C) = 0.5263	D (E,C) = 0.4737
C (E,D) = 0.1974	D (E,D) = 0.8026
C (E,F) = 0.3421	D (E,F) = 0.6579
C (E,G) = 1.000	D (E,G) = 0.00
C (F,A) = 0.7456	D (F,A) = 0.2544
C (F,B) = 0.6710	D (F,B) = 0.3290
C (F,C) = 0.5833	D (F,C) = 0.4167
C (F,D) = 0.00	D (F,D) = 1.00
C (F,E) = 0.5833	D (F,E) = 0.4167
C (F,G) = 1.00	D (F,G) = 0.00
C (G,A) = 0.5263	D (G,A) = 0.4737
C (G,B) = 0.0877	D (G,B) = 0.9123
C (G,C) = 0.5833	D (G,C) = 0.4167
C (G,D) = 0.00	D (G,D) = 1.00
C (G,E) = 0.00	D (G,E) = 1.00
C (G,F) = 0.0877	D (G,F) = 0.9123

$\sum$ C = 23,3391; $\sum$ D = 18,6509; $\overline{C}$ = 0.5557; and $\overline{D}$ = 0.4441.

Concordance and discordance indices are shown in Table 8. Weight values (W_{ij}) in Table 4 were utilized to calculate the concordance index and then the discordance index was calculated by using the values in Table 6. The sum of them is equal to 1. The average of *C* and *D* were calculated to be able to compare the superiority after the calculation of the indices. Table 9 shows the superiority comparisons.

If $C_{pq} \geq C_{average}$ and $D_{pq} < D_{average}$, it means that $A_p \rightarrow A_q$. In other words, the p. unit superior to the q. unit.

Table 9. Superiority comparison.

C_{pq}	$C_{pq} \geq \overline{C}$	D_{pq}	$D_{pq} < \overline{D}$	$A_p \rightarrow A_q$
C (A,B) = 0.3421	no	D (A,B) = 0.6579	no	
C (A,C) = 0.1447	no	D (A,C) = 0.8503	no	no
C (A,D) = 0.1097	no	D (A,D) = 0.8903	no	no
C (A,E) = 0.2544	no	D (A,E) = 0.7456	no	no
C (A,F) = 0.5614	yes	D (A,F) = 0.4386	yes	A → F
C (A,G) = 0.5614	yes	D (A,G) = 0.4386	yes	A → G
C (B,A) = 0.8553	yes	D (B,A) = 0.1447	yes	B → A

Table 9. *Cont.*

C_{pq}	$C_{pq} \geq \overline{C}$	D_{pq}	$D_{pq} < \overline{D}$	$A_p \rightarrow A_q$
C (B;C) = 0.5833	yes	D (B;C) = 0.4167	yes	B → C
C (B;D) = 0.1097	no	D (B;D) = 0.8903	no	no
C (B,E) = 0.4737	no	D (B,E) = 0.5263	no	no
C (B,F) = 0.5614	yes	D (B,F) = 0.4386	yes	B → F
C (B,G) = 1.0000	yes	D (B,G) = 0.0000	yes	B → G
C (C,A) = 0.8553	yes	D (C,A) = 0.1447	yes	C → A
C (C,B) = 0.4167	no	D (C,B) = 0.5833	no	no
C (C;D) = 0.1974	no	D (C;D) = 0.8026	no	no
C (C,E) = 0.3290	no	D (C,E) = 0.6710	no	no
C (C,F) = 0.4167	no	D (C,F) = 0.5833	no	no
C (C,G) = 1.0000	yes	D (C,G) = 0.0000	yes	C → G
C (D,A) = 1.0000	yes	D (D,A) = 0.0000	yes	D → A
C (D,B) = 1.0000	yes	D (D,B) = 0.0000	yes	D → B
C (D,C) = 0.8903	yes	D (D,C) = 0.1097	yes	D → C
C (D,E) = 0.9123	yes	D (D,E) = 0.0877	yes	D → E
C (D,F) = 1.0000	yes	D (D,F) = 0.0000	yes	D → F
C (D,G) = 1.0000	yes	D (D,G) = 0.0000	yes	D → G
C (E,A) = 0.8553	yes	D (E,A) = 0.1447	yes	E → A
C (E,B) = 1.0000	yes	D (E,B) = 0.0000	yes	E → B
C (E,C) = 0.5263	no	D (E,C) = 0.4737	no	no
C (E,D) = 0.1974	no	D (E,D) = 0.8026	no	no
C (E,F) = 0.3421	no	D (E,F) = 0.6579	no	no
C (E,G) = 1.0000	yes	D (E,G) = 0.0000	yes	E → G
C (F,A) = 0.7456	yes	D (F,A) = 0.2544	yes	F → A
C (F,B) = 0.6710	yes	D (F,B) = 0.3290	yes	F → B
C (F,C) = 0.5833	yes	D (F,C) = 0.4167	yes	F → C
C (F,D) = 0.0000	no	D (F,D) = 1.0000	no	no
C (F,E) = 0.5833	yes	D (F,E) = 0.4167	yes	F → E
C (F,G) = 1.0000	yes	D (F,G) = 0.0000	yes	F → G
C (G,A) = 0.5263	no	D (G,A) = 0.4737	no	no
C (G,B) = 0.0877	no	D (G,B) = 0.9123	no	no
C (G,C) = 0.5833	yes	D (G,C) = 0.4167	yes	G → C
C (G,D) = 0.0000	no	D (G,D) = 1.0000	no	no
C (G,E) = 0.0000	no	D (G,E) = 1.0000	no	no
C (G,F) = 0.0877	no	D (G,F) = 0.9123	no	no

