REPUBLIC OF TURKEY
ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF INDUSTRIAL ENGINEERING

SELECTION OF RENEWABLE ENERGY SOURCES USING FUZZY AHP

OZAN VELİ YILDIRAN

MASTER OF SCIENCE

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I hereby declare that all information in this thesis has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all information that is not original to this work.

[Signature]

Ozan Veli YILDIRAN

ABSTRACT

SELECTION OF RENEWABLE ENERGY SOURCES USING FUZZY AHP

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The importance of renewable energy is increasing both with the insufficiency of traditional energy resources and environmental consciousness. In addition, potential of the renewable energy sources in Turkey is very large, and utilizing the potential is an inevitable alternative for increasing its self-sufficiency with an environmentally friendly way. Also, The Republic of Turkey plans to supply 30% of its energy demand from renewable energy alternatives in 2023. Therefore, evaluation of renewable energy alternatives and determination of the most suitable renewable energy alternative are important issues to make a reasonable energy investment plan. In this thesis, a modified fuzzy AHP methodology is applied for the case of Turkey to rank renewable energy sources by taking suitability and effectiveness into consideration. Biomass energy, geothermal energy, solar energy, wind energy, and hydropower energy are investigated as renewable energy alternatives. Four main criteria (social, technical, environmental, and economic) and eight sub-criteria are taken into consideration. Later, the results are presented and discussed. Solar energy is found as the most suitable renewable energy alternative for Turkey, followed by wind energy, geothermal energy, hydropower energy and biomass energy.

Keywords: Fuzzy Analytic Hierarchy Process, Energy Strategy, Renewable Energy.

ÖZET

BULANIK AHP KULLANILARAK YENİLENEBİLİR ENERJİ KAYNAĞI SEÇİMİ

Ozan Veli YILDIRAN
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Yenilenebilir enerjinin önemi hem geleneksel enerji kaynaklarının yetersizliği hem de çevre bilincinin artmasıyla artmaktadır. Türkiye, yenilenebilir enerji kaynakları için büyük bir potansiyele sahiptir ve bu potansiyeli kullanmak, kendi kendine yeterliliğini çevre dostu bir şekilde artırmak için kaçınılmaz bir alternatiftir. Bunlara ek olarak, Türkiye Cumhuriyeti 2023 yılında enerji ihtiyacının % 30'unu yenilenebilir enerji kaynaklarından tedarik etmeyi planlamaktadır. Bu nedenle, ülke için yenilenebilir enerji alternatiflerinin değerlendirilmesi ve en uygun yenilenebilir enerji alternatifinin belirlenmesi, makul enerji yatırım planının yapılması için önemli bir konudur. Bu tez çalışması içerisinde Bulanık Analitik Hiyerarşi Prosesi yöntemi kullanılarak yenilenebilir enerji kaynakları değerlendirilmiştir. Yenilenebilir enerji kaynak alternatiflerinden jeotermal enerji, biyokütle enerjisi, güneş enerjisi, rüzgâr enerjisi ve hidrolik enerji göz önünde bulundurulmuştur. Bu enerji kaynaklarını incelemek için dört ana kriter olarak ekonomik, teknik, sosyal ve çevre kriterleri göz önünde bulundurulmuştur. Bu ana kriterlere ek olarak sekiz alt kriter göz önünde bulundurulmuştur. Çalışmanın sonucunda Türkiye için güneş enerjisi alternatifi en uygun alternatif olarak ortaya çıkmıştır. Güneş enerjisinin sonrasında sırası ile rüzgâr enerjisi, jeotermal enerji, hidrolik enerji ve biyokütle enerji alternatifleri en uygun alternatifler olarak elde edilmiştir.

Anahtar Kelimeler: Bulanık Analitik Hiyerarşi Prosesi, Enerji Stratejisi, Yenilenebilir Enerji.

Dedicated to my father Fuat YILDIRAN

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

TEP	:Tons of Equivalent Petroleum
MCDM	:Multi-Criteria Decision Making
AHP	:Analytic Hierarchy Process
OWA	:Ordered Weigh Averaging
MACBETH	:Measuring Attractiveness by a Categorical Based Evaluation Technique
ANP	:Analytic Network Process (ANP)
BOCR	:Benefits, Opportunities, Costs, Risk
TOPSIS	:Technique for Order Preference by Similarity to Ideal Solution
PROMETHEE	:Preference Ranking Organization Method for Enrichment Evaluations
COPRAS	:Complex Proportional Assessment

1. INTRODUCTION

Energy is a really important issue for the social and economic development of societies. In Tukey, energy consumption is rising day by day because of a young and growing population, urbanization. In 2008, 106.3 million Tons of Equivalent Petroleum (TEP) was consumed as the total primary energy consumption of Turkey, at the same time, 29.2 million TEP was produced. Regarding of total energy supply, gas (32%) is the first one and it is followed up by petrol (29.9%), and renewable energy sources containing hydraulic (8.6%). Primary energy consumption of Turkey is anticipated to grow by 4% each year by 2020 ("Turkey Energy Situation", 2018). For that reason, finding the most suitable way of obtaining additional energy for Turkey is a very important issue.

Turkey is an energy importer country. More than nearly 60% of the consumption is supplied by imports and this percentage is growing each year in Turkey (Kaya, 2006). Energy expenditure of Turkey was about 60 billion US$ in 2013, mostly natural gas, which was 1/4 of the import of a total of 237 billion US$ and over 75% of natural gas is being imported just from two states, Iran and Russia. In the future, this is clearly not suitable and supplying energy demand by using renewable energy sources is a critical issue (Melikoğlu, 2013b).

More countries are addressing renewable energy sources beyond traditional ones. Renewable energy sources, which are solar, biomass, hydro, wind, ocean, and geothermal energy, are regarded as endless sources and propose many environmental benefits above conventional energy sources (Kaya, 2006). The generation of renewable or clean technologies can provide many economic opportunities for countries with substantial traditional energy resources and countries that deficiency such sources by suggesting alternative ways to enrich their economies and supply job opportunities for their public (WEF, 2012). Traditional energy production systems are known as more competitive than renewable energy production systems, mainly due to their intermittency and expensive maintenance cost. Nevertheless, there are several advantages of renewable energy, as an example of decline considering reliance on fossil fuel resources and the reduction of particle emissions onto nature. Additionally, safety problems, which are derived from atomic power, can be avoided by using renewable energy sources, it makes renewable energy production to become more desirable for the adoption of nature (Banos, Reca, Martínez, Gil and Márquez, 2011).

Turkey's climate gives some opportunities to use renewable energy sources extensively. There are several kinds of renewable energy sources abundantly such as hydro, solar, wind, biomass, and geothermal in Turkey. Notwithstanding, Turkey is an energy importing country with more than half of the energy requirement being supplied by imports, and it causes air pollution which is getting the more important concern in the country. In this context, renewable energy plants are appeared to be one of the most useful solutions for sustainable energy development and the prevention of environmental pollution in Turkey (Kaygusuz and Sarı, 2003). Thus, the important decision for Turkey is whether or not to build renewable energy plants in a given place, to make a decision about which renewable energy source or combination of sources is the best choice (Banos et al., 2011).

Renewable energy decision-making problem can be considered as a multiple criteria decision-making problem with associating criteria and alternatives. In the decision-making procedure, several conflicting aspects should be taken into consideration, by means of the increasing importance of social, environmental, technological, and economic factors. Traditionally single criteria decision-making procedures cannot deal with the complexity of this problem (Iskin, Taha and Daim, 2013). A traditional single-criteria decision-making procedure which is targeted to identify the efficient source option at low cost was famous during the 1970's. Growing environmental concerns in the 1980s imposed a modification on decision making procedure by taking into account environmental and social considerations in energy planning. Thereby, the selection among energy sources to use has become a multi-criteria decision-making problem with conflicting criteria such as economic, technical, political, social, and environmental. As a result, a multi-criteria approach for decision making appears to be the best tool to investigate some alternatives by taking into consideration benefits and difficulties based on selection criteria.

1.1. Definition of Renewable Energy and Turkey's RE Potential

Energy sources are divided into two main categories as renewable and non-renewable energy by regarding the energy is whether or not a reusable source. Renewable energy is the kind of energy deemed as almost infinite and which can be continually re-used. As an example, the solar energy source is the sun, and it can be transformed into electricity or heat energy. Wind energy and geothermal energy comes from the earth. Biomass energy sources obtained from the plants and hydro-renewable energy sources obtained from water. Renewable energy is considered as the energy which can be re-used as soon as possible (Satman, 2006).

1.1.1. Wind Energy Potential of Turkey

According to feasibility studies, there is a huge potential for wind energy. In theory, the estimated potential form wind energy source is 160 TWh each year in Turkey. But, approximately 124 billion kWh is technically possible, and for some special area, about 14 billion kWh per year can be reachable. The first power plant of Turkey, which had a capacity of 1.5 MW, founded in 1998, and total established capacity has risen to 730 MW by late 2009 (Melikoğlu, 2013b).

1.1.2. Solar Energy Potential of Turkey

In Turkey, there is a plentiful source of solar energy and the approximate solar radiation is 3.6 kWh/m2 per day and total annual radiation period is about 2610 h. In theory, the annual solar energy potential of Turkey is predicted to be 6150 TWh, and economic potential is predicted to be 205 TWh. Regrettably, the solar energy source of Turkey is almost exclusively benefitted for water heating systems. Nevertheless, in the early 21st century, the total established solar electrical energy capacity of Turkey was nearly 300 kW for photovoltaic cells, which are commonly used by communication stations, sea lighthouses, fire observation stations and highway lighting (Melikoğlu, 2013b).

1.1.3. Biomass Energy Potential of Turkey

Biomass production of Turkey is mainly based on wood, wheat straw, hazelnut shell, cocoon shell, fruit tree, crop residues, and grain dust. The annual energy potential of biomass in Turkey is predicted to be about 372,000 GWh or 32 Mtoe and the total possible share is predicted to be around 16.9 Mtoe of 197,000 GWh. Turkey’s first electric production project by using biomass is under development in Adana with 45 MW capacity, and there are two projects under planning in Mersin with 30 MW total capacity (Melikoğlu, 2013b).

1.1.4. Geothermal Energy Potential of Turkey

Turkey is directly using geothermal energy and holding 1/8 of the world's total potential. But unfortunately, most of this potential is comprised of low enthalpy, which is not suitable to produce electric but advisable for heating utilization. The total source of geothermal energy is predicted to be 30,000 GW, but only less than 7,000 GW of this source is suitable for electric production. Geothermal source of electric production in Turkey is predicted to be 2000 – 4500 MW or up to 35,000 GWh each year. As reported by "The Ministry of Energy and Natural Resources", Turkey has a capacity of 77 MW producing 436 GWh yearly by using geothermal energy in 2009 (Akat, 2014).

1.1.5. Hydro Energy Potential of Turkey

Turkey's estimated yearly hydropower potential is to be 432 TWh, which is nearly 1.5% of all around the world's potential and also nearly 14% of Europe's potential. Approximately half of this potential is technically useable, and 28% of this potential or 124,000 GWh yearly is profitable. In accordance with "The General Directorate of State Hydraulic Works" (DSI), Turkey has huge potential, which is nearly 54,000 GWh yearly down from 2012, which is nearly 40% of the exploitable potential (Melikoğlu, 2013a).

1.2. Thesis Scope and Aim

This thesis focuses on determining the rate of renewable energy sources using fuzzy AHP method and ranking renewable energy alternatives regarding Turkey.

The motivation for this study can be listed briefly as follows:

- ❖ Turkey should deal with serious challenges in supplying its increasing energy requirement. To sustain a very quickly growing economy, Turkey's electric demand is rising by an average of 8-9% annually (Ata, 2013).
- ❖ Turkey is an energy importer country. Additionally, there are several alternative energy sources such as hydro, wind, solar, biomass and geothermal abundantly in Turkey. These renewable energy sources are regarded as the key factor to deal with the increasing energy problem of Turkey (Kabak and Dağdeviren, 2014).
- ❖ Turkey should use its sustainable sources so as to be less reliant on other countries. For this reason, the Turkish Government announced a set of very important targets for Turkey's energy sectors under the Vision 2023 agenda. The main target of this agenda

is to curtail the country's dependence on importing fossil fuels, reduce greenhouse gas emission, augment the share of renewable sources in the country's energy mix to 30%, and general rise the country's energy capacity in a sustainable manner (Melikoğlu, 2013b).

- ❖ Energy policy contains deciding the best energy alternatives and deciding investment quantities. So, Turkey's sustainable development count on determining the most suitable renewable energy alternatives.

In this thesis, the MCDM model based on the revised fuzzy AHP approach proposed by Aydın and Kahraman (2011) is applied to Turkey's renewable energy selection problem. The target of this research is to evaluate the most appropriate renewable energy alternatives and to determine ratings of each renewable energy alternatives. The revised fuzzy AHP is an effective and newly published technique. This technique was firstly proposed by Aydın and Kahraman (2011), and later triangular fuzzy scale was revised slightly in their later study published in 2018 (Aydın and Kahraman, 2018).

2. LITERATURE REVIEW

Energy demand has been always growing since the industrial revolution and also restricted energy sources have been a big challenge for many years. This problem has many sub-problems such as determining the best area to construct, selection of best renewable and sustainable energy source, making the best energy policy for a country or specific region regarding many aspects such as economic, social, technical and etc. For this reason, many methods are applied to deal with those problems and these methods are applied by using specific case studies.

2.1. Multi-Criteria Decision Making (MCDM)

"Multi-Criteria Decision Making" (MCDM) is an area of operation research models and a well-known brunch of decision-making. These methods can handle both quantitative as well as qualitative criteria and analyze conflict in criteria and decision-makers (Iskin, et al. 2013; Pohekar and Ramachandran, 2004). There are several categories for this method but generally, these categories are divided into two main categories called "Multi-Objective Decision-Making" (MODM) and "Multi-Attribute Decision-Making" (MADM) (Climaco, 2012). In MODM, the decision problem is characterized by the existence of multiple and competitive objectives that should be optimized against a set of feasible and available constraints (Iskin, et al. 2013; Diakaki et al., 2010). On the other hand, MADM is one of the most famous MCDM methods to be accepted to deal with problems affiliated with different viewpoints (Iskin, et al. 2013). They contain various methods of which the most essential are Analytic Hierarchy Process (AHP), "Preference Ranking Organization Method for Enrichment Evaluations" (PROMETHEE), "Elimination Et Choix Traduisant la Realité" ("Elimination and Choice Expressing Reality" or more called ELECTRE), and "Multi-Attribute Utility Theory"(MAUT) (Iskin, et al. 2013; San Cristóbal, 2011). All these methods have been used to define the best alternative of renewable energy sources for many years.

2.1.1. Renewable Energy Selection Studies Using Analytic Hierarchy Process (AHP)

Saaty (1980) is the developer of the Analytic Hierarchy Process and first user of this method. The purpose of this method is the disintegration of complicated problems into several basic problems. In AHP, the case is generated as a hierarchy. The objective is at a high level, criteria and sub-criteria are at intermediate and also all alternatives are at the lowest of the hierarchy. The decision of experts is represented pairwise comparison and the optimum alternative can be chosen in accordance with the maximal score among alternatives (Iskin, et al. 2013).

Aras, Erdoğmuş and Koç (2004) used AHP to determine the optimum area to construct a wind observation station at a university campus. Wind observation station is a device to measure wind velocity and wind's pathway for selection the best wind turbine area. In regard to gathering trustworthy data, wind observation station should be constructed at an optimum area. It is a very important issue for this project.

Nigim, Munier and Green (2004) attempted to examine which renewable energy source is the best choice for a special area. Two different methods called AHP and SIMUS are used for this problem. Those two methods are proved to be useful and help decision-makers for the selection of the best renewable energy source.

Kahraman, Kaya and Cebi (2009) used two methodologies to select the best renewable energy source for Turkey. The first methodology is Fuzzy AHP and another one is Axiomatic Design under Fuzziness. In this study, four different expert decisions are taken to rank four main criteria and seventeen sub-criteria.

Lee, Chen and Kang (2009) applied AHP to define which wind farm project is the best among five different projects. They used several criteria are related to risk, opportunity, benefits, risk of the project and this method applied a case study and they ranked alternatives.

Heo, Kim and Boo (2010) used Fuzzy AHP to help Korean Government to catch up government's target of energy by 2030. The purpose of the Korean Government is to supply 11% energy demand from renewable energy sources. Fuzzy AHP method was used to investigate renewable energy sources for the potential of Korean. Five main criteria and seventeen sub-criteria are applied for this study.

Taiwanese Government published the Sustainable Energy Policy Principles in 2008. According to the principles, renewable energy should comply with 3E goals which are economy, environment, and energy. Shen et al (2010) published a study about renewable energy sources of Taiwanese. In this study, Fuzzy AHP method is used to assess which renewable energy source is suitable for Taiwanese respecting 3E goals.

In every country, energy policy has a huge impact on the economy and also the environment. Due to this reason, Kahraman and Kaya (2010) generated a methodology by using Fuzzy AHP method to aid decision-makers and policymakers for making the best selection of energy alternative. This methodology is applied to Turkey. Their result indicates that wind energy generation is the best alternative for Turkey.

Al-Yahyai, Charabi, Gastli, Al-Badi and Wind (2012) used AHP and "Ordered Weigh Averaging" (OWA) to categorize Oman's land regarding their suitability of wind energy.

Erol and Kılkıs (2012) generated a method so as to make a plan for energy source by using AHP. This method was applied to a case study for Aydın City in Turkey. Their results conclude that solar energy source is the best alternative to invest in this area. And also, entrepreneur and government can invest in geothermal energy source and de-centralized lignite power plants using clean technology.