As it can be seen from the ranking relationship, only alternative D stays inside the seed: (A → F), (A → G), (B → A), (B → C), (B → F), (B → G), (C → A), (C → G), (D → A), (D → B), (D → C), (D → E), (D → F, (D → G), (E → A), (E → B), (E → G), (F → A), (F → B), (F → C), (F → G), and (G → C).

After obtaining the net concordance and net discordance indices, the dominant alternative can be obtained. Table 10 shows the dominated alternatives.

Table 10. Dominated alternatives.

Net Concordance Index		Net Discordance Index	
C (A)	−2.8841	D (A)	2.8841
C (B)	0.0699	D (B)	−0.0659
C (C)	−0.0961	D (C)	0.1011
C (D)	5.1884	D (D)	−5.1884
C (E)	1.3634	D (E)	−1.3634
C (F)	0.7016	D (F)	−0.6139
C (G)	−4.2564	D (G)	4.2764

As shown in Table 10, after the net concordance (C_p) and the net discordance (D_p) indexes are calculated, the net C_p values are sorted in descending order and the net D_p values are sorted in ascending order. Thus, the sorting result is obtained. Table 11 shows the sorting results for the net C_p and the net D_p indexes (ELECTRE).

Table 11. Sorting results for the net C_p and the net D_p indexes (ELECTRE).

C_{p1}; C(D) 5.1884: Mediterranean region	D_{p1}; D(D) −5.1884
C_{p2}; C(E) 1.3634: Central Anatolia Region	D_{p2}; D(E) −1. 3630
C_{p3}; C(F) 0.7016: Southeastern Anatolia Region	D_{p3}; D(F) −0.6139
C_{p4}; C(B) −0.0699: Aegean Region	D_{p4}; D(B) − 0.0659
C_{p5}; C(C) −0.0961: Marmara Region	D_{p5}; D(C) 0.1011
C_{p6}; C(A) −2.8841: Black Sea Region	D_{p6}; D(A) 2.8841
C_{p7}; C(G) −4.2564: Eastern Anatolia Region	D_{p7}; D(G) 4.2764

The Mediterranean region has the highest value among the C_p values and the lowest value among the D_p values when considered in terms of the potential of all renewable energy sources. Therefore, the region is identified as the most suitable geographical region for renewable energy facilities with respect to the ELECTRE method and the ranking is Mediterranean region, Central Anatolia region, Southeastern Anatolia region, Aegean region, Marmara Region, Black Sea Region, and Eastern Anatolia Region respectively. The Mediterranean region is suitable for all renewable sources. According to the final result, solar and biomass energy for Central Anatolia region; solar and hydroelectric energy for the Southeastern Anatolia; solar and biomass energy for the Eastern Anatolia regions; wind and geothermal energy for the Aegean; geothermal, wind, and biomass energy for the Marmara; and hydroelectric energy for the Black Sea are recommended.