Ertay, Kahraman and Kaya (2013) applied AHP and "Measuring Attractiveness by a Categorical Based Evaluation Technique" also known as MACBETH with fuzzy set to help Turkey to select the best renewable energy source. Because the energy demand of Turkey has risen for thirty years and still goes on. Turkey government must deal with this increment.

Demirtaş (2013) focused on the examination of the most excellent renewable energy production source for the planning of sustainable energy. For this purpose, the AHP method was applied in this proposed method. Selection criteria's weights are discovered by means of pairwise comparison matrices of AHP. As a result of this study, the wind energy source is the best alternative for energy production.

Feili, Rabiei, Ahmadian, Karimi and Majidi (2016) (2016) used the AHP method to rank renewable energy alternatives as biogas, biomass, and wind for Esfahan, Iran. Four criteria as efficiency, cleanliness, reliability, and cost are used and biogas energy alternative is selected as the best one.

Solangi, Tan, Mirjat and Ali (2019), used "Strengths, Weaknesses, Opportunities and Threats" (SWOT) analysis to examine criteria and subcriteria for the case of Pakistan's renewable energy planning strategies. And then AHP used to calculate weights of criteria and subcriteria of the case. Lastly, Fuzzy TOPSIS Methodology is applied to rank 13 energy strategy to achieve the target of Pakistan's renewable energy planning.

2.1.2. Renewable Energy Selection Studies Using VIKOR & ANP

Because of the continuously rising energy demand in Turkey. Ulutaş (2005) used the analytic network process (ANP) method to investigate nine different energy sources to make a suggestion to use. A case study was conducted. Their result indicated that biogas energy source is the best alternative for Turkey.

San Cristóbal (2011) published a study to support the Spanish Government to curb import which related energy. Because the Spanish government's import was at a high level in this area. In this study, the VIKOR method was used to determine which energy sources are good to choose for Spanish. In conclusion, biomass is chosen as the fittest alternative for Spanish. Respectively, wind power and solar thermo-electric are suitable for Spanish.

Vučijak, Kupusović, Midžić-Kurtagić and Ćerić (2013) used VIKOR to assist decision-makers for the design of process, selection of hydropower plant site, operational and technical parameters when they are deciding project of hydropower plant regarding many criteria about economic and environmental as to technical, operational and selection of a site.

Cannemi, García-Melón, Aragonés-Beltrán and Gómez-Navarro (2014) worked on a case study with two scenarios which investing biomass power plant in Italy by using ANP method. First scenario using old fashion decision-making method, another one is applying a new method. This study revealed the opinions of public administrations and investors for two scenarios. The target of this study is to generate new methods for policymakers as to the renewable energy industry.

Kabak and Dağdeviren (2014) attempted to suggest a new model prioritize renewable energy sources for Turkey in their publication. ANP and BOCR (Benefits, Opportunities, Costs, Risk) methods are used with nineteen related criteria. In this study, a case study applied, and hydro energy source was selected as the best one of renewable energy source for Turkey.

2.1.3. Renewable Energy Selection Studies Using TOPSIS

Doukas and Psarras (2009) attempted to help the energy sector's actor by suggesting a new method. This new method provided a flexible and transparent way to appraise renewable energy alternatives for those actors by using the TOPSIS method. And also, Greece's renewable energy industry and potential were investigated in this study.

Perera, Attalage, Perera and Dassanayake (2013) used fuzzy TOPSIS and multi-objective optimization to aid decision-makers during the design period of hybrid energy systems. Four different objectives are considered. In this study, this method's efficiency is approved to determine objective's relative weights by giving an accurate picture of the objectives to decision-makers when finding the best hybrid energy system.

Şengül, Eren, Eslamian-Shiraz, Gezder and Şengül (2015) have ranked renewable energy sources in Turkey by using Fuzzy TOPSIS method. In this study, they used "The Interval Shannon's Entropy Method" while deciding the criteria's weight rate. In the case study, four main and nine sub-criteria are used to classify renewable energy production systems. The hydro energy power source was selected as the best one.

2.1.4. Renewable Energy Selection Studies Using PROMETHEE II

Haralambopoulos and Polatidis (2003) proposed a framework to help decision-makers by using PROMETHEE II. This framework is tested with a case study in an island's geothermal energy potential. This generated method enables decision-makers to investigate all renewable energy sources effectively by taking an idea from different experts. Thanks to this method decision-makers could lead the way towards a general agreement.

Tsoutsos, Drandaki, Frantzeskaki, Iosifidis and Kiosses (2009) used both PROMETHEE I and PROMETHEE II at the same case study which related plans of sustainable energy sources on Greece's island called Crete. Many energy planning options, which are included renewable energy source alternatives, are investigated regarding some criteria as to the economy, social, environment and engineering ranked by renewable energy experts in Greece. This study revealed all renewable energy sources for the Island in a numeric classification.

Troldborg, Heslop and Hough (2014) aimed to generate and use multi-criteria analyses for Scotland's sustainable energy capacity assessment and line up eleven renewable energy for Scotland and to accurately analyze uncertainties. PROMETHEE method is applied for multi-criteria analyses using three main criteria and nine sub-criteria. This study supports a probabilistic ranking for renewable energy sources.

2.1.5. Renewable Energy Selection Studies Using MCDM Integrated Methods

The selection of a residential energy system is hard to choose, and it is dealt with financial, efficiency and also environmental aspects. Ren, Gao, Zhou and Nakagami (2009) generated an integrated model to solve this problem by using AHP and PROMETHEE. This model is used to detect which energy system is the best selection for residential energy taking into consideration many related data. A case was conducted in Kitakyushu, Japan. In this case, traditional and renewable energy systems are investigated to solve this problem. In conclusion, renewable energy systems are not good selection without environmental criteria, and it is really important in the current situation. Moreover, the result of the investigation is affected by priorities of criteria in addition to the method of evaluation.

Kaya and Kahraman (2010) used an integrated method which is AHP and VIKOR for two different aim related selection of renewable energy alternatives and energy. The first purpose is to define the best renewable energy source in İstanbul, Turkey by using this method. Another one is to select the optimum energy generation area in İstanbul by using the same methods. AHP is used to rank the selection criteria with weights by using pairwise comparison matrices. In this problem generally, decision-makers cannot make a decision properly because of uncertainty. To deal with this problem, fuzzy logic is applied by taking suggestions from many experts. The outcome of this case, the wind energy source is selected for the best choice to produce energy. And also, the selection of the best region to produce energy is Çatalca district.

Kaya and Kahraman (2011c) suggested a modified fuzzy TOPSIS methodology to choose energy alternative for Turkey. In this study, Fuzzy AHP was used to determine the weights of selection criteria. A multi-criteria energy planning problem was applied in a case study and wind energy source was selected best choose for Turkey.

Streimikiene, Balezentis, Krisciukaitienė and Balezentis (2012) generated a framework to support multi-criteria decision to select the best sustainable energy source and technologies. This framework investigates many contradictory criteria and uses multi-criteria methods called MULTIMOORA and TOPSIS to analyze sustainable energy sources. The system indicator involves many different ways to reveal the sustainability of energy technologies. The sustainable energy technologies, which using solar, thermal and water, is selected as the best alternatives for future energy sources. Also, this framework is suggested to be a basis for sustainable energy policymakers to use for sub-regional optimization.

Yazdani-Chamzini, Fouladgar, Zavadskas and Moini (2013) used an integrated method by using COPRAS (Complex Proportional ASsessment) and AHP to select the most excellent renewable energy technology. AHP is a familiar method of MCDM methods to determine evaluation criteria's weights. And also, COPRAS is an MCDM method to define the best alternatives by using the calculation of ratios. Because of the validation of this methodology, the results of outcomes are checked against five different MCDM methods in this publication.

Solar energy alternative is one of the famous renewable energy sources. Regarding Iran's climatic properties and also huge potential, solar energy production is a really good alternative to construct a solar power plant for Iran. On the otherwise, defining the best area for solar energy is a very important problem to achieve optimum productivity target and determine the practicable area for the building of a high-priced solar power production plant. Contrary to popular opinion, the project of a solar energy production plant is based on not only the quantity of received solar radiation, and also many criteria such as environmental, technical, social, risk and financial. All possible criteria must be taken into consideration to get the best feedback. Vafaeipour, Zolfani, Varzandeh, Derakhti and Eshkalag (2014) used a hybrid MCDM by using "The Step-wise Weight Assessment Ratio Analysis" (SWARA) and "The Weighted Aggregated Sum Product Assessment" (WASPAS). SWARA was used to rank criteria, and WASPAS was applied to prioritize each alternative city. Eventually, they

performed this approach for 25 cities all around the country. This generated hybrid method could help policymakers and decision-makers for the energy sector.
Yeh and Huang (2014) applied an integrated method to decide the best area of wind energy production location by using “The Decision-Making Trial and Evaluation Laboratory” (DEMATEL) and ANP. 28 criteria, which related economy, quality, social, and etc. are taken into account to determine each location and they applied to a case study. This study provided support for the public and business to understand wind power and also this integrated method can give a reference for decision-makers and enterprisers to make good choices.

Büyüközkan and Güleryüz (2014) generated a framework to help decision-makers in the energy sector in order to prioritize renewable energy sources. In this framework, fuzzy AHP was used to deal with vague information taken from decision-makers when defining weights of evaluation criteria. Then, the TOPSIS method was applied to prioritize each renewable energy source and also pick out the best renewable energy source. The result indicated wind energy source as the best one of renewable energy source alternatives of Turkey.

In 2005, “Atomic Energy Agency” published Energy indicators for sustainable development and Kuleli Pak, Albayrak and Erensal (2015) used these indicators to figure out the situation of renewable energy perspective in Turkey. In this study, an integrated model was generated using ANP and TOPSIS. The decision-making process was executed with several criteria as to economical, public, environmental factors. And also, each criterion weight is checked with applying sensitivity analysis. Their study emphasized that hydro energy source is the most effective source for Turkey.

Erdogan and Kaya (2016) used an integrated decision-making method with type-2 fuzzy numbers to prioritize renewable energy sources in Turkey. After that, they created a roadmap to follow in regard to best benefit. Fuzzy set theory was used to tackle uncertainties by taking decisions from many decision-makers. Firstly, type 2 fuzzy set and AHP were used to define criteria’s weights which are influencers. Then, AHP results are applied TOPSIS method to obtain weights of renewable energy source alternatives. In regard to weights of renewable energy source alternatives, a road map for energy policies in Turkey was constructed. Also, this study revealed that wind energy source is the best one for Turkey and wind energy power should be utilized plentifully for energy production.

Büyüközkan and Güleryüz (2016) used the DEMATEL method which is integrated by Analytic Network Process (ANP) to select the best one of suitable renewable energy production sources for Turkey regarding the perspective of enterprisers. In this study, this integrated method was applied to this problem of Turkey for the first time. The study's case study suggested that wind energy source is the best one to produce energy for Turkey.

2.1.6. Renewable Energy Selection Studies Using Mathematical Models

Iniyan and Sumathy (2000) generated a model to minimize the cost/efficiency ratio and to decide the best distribution of renewable energy production sources for different end-users. The way of renewable energy distribution was decided in regard to each renewable energy source potential, energy demand, dependability of each renewable energy source and social acceptance. A case study is investigated to suggest the renewable energy source distribution option for India which helps decision-makers to benefit renewable energy sources markedly.

Borges and Antunes (2003) generated an interactive way to solve fuzzy objective linear programming problems. The generated method is used to deal with vague information and intended to help decision-makers to understand the connection between economic issues and energy production systems at the national level.

Sadeghi and Hosseini (2006) used the "Fuzzy Linear Programming Model" to optimize energy supplying systems and applied this method to a case study of Iran. Fuzzy coefficients are contained for capital cost. Fuzzy linear programming provides decision-makers with a simple and responsive way to make a decision.

Jayaraman, Liuzzi, Colapinto and Malik (2017) offered an analytical framework by using fuzzy goal programming to allocate resources because of real-world challenges imprecise information. This framework was developed to assign sources ideally in regard to energy demand, energy supply, lowering of particle emission, labor force, and economic factors. Also, this method was applied to the United Arab Emirates. Using the method, decision-makers can make strategic plans and investment allocation for sustainable development.

Incekara and Ogulata (2017) suggested a new mathematical model to make a suggestion to achieve Turkey's energy production target in 2030. Required data was taken from official sources like "The Republic of Turkey Ministry of Energy and Natural Resource". This mathematical model constructed on the objective of minimization of energy production costs taking into account particle emission, environmental effects, minimizing fossil fuel using and etc.

2.1.7. Renewable Energy Selection Studies Using Distribution Based on Other Techniques

Buchholz, Rametsteiner, Volk and Luzadisand Multi (2009) aimed to appraise the possibility of Multi-Criteria Analysis to assist the process of application of sustainable bioenergy enterprises. Four Multi-Criteria Analysis tools such as Super Decisions, NAIADE, DecideIT, Decision Lab are examined for their applicability to define the sustainability of bioenergy production in regard to multi stakeholder's perspective. A multi-stakeholder bioenergy case study supplied precious data to be used on Multi-Criteria Analysis tools. Multi-Criteria Analysis is able to pave a way to overcome difficulties by firstly organizing the problem, secondly aiding to identify unclear parts of bioenergy systems and finally incorporating stakeholders for decision phase.

Balezentiene, Streimikiene and Balezentis (2013) suggested an MCDM frame to prioritize energy production technologies by using the fuzzy MULTIMOORA method. Fuzzy MULTIMOORA method allows dealing with inaccurate information. In this study, respective numeric and linguistic indicators are defined in regard to environmental suitability and minimum hazard for environmental. Then set of alternatives was applied for the acceptability of energy corps in the Lithuanian's weather of the region. Accordingly result of this study suggested potential crop mix for energy production with prioritization.

Renewable energy production has several disadvantages like that constant energy production is impossible with the use of one type of renewable energy source. Because renewable energy sources rely on the weather and climate changes, more than one renewable using in a hybrid-systems give a chance to defeat this disadvantage. So that during one of the sources is unavailable, the other one can produce energy. Renewable energy source's other disadvantage is that renewable energy sources cannot be constructed everywhere, each renewable source has special requirements to supply energy. Aydin, Kentel and Duzgun (2013) applied the Ordered Weighted Average method to combine different kind energy source into a hybrid system in regard to special requirements of different renewable energy sources for western Turkey.

Santoyo-Castelazo and Azapagic (2014) used a life cycle approach to examine sustainability for energy technologies by using a framework. This framework included estimation of the life cycle, scenario analysis, spending while life cycle, estimation of social sustainability and also multi-criteria decision-making analysis, those parameters are used to determine the best alternative of sustainable energy production alternative. This framework was applied to Mexico's future electricity production. In this study, any technology options, electricity mixtures and also estimation of climate changes are considered to construct eleven different scenarios just before 2050.

Chang (2015) suggested a multi-choice goal programming model handle capacity growth duty for renewable energy production area selection. In this model, an objective function is defined under constrains for the optimum combination of different energy sources, selection of location and subject-related criteria. A mixture of different kind energy plants should be constructed in the best optimum places, which are taken from goal programming, in order to meet optimum.

3. MATERIALS AND METHODS

3.1. Materials

In this section, renewable energy alternatives and selection criteria considered in the study are explained. Taking into account RES potential in Turkey, five renewable energy source called wind, biomass, geothermal, solar and hydropower are determined as alternatives. The considered RES alternatives are evaluated using four main criteria and eight sub-criteria. The criteria are chosen according to the study of Kaya and Kahraman (2011b). They have presented the most frequently used main and sub-criteria. In the following subsection, energy alternatives and descriptions of the criteria are given in detail.

3.1.1. Renewable Energy Sources and Potentials

The main policy concerns of Turkey about energy consists of three main subjects as security of energy, the sustainability of energy supply, curbing particle emission. Turkey attributes serious importance to;

- Supporting energy production by using renewable energy alternatives with regard to secure, financial, and profitable,
- Enlarging usage of renewable energy sources in Turkey,
- Expanding the diversity of energy sources in Turkey,
- Curbing greenhouse gas emission,
- Utilization of garbage products and taking care of nature,
- Prospering related manufacturing sectors (Akat, 2014).

In 2023, the electricity demand of Turkey is forecasting to be about 530,000 GWh and Turkey aims to provide 30% of the expected requirement by using renewable energy sources in accordance with the declared Government Agenda of Vision 2023 (Melikoğlu, 2013a). The government of Turkey defined targets for each renewable energy source to construct until 2023, given in Table 3.1.

Table 3.1. The Vision 2023 target of Government of Turkey according to the renewable energy source type.

Source Type	Reference	Installed Capacity Targets (MW)
Hydro	(Melikoğlu, 2013a)	Full Utilization (36,000)
Wind	(Melikoğlu, 2013a)	20
Solar	(Melikoğlu, 2013a)	3
Geothermal	(Melikoğlu, 2013a)	600
Biomass	(Akat, 2014)	1500
Total Target		**61,100**

The clearest advantage of hydropower for every country is associated with low priced production of electricity and reasonably low green gas emission (Evans, Strezov and Evans, 2009).). Hydroelectric energy is produced by using hydraulic turbines in consequence of plenty of water reservoir. The production of hydroelectric energy needs suitable geography with many rivers (Alkan, 2014). It is very important that hydropower should be fully utilized in accordance with Turkey's Vision 2023 agenda (Melikoğlu, 2013b). According to "Ministry of Energy and Natural Resources", Turkey's hydroelectric potential is 36,000 MW. Turkey's Vision 2023 aim to use all this potential.