5. Discussion

Renewable energy sources (RES) are very attractive as alternative energy sources. Therefore, successful decision making about optimum site selection for use of RES is a significantly difficult issue. Before construction of RES power stations, both economic and ecological determinants should be considered. The electricity generation from hydroelectric plants in rivers known for their superior ecological characteristics in the Black Sea Region constitutes many negative environmental impacts, so this issue is still controversial. Moreover, the projects and basic principles to be established about RES are substantially significant in terms of preventing global climate change and creating a livable environment. Observation of every project developed on this issue by international organizations such as the European Environmental Information and Observation Network (EIONET) will be an important step in this area. Besides, in which area what kind of MCDM is used was decided at the end of years of studies. For instance, Çolak and Kaya [54] used a fuzzy MCDM design that includes a fuzzy AHP and fuzzy TOPSIS approaches. They estimated the best appropriate renewable energy alternatives for Turkey. The alternatives were solar, wind, hydraulic, geothermal, biomass, hydrogen, and wave energies. The weights of main and sub-criteria were calculated by applying AHP and then the alternative rankings were determined by applying TOPSIS. In consequence, according to the suggested MCDM model, the most convenient renewable energy resources are wind energy, solar energy, hydraulic energy, biomass energy, geothermal energy, wave energy, and hydrogen energy respectively, while the ranking results of [Kabak and Dağdeviren [18]] used ANP in weighting were hydro, solar, wind, geothermal, and biomass energy respectively. As seen, different results were obtained in two studies for Turkey. This is due to the subjective nature of the MCDM methods and this characteristic is considered as the biggest weakness. The same problem assessed by different experts may give different results. AHP and ANP are the most popular MCDM methods due to their simplicity in process. As outlined in the second section, the proposed ELECTRE method is one of the outranking methods and considers concordance and discordance. Therefore, it is recommended for the energy and environment planning studies compared to other MCDM methods. ELECTRE and PROMETHEE are also popular for sustainable renewable energy development fields. Especially, ELECTRE is suggested in energy planning. Decision makers used it due to the large perspective that gives a useful observe in computing all the queries or doubts. These techniques are more advantageous in practices based on energy demand allocation.

The estimation of the most appropriate renewable energy sources for geographic regions in Turkey has been discussed in many studies. As a future study proposal, different MCDM methods may be applied to solve this problem and the outputs may be compared with this article.

6. Conclusions

The paper detailed energy targets and opportunities within the framework of the 2023 strategic plan in the introduction and alternatives sections. The need for energy in Turkey until 2023 is expected to increase between 4–6 percent annually, so Turkey aims to increase the capacity of RES energy to 30 percent by 2023. The estimated energy investment will be approximately 110 billion dollars up to 2023. Therefore, Turkey is a significant market for companies and investors operating in the energy sector. Turkey has great potential with respect to RES. Wind and solar energies are at the top of the Turkish renewable energy market and they have become attractive for local and foreign investors since 2010, because many positive regulations and incentive plans came into force. The paper also aims to inform all local or foreign investors related to energy and especially RES. At this point, the site selection for energy investment is very important problem. In this study, multi-criteria decision making (MCDM) method was applied to decide on the most appropriate renewable energy sources based on seven geographical regions in Turkey. Hence, the recommended approach (ELECTRE) estimated the allocation of RES through considering their regional conditions and potentials. The proposed convenient renewable energy sources (RES) for electricity production in Turkey are solar, hydroelectric, wind, biomass, and geothermal power. The Mediterranean region is identified as the most suitable geographical region for renewable energy facilities with respect to the ELECTRE method and the ranking is Mediterranean, Central Anatolia, Southeastern Anatolia, Aegean, Marmara, Black Sea, and Eastern Anatolia respectively. The Mediterranean region is suitable for all renewable sources. According to the final result, solar and biomass energy for Central Anatolia region; solar and hydroelectric energy for the Southeastern Anatolia; solar and biomass energy for the Eastern Anatolia regions; wind and geothermal energy for the Aegean; geothermal, wind, and biomass energy for the Marmara; and hydroelectric energy for the Black Sea are recommended.

The way of using and generating energy should not cause a negative effect on society's health and environment. We should stop ignoring or avoiding environmental problems. It is required that policy makers compose a strategy to stimulate the larger use of renewable resources. Accelerating support of research and development, education, and public consciousness will help to carry out renewable energy goals. There are endless, fresh, and unused resources at our fingertips. The economy and simplicity of fossil fuels should not blind us to the truth that they are a seriously finite source, and damaging to our ecosystem. With the support of renewable energy resources such as hydroelectric, solar, wind, geothermal, and biomass, we may move towards a sustainable world.

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