As a consequence of pressure changes in the atmosphere, wind exists as an energy potential in nature. "Renewable Energy General Directorate of Turkey" (YEGM, Turkish acronym) explains advantages of the wind energy source as:

- Clean and renewable energy,
- In a relatively short time, it can be constructed.
- Safe and inexhaustible energy source,
- Creates new job opportunities for the public,
- Reasonably cheap operation and maintenance cost,
- Using wind energy source doesn't need to export any material ("Renewable Energy General Directorate of Turkey", 02.07.2018).

In spite of all advantages, there are some disadvantages such as expensive capital cost, low capacity factor and the uncertain nature of wind energy (Alkan, 2014). Turkey has 48,000 MW capacity of wind energy source (Melikoğlu, 2013a). Regarding Vision 2023, the

Government of Turkey aims to construct 20,000 MW capacity of wind energy plant until 2023 (Melikoğlu, 2013a).

The Earth's energy source is released by the Sun. In spite of the utilization of solar energy is not popular, this source has a huge potential to supply heating and electricity requirements of the World. And also, solar energy applications can contribute many opportunities for nature (Alkan, 2014). Turkey has a high solar energy potential because of its geographical location. As of the end of 2017, there were 3616 solar power plants with a total installed capacity of 3421 MW. This is the equivalent of 4% of the total potential. In 2017, electricity production based on solar energy has realized 2684 GWh and 0.91% of the electricity production was obtained from solar energy ("Republic of Turkey Ministry of Energy and Natural Resources - Solar", 02.07.2018). In Agenda 2023, Turkey's target is to use 3,000 MW of solar energy potential in 2023 (Melikoglu, 2013b).

One of the most important advantages of biomass is that waste products are used to get energy and it will be helpful to dissolve the disposal problem. Using biomass energy sources is an opportunity for oil importer countries. There will never be a price fluctuation and doesn't rely on imports from other countries because it is a domestic source (Alkan, 2014). Biomass potential is assessed about 8.6 million tonnes of equivalent petrol (MTEP). At the end of 2017, there are 122 renewable waste power plants with a total installed capacity of 634.2 MW. This is equal to 0.7% of the total potential ("Republic of Turkey Ministry of Energy and Natural Resources – Bio-Fuels", 02.07.2018).

Geothermal energy is obtained by taking heat waters from earth to be utilized for producing electricity and heating purposes. If the high-temperature water supply is close to the surface of the earth, this geothermal source is more useful. In accordance with the information of the International Geothermal Association, generally, the geothermal energy source is utilized by using to heating purposes of commercial or residential heating since 2000 (Evans, 2007). To be profitable in electric production, a geothermal energy source's temperature must be at least 400 °C. The production cost is related to the temperature of water, pressure, reservoir depth, technology type and drilling (IEA, 2010).

Turkey has the important geothermal potential for its direct use and for electricity production. 40 geothermal power plants with a total installed capacity of 1,064 MW are in use at the end of the year 2017 and this is the equivalent of 1.2% of the total potential ("Republic of Turkey Ministry of Energy and Natural Resources – Geothermal", 02.07.2018). The government aims to achieve 1000 MW installed power by the year 2023 (Özcan, 2018). So, the government has already achieved its 2023 target for geothermal energy. But there is also a vast amount of geothermal potential which is not used.

3.1.2. Selection Criteria

Four main criteria and eight sub-criteria are taken into account while ranking each renewable energy source alternatives. Those main criteria and sub-criteria are familiar with renewable energy planning. Table 3.2 summarizes the studies that use the same main criteria and sub-criteria with the thesis.

Table 3.2. List of the studies which use the same criteria with the thesis.

	C1: Technical		C2: Economic		C3: Environmental		C4: Social	
Referances	**C11**	**C12**	**C21**	**C22**	**C31**	**C32**	**C41**	**C42**
Afgan and Carvalho (2002)	√	–	√	–	–	√	–	–
Afgan and Carvalho (2004)	√	–	√	–	–	√	–	√
Afgan and Carvalho (2008)	√	–	√	–	–	–	–	–
Akash, Mamlook and Mohsen (1999)	√	–	√	√	–	–	–	–
Beccali, Cellura and Mistretta (2003)	–	–	–	–	√	√	–	√
Begic and Afgan (2007)	√	–	√	–	–	–	–	√
Burton and Hubacek (2007)	–	–	√	√	–	–	–	–
Büyüközkan, Karabulut and Güler (2018)	–	–	√	√	–	√	√	√
Cavallaro and Ciraolo (2005)	–	–	√	√	–	–	√	–
Chattopadhyay and Ramanathan (1998)	–	–	–	√	–	–	–	–
Chatzimouratidis and Pilavachi (2007)	–	–	–	–	√	–	–	–
Chatzimouratidis and Pilavachi (2008)	–	–	–	–	√	√	√	√
Chatzimouratidis and Pilavachi (2009)	√	–	√	√	–	–	–	–
Diakoulaki and Karangelis (2007)	–	–	√	–	–	–	–	–
Dinca, Badea, Rousseaux and Apostol (2007)	√	√	√	√	–	–	–	–
Doukas, Andreas, and Psarras (2007)	√	–	√	–	–	–	–	√
Goumas, Lygerou, and Papayannakis (1999)	–	–	–	–	–	–	–	√
Haralambopoulos and Polatidis (2003)	–	–	–	–	–	–	–	√
Huang, Wu, Wang and Huang (2005)	–	–	√	–	–	–	–	–
Jovanovic, Afgan, Radovanovic and Stevanovic (2009)	√	–	√	–	–	–	–	–
Liposcak, Afgan, Duic and da Graca Carvalho (2006)	–	–	√	–	√	–	√	–
Løken, Botterud and Holen, (2009)	–	–	√	√	–	–	–	–
Madlener, Kowalski and Stagl (2007)	√	–	√	–	–	√	–	√
Mamlook, Akash and Mohsen (2001)	√	–	√	√	–	–	–	–
Mamlook, Akash and Nijmeh (2001)	√	–	√	–	–	–	–	–
Mohsen and Akash (1997)	√	–	√	√	–	–	–	–
Pilavachi, Roumpeas, Minett, and Afgan (2006)	√	–	√	–	–	√	–	–
Pilavachi, Stephanidis, Pappas and Afgan (2009)	√	–	√	√	–	–	–	–
Sarmad, Saad and Yousaf (2017)	√	–	–	√	–	–	–	–
Yunna, Chuanbo, and Ting (2018)	√	–	√	√	–	√	–	–
Wang, Jing, Zhang, Shi and Zhang (2008)	–	√	√	–	–	√	–	–
Wang, Jing, Zhang, Zhang and Shi (2008)	–	√	√	√	–	√	–	–

*This table revised by using Wang, Jing, Zhang, and Zhao (2009) and updated.

** "√" symbol refers to be included but "-" symbol refers not to be included.

Technical criteria are related to all mechanic aspects of renewable energy technologies and it is a main-criteria for this problem. Technical criteria could have many sub-criteria such as rational efficiency, maturity, primary energy ratio, efficiency, safety, reliability and etc. In the thesis, two sub-criteria called efficiency (C11) and rational efficiency (C12) are used. Efficiency is the most famous technical criteria to investigate energy alternatives (Wang et al., 2009).

Efficiency refers to how much useful energy can be extracted from an energy source and it is measured generally using efficiency ratio. The efficiency ratio is calculated by dividing the produced energy to the input energy. Energy efficiency is accepted as one of the "twin pillars" of sustainable energy policy (Prindle, Eldridge, Eckhardt and Frederick, 2007). Effective energy utilization is crucial to cope with the energy need growth Rational efficiency is also known as exergy efficiency and second law efficiency. It investigates the efficiency of renewable energy technology regarding the second law of thermodynamics. In a process, energy transforms from a form to another one. On the contrary, exergy is regarded for the irreversibility of a process because of growth in entropy. Energy is always destroyed when a process affected by the change of temperature. Analysis of exergy is executed in the area of industrial ecology to benefit energy more productively, and this area is firstly founded by (Rant, 1956).

As another main criterion, economical aspects are very important issues to make an effective renewable energy planning. According to Wang et al. (2009), economic criteria can be investigated by using many sub-criteria for example investment cost, operation maintenance cost, fuel cost, electric cost, net present value cost, payback period, service life, equivalent annual cost, and etc. In this thesis, two sub-criteria to investigate economic aspects called investment cost (C21), operation maintenance cost (C22) are considered.

Investment cost contains total costs which entrepreneur expense such as expenditure of mechanic equipment, the establishment of technological, the building of roads and links to the national grid, engineering support, and coincidental construction operations. Maintenance costs of equipment and employee costs are not involved in investment cost. In the literature, the investment cost is very famous sub-criteria and it is used in many studies (Wang et al., 2009).

Operation and maintenance cost sub-criteria are divided into two parts. One of them is the operation cost related to labor cost, and expenditure of energy, products, and services for the plant operation. The other is the maintenance cost, which is all expenditure for lengthen energy production plant life and to prevent possible failures which may cause a delay in the plant's operation. In the literature, the operation and maintenance costs are also separated into two subcategories called fixed and variable costs (Wang et al., 2009).

Producing electricity has many effects such as ecological, atmosphere, climate and etc. For this reason, any energy planning process could not be without an environmental aspect. In this thesis, environmental effects are investigated by two sub-criteria as particle emission (C31) and land use (C32).

Electric production could cause particle emission to nature and it is one of the main problems that the energy sector created. Particle emission is essentially leaked by oil and coal, biomass and also solar power plants (because of cell construction of it). Particle emission cause to make hazy conditions, lessen visibility and conduce to haze in a region. At the same time, particle emission is the most hazardous kind of emission for humankind. The danger for the human body relies on the amount, distribution, chemical composition, and microstructure of the released particle. (Wang et al., 2009; Chatzimouratidis and Pilavachi, 2008). Also, energy production plants need an area and this situation is an important matter to evaluate (Wang et al., 2009; Chatzimouratidis and Pilavachi, 2008). Each energy plants need to be constructed in a special area regarding special requirements (Wang et al., 2009). The landscape and nature are influenced by the used area. It refers to one of the vital matters for the construction site, essentially where the public activities are the relevant concern of environmental pressure. Necessary constructions of tunnels, roads, and etc. cause bad effect on plant cover, animals, and the environment because of destabilization (Beccali, Cellura and Mistretta, 2003).

Social criteria are an important issue for the public. Social criteria refer to the decision of the public for energy production systems. Two sub-criteria called job creation (C42) and social acceptability (C41) is considered in the thesis. Social acceptability is defined as the overview of options related to the energy systems by the local population. It is really important because the public decision and of pressure groups could affect project scheduling. Social acceptance couldn't be expressed in a quantitative way but qualitative. To transforming qualitative decisions into quantitative, survey methods could be used (Wang et al., 2009). Energy production plant needs human resources for the construction of the plant, operation, and maintenance of the plant. Each energy plants supply job opportunities for local societies, and it prospers local societies. However, each energy plants creates different job opportunities and decision-makers should select an energy source and plant type by taking into consideration the local community (Wang et al., 2009).

3.2. Methods

In this section, firstly, fuzzy set theory is mentioned in a general perspective. Secondly, ranking methods of fuzzy numbers are given. Finally, Analytic Hierarchy Process (AHP) and Fuzzy Analytic Hierarchy Process, which is used in the thesis, is explained.

3.2.1. Fuzzy Set

A fuzzy set can give a better way of reality than the binary representation of classical mathematics. The membership of fuzzy sets is gradual thus that makes the theory of fuzzy set priceless to suggest an inadequate level of precision for subjective decision (Dubois, Ostasiewicz and Prade, 2000). Firstly, the fuzzy set theory was introduced by Zathi Asker Zadeh with publishing his paper in 1965. Zadeh improved the groundwork of fuzzy set theory by linking with fuzzy decision-making and linguistic hedges between 1965 and 1975. The first fuzzy logic controller was generated in 1970. Several industrial utilization of fuzzy logic started in Japan and Europe in 1977 (Zadeh, 2008). There are many publications that use fuzzy set theory in many areas such as mathematics, engineering, computer science, decision making, physical science, life science, health care and etc. According to (Kahraman, Öztayşi and Çevik, 2016);

- 71928 academical publication and 355 patents have been taken by using fuzzy numbers for engineering;
- there are 67898 publication and 1241 patents based fuzzy numbers for computer science;
- for mathematics science there are 31073 paper and 855 patents by using fuzzy set theory;
- for decision making there are 10273 papers and 6 patents;
- in life science 4598 academical publication;

- in the area of physical science, which is involved in the study of nonliving systems, there are 8414 academical study by using fuzzy number;
- For the area of health care, there are 883 study based fuzzy set theory;
- In social science and humanities, there are 3244 studies conducted with fuzzy set theorem.

A fuzzy set is described as a fuzzy interval in the real number R. Because the limit of this interval is uncertain, the interval is also called a fuzzy set. Fuzzy numbers are able to model epistemic uncertainty and their probation through computation. The concept of fuzzy numbers is essential for fuzzy differential equations and fuzzy analysis, and a deeply effective tool in many applications of fuzzy logic and fuzzy sets (Bede, 2013).

Commonly a fuzzy set is expressed with two limit points a_1 and a_3 and maximum point a_2 as$[a_1, a_2, a_3]$.Fuzzy triangular number is expressed in Figure 3.1. (Zang and Liu, 2006).

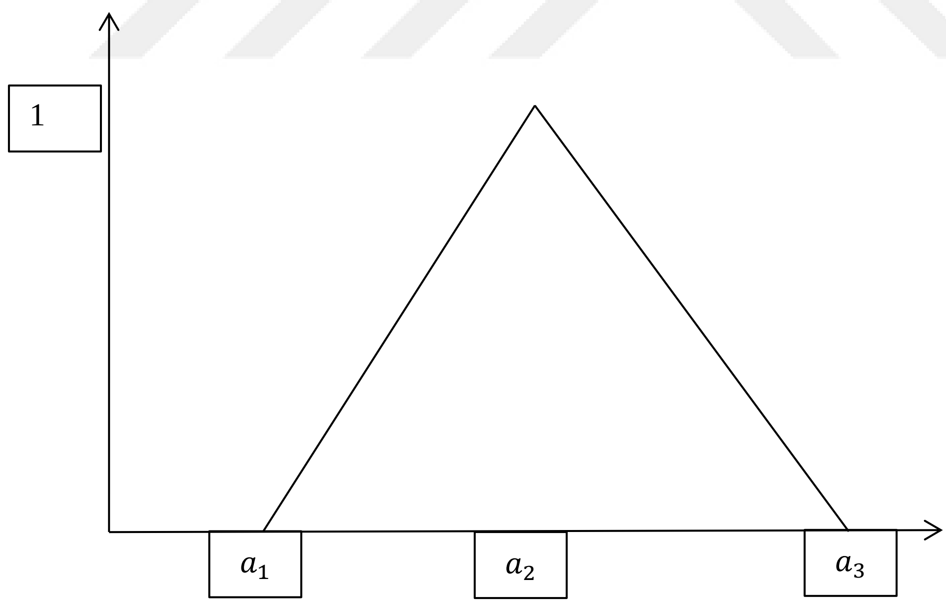


Figure 3.1. Fuzzy triangular number membership function (Zang and Liu, 2006).

A triangular fuzzy set is the most famous one of fuzzy set types. A triangular fuzzy set is expressed by using 3 points as below;

$$A = \{a_1, a_2, a_3\}$$

The membership function of the triangular fuzzy number is given in Equation 1 (Zang and Liu, 2006).

$$\mu_A(x) = f(x) = \begin{cases} 0, & x < a_1 \\ \dfrac{x - a_1}{a_2 - a_1}, & a_1 \leq x \leq a_1 \\ \dfrac{a_1 - x}{a_3 - a_2}, & a_2 \leq x \leq a_3 \\ 0, & x \geq a_3 \end{cases} \tag{1}$$

Also, the mathematical operations of the triangular fuzzy number are shown below.

Assume that A and B as a triangular fuzzy number; $A = \{a_1, a_2, a_3\}$ and $B = \{\beta_1, \beta_2, \beta_3\}$

Summing;

$$A + B = (a_1, a_2, a_3) + (\beta_1, \beta_2, \beta_3)$$

$$A + B = (a_1 + \beta_1, a_2 + \beta_2, a_3 + \beta_3) \tag{2}$$

Subtracting;

$$A - B = (a_1, a_2, a_3) - (\beta_1, \beta_2, \beta_3)$$

$$A - B = (a_1 - \beta_1, a_2 - \beta_2, a_3 - \beta_3) \tag{3}$$

Multiplication;

$$A\ x\ B = (a_1, a_2, a_3)\ x\ (\beta_1, \beta_2, \beta_3)$$

$$A\ x\ B = (a_1\ x\ \beta_1, a_2\ x\ \beta_2, a_3\ x\ \beta_3) \tag{4}$$

Division;

$$A \,/\, B = (a_1, a_2, a_3) \,/\, (\beta_1, \beta_2, \beta_3)$$

$$A \,/\, B = (a_1 \,/\, \beta_3, a_2 \,/\, \beta_2, a_3 \,/\, \beta_1) \tag{5}$$

Symmetric operation;

$$-(A) = \{-a_3, -a_2, -a_1\} \tag{6}$$

Important properties of mathematical calculations for triangular fuzzy number are below;

- ❖ Summing and subtracting for triangular fuzzy numbers brings triangular fuzzy number result.
- ❖ Division and multiplication for triangular fuzzy numbers don’t bring triangular fuzzy number result.
- ❖ Operation of max and min operations don’t give a result as a triangular fuzzy number.

3.2.2. Ranking Fuzzy Numbers

Ranking fuzzy numbers is not an easy operation. Contrary to real numbers, there is no natural order among fuzzy numbers (Wang and Kerre, 2001). Ranking among fuzzy numbers is one of the most valuable areas of fuzzy set theory. If decision making includes fuzzy parameters, operation and ranking on fuzzy numbers are required. Thus, there are many studies about the ranking of fuzzy numbers (Göçken, 2009).

In this thesis, the signed distance method is used to rank each alternative by conversing triangular fuzzy numbers to reel numbers. This methodology is generated by Yao and Wu (2000) to rank each alternative easily.

$$A = (a_1, a_2, a_3) = \frac{\left(a_1 + a_3 + (2xa_2)\right)}{4} \tag{7}$$

3.2.3. Analytic Hierarchy Process (AHP)

Analytic hierarchy process (AHP) is one of the most well-known methods in MCDM methods (Vaidya and Kumar, 2006). It has been used by researchers and decision-makers, as a result of that, it is an uncomplicated and capable tool (Forman and Gass, 2001). Thomas L. Saaty has generated this methodology by looking for an efficient procedure to determine ranking and aid complex decision making (Forman and Gass, 2001).

There are three main AHP methodologies part called constructing synthesis, measurement, and complexity. For the construction complexity part, Saaty (2008) maintains that to manage the complexity of a decision-making process we should define all factors which influence the result and arrange them in a hierarchical order of "homogenous cluster of factors". The measurement is examined benchmarking those factors in pairs rationally. General steps of AHP is defined below as 6 parts;

Step 1: Define the case and examine the set of knowledge sought. The case to be investigated is selected from all those regarded as vital or complicated enough to be investigated. This section could be itself a complicated case for which an individual analysis is required (Haller, Tiedeman and Whitaker, 1996). In examining and choosing a case it essentially makes accurate all acceptances and the viewpoint by which this conclusion has been regarded (Russo and Camanho, 2015).

Step 2: Construct a decision hierarchy through middle levels criteria to the smallest level (Saaty, 2008). Example of order decision hierarchy is shown as below Figure3.2.

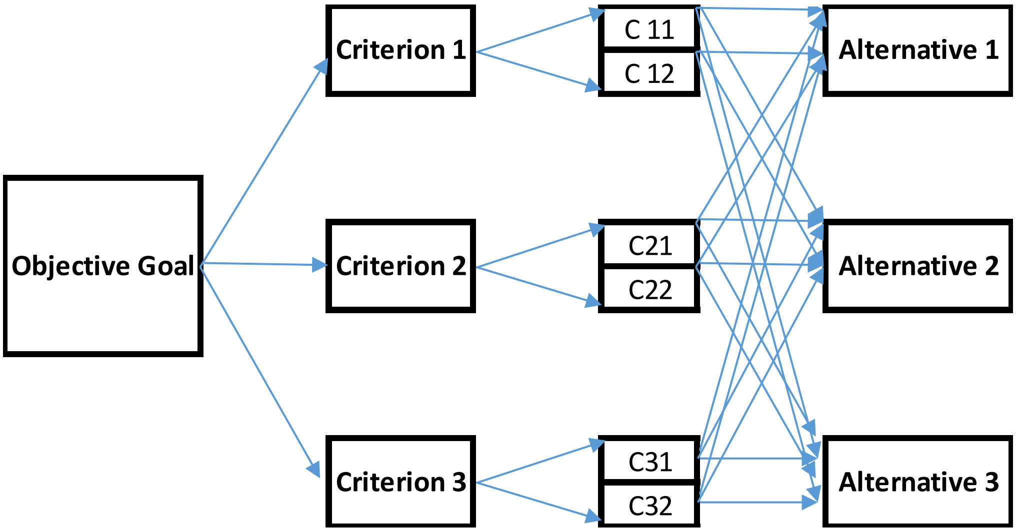


Figure 3.2. A decision hierarchy example

Step 3: Make matrices to calculate a set of pairwise comparison. The matrix should be constructed for one by one criterion. The benchmarking must be constructed through a scale to identify how many times more critical or serious one factor is over another factor with regard to the criteria (Saaty, 2008). Ranking scale of Saaty (1990) shown in Table 3.3.

Table 3.3. Satty's (1990) ranking scale

Interpretation	Importance
Just Equal	1
Important but Weakly	3
Important	5
Important and More	7
Important and Very More	9
Intermediate Value	2,4,6,8

Representation of a pairwise comparison matrix is shown below.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix}_{nxn}$$

Step 4: Compute the relative weight of the parts for each level by using this procedure;

i. Sum the value of the column for normalization the matrix

ii. Add all the lines to define the relative order of the criteria in the normalized matrix

iii. Check out concurrency of the matrix, by computing the eigenvalues to benchmark the random concurrency regarding matrix size. Researchers have to check out his/her benchmarking to recover these

iv. The previous step must be completed for all criteria

v. Calculate values of all alternatives for all criteria are contained in a matrix with the function of computed preference

vi. Sum the values of all alternatives to define the final value. The best option is the alternative with the maximum value (priority) (Haller, Tiedeman and Whitaker, 1996).

Formulation of this calculation is shown;

$$B_i = \left[b_{ij}\right]_{nx1} \qquad i = 1, \dots, n$$

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{8}$$

$$C = \left[b_{ij}\right]_{nxn} \qquad i = 1, \dots., n \qquad j = 1, \dots., n$$

$$W_i = \frac{\sum_{j=1}^{n} c_{ij}}{n} \qquad W = [W_i]_{nx1} \tag{9}$$

Step 5: Controlling the decision. This part is required if the final value of AHP is not accaptable with the assumptions and AHP results (Russo and Camanho, 2015). Consistency analysis can be calculated by using the below formulas.

$$D = \left[a_{ij}\right]_{nxn} x [w_i]_{nx1} = [d_i]_{nx1} \tag{10}$$

$$E_i = \frac{d_i}{w_i} \qquad i = 1, . \dots, n \tag{11}$$

$$\lambda = \frac{\sum_{i=1}^{n} E_i}{n} \tag{12}$$

$$CI = \frac{\lambda - n}{n-1} \tag{13}$$

Table 3.4. Rassal Index table according to the dimension of the matrix to use consistency analysis.

Dimension of Matrix	1	2	3	4	5	6	7	8	9	10
Rassal Index	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

*Saaty, (1990)

$$CR = \frac{CI}{RI} < 0.10 \tag{14}$$

Step 6: Make documentation of AHP results. Saving all the reasons which regarded how and why the decision is made is important. These records can be useful to identify the method for others or continuous improvement of decision-making methodologies (Russo and Camanho, 2015).

3.2.4. Fuzzy Analytic Hierarchy Process (FAHP)

In this thesis, the fuzzy AHP method which is proposed by Aydın and Kahraman (2011) is used. Aydın and Kahraman (2018) clearly rearranged the triangular fuzzy scale in their later publications. In this thesis, this fuzzy scale applied the case as given in Table 3.6.

Table 3.5. The fuzzy scale of proposed fuzzy AHP.

Interpretation	Scale of TFN	Reciprocal Scale of TFN
"Just Equal"	(0,0,0)	(0,0,0)
"Weakly Important"	(0,1,3)	(-3,-1,0)
"Important"	(1,3,5)	(-5,-3,-1)
"Strongly More Important"	(3,5,7)	(-7,-5,-3)
"Very Strongly More Important"	(5,7,9)	(-9,-7,-5)
"Absolutely More Important"	(7,9,9)	(-9,-9,-7)

*Aydın and Kahraman, (2011); Aydın and Kahraman, (2018) The process step of the Fuzzy AHP is explained as follows (Aydın and Kahraman, 2011; Aydın and Kahraman, 2018).

The weights (e) are assigned to a specialist on the theory of their proficiency, background, etc. Assume that m specialists in the group and the k_{th} expert is E_k is attached a specialist weight e_k,

Where

$$e_k \in [0,1],\ e_1+e_2+...+e_m = 1 \tag{15}$$

To get a group inclination from singular inclination, the gathering of the fuzzy number result is completed as Equation 16;

$$\hat{a}_{ij} = \hat{a}_{ij1} \otimes e_1 \oplus \hat{a}_{ij2} \otimes e_2 \cdots \oplus \hat{a}_{ijm} \otimes e_m \tag{16}$$

Where a_{ij} is gathered fuzzy result from all observations.

a_{ij1}, a_{ij2}, a_{ij3}, a_{ij4}, …, $a_{ijm}$are observations are done by the fuzzy number scales used by specialists. $\otimes$ and $\oplus$ motifs are indicated multiplication and summing for fuzzy numbers respectively.

Generally, the results for the old fashioned AHP methodology are also established on exponential significance. Thus, to adapt adverse fuzzy numbers to positive fuzzy numbers, comparable exponential values of adverse results are computed as Equation 17;

$$\tilde{a}^*_{ij} = e^{\left(\frac{\tilde{a}_{ij}}{4}\right)} \tag{17}$$

Where $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$

The comparison matrix constructed as Equation 18;

$$\tilde{A}_{ij} = \tilde{a}_{ij} = \begin{bmatrix} (1,1,1) & \cdots & (l_{ij}, m_{ij}, u_{ij}) \\ \vdots & \ddots & \vdots \\ (l_{ij}, m_{ij}, u_{ij}) & \cdots & (1,1,1) \end{bmatrix} \quad (18)$$

Where $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$and $〚\tilde{a}_{ij}{}^{-1} = (\frac{1}{u_{ij}}, \frac{1}{m_{ij}}, \frac{1}{l_{ij}})$for i, j=1,…,n and i≠j. A formula, which is below, computes the normalized matrix of $\widetilde{N}$;

$$\widetilde{N} = \left[\tilde{n}_{ij}\right]_{m \times n} \quad (19)$$

$$\widetilde{N} = \left(\frac{l_{ij}}{u^*{}_j}, \frac{m_{ij}}{u^*{}_j}, \frac{u_{ij}}{u^*{}_j}\right) \quad (20)$$

$$u^*{}_j = \max_i u_{ij} \quad (21)$$

Effect of weights of criteria and alternative is computed by using the Equation 22;

$$W'_i = \left(\frac{\sum_{j=1}^{n} \tilde{n}_{ij}}{\sum_{k=1}^{n} \sum_{j=1}^{n} n_{kj}}\right) \qquad k = 1,2, \dots, n \quad (22)$$

The weights of sub-criteria are multiplied by all alternative’s rating and summed to reach local weight due to each criterion. After that local weights must be multiplied to weights of criteria and summed to get global weight.

The final step of the AHP procedure, we grade the final fuzzy numbers. That one-way grade the fuzzy numbers, signed distance value procedure which is developed by Yao and Wu (2000) is used.

4. RESULTS AND DISCUSSIONS

There are mainly five important renewable energy sources called wind, hydro, biomass, solar and geothermal energy in Turkey. Firstly, the description of criteria and alternatives must be clearly defined. Description of alternatives, criteria, and sub-criteria are already mentioned in the material section. The hierarchical situation of the case is shown in Figure 4.1.

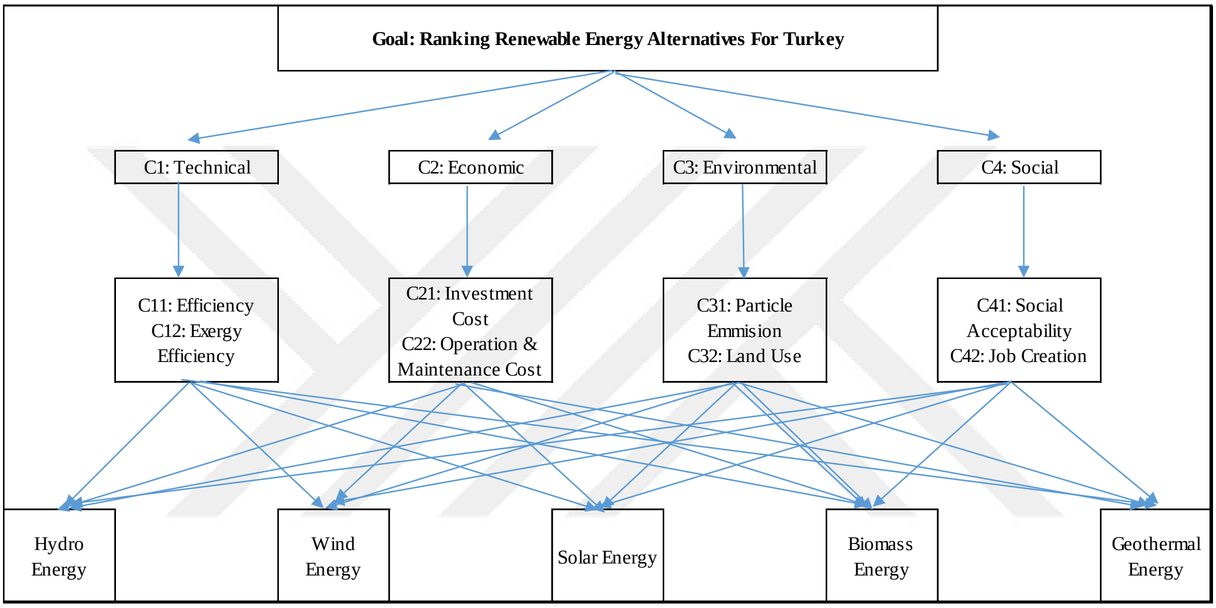


Figure 4.1. The hierarchical structure of the case

Secondly, the relative importance of criteria must be defined by taking an idea from professional and expert groups. This group is included academicians, private sector professionals and members of the professional chamber. They are working on especially the energy sector. The information for the main criteria is shown in Table 4.1.

Table 4.1. Decisions of experts and professionals for criteria.

	Weight	C1	C2	C3	C4
C1	0,33	(0,0,0)	(1,3,5)	(0,1,3)	(0,1,3)
	0,33	(0,0,0)	(7,9,9)	(0,1,3)	(1,3,5)
	0,33	(0,0,0)	(1,3,5)	(-9,-9,-7)	(3,5,7)
C2	0,33	(-5,-3,-1)	(0,0,0)	(-5,-3,-1)	(0,0,0)
	0,33	(-9,-9,-7)	(0,0,0)	(-9,-9,-7)	(-3,-1,0)
	0,33	(-5,-3,-1)	(0,0,0)	(-9,-9,-7)	(1,3,5)
C3	0,33	(-3,-1,0)	(1,3,5)	(0,0,0)	(3,5,7)
	0,33	(-3,-1,0)	(7,9,9)	(0,0,0)	(5,7,9)
	0,33	(7,9,9)	(7,9,9)	(0,0,0)	(3,5,7)
C4	0,33	(-3,-1,0)	(0,0,0)	(-7,-5,-3)	(0,0,0)
	0,33	(-5,-3,-1)	(0,1,3)	(-9,-7,-5)	(0,0,0)
	0,33	(-7,-5,-3)	(-5,-3,-1)	(-7,-5,-3)	(0,0,0)

Afterward getting the summing of the fuzz numbers scores by using equation 15, negative fuzzy numbers are changed to positive fuzzy numbers by using equation 17. Subsequently, we have changed the Comparison Matrix as Table 4.2.

Table 4.2. Aggregated fuzzy comparison matrix for main criteria.

Main Criteria	C1	C2	C3	C4
C1	(1,1,1)	(2.117,3.49,4.871)	(0.472,0.558,0.92)	(1.396,2.117,3.49)
C2	(0.205,0.287,0.472)	(1,1,1)	(0.147,0.174,0.287)	(0.846,1.181,1.517)
C3	(1.087,1.792,2.117)	(3.49,5.755,6.798)	(1,1,1)	(2.501,4.123,6.798)
C4	(0.287,0.472,0.717)	(0.659,0.846,1.181)	(0.147,0.243,0.4)	(1,1,1)

After that, we have reached a normalized matrix by using equation 19, equation 20, and equation 21. The matrix is shown in Table 4.3.

Table 4.3. Normalized fuzzy comparison matrix for main criteria.

Main Criteria	C1	C2	C3	C4
C1	(0,.472,0.472,0.472)	(0.311,0.513,0.717)	(0.472,0.558,0.92)	(0.205,0.311,0.513)
C2	(0.097,0.136,0.223)	(0.147,0.147,0.147)	(0.147,0.174,0.287)	(0.124,0.174,0.223)
C3	(0.513,0.846,1)	(0.513,0.847,1)	(1,1,1)	(0.368,0.607,1)
C4	(0.136,0.223,0.339)	(0.097,0.124,0.174)	(0.147,0.243,0.4)	(0.147,0.147,0.147)

Finally, we have used equation 22 to calculate the importance weights of the main criteria.

$$W^{\cdot}_{C1} = (0.170, 0.284, 0.535)$$

$$W^{\cdot}_{C2} = (0.060, 0.096, 0.179)$$

$$W^{\cdot}_{C3} = (0.279, 0.505, 0.816)$$

$$W^{\cdot}_{C4} = (0.061, 0.113, 0.216)$$

According to the result, the most important criteria is “environmental” for experts. And also, the second one is shown as “technical”. Environmental and technical issues are more important factors for experts. To convert triangular fuzzy number results to reel numbers, signed distance value formula is used by using Equation 7. The results are shown in Table 4.4 and Figure4.2.

Table 4.4. The weights of the main criteria and their signed distance values.

Main Criteria	Fuzzy Weights of Main Criteria	Signed Distance Value
C1	(0.171,0.284,0.536)	0.31875
C2	(0.06,0.097,0.18)	0.1085
C3	(0.28,0.506,0.817)	0.52725
C4	(0.062,0.113,0.217)	0.12625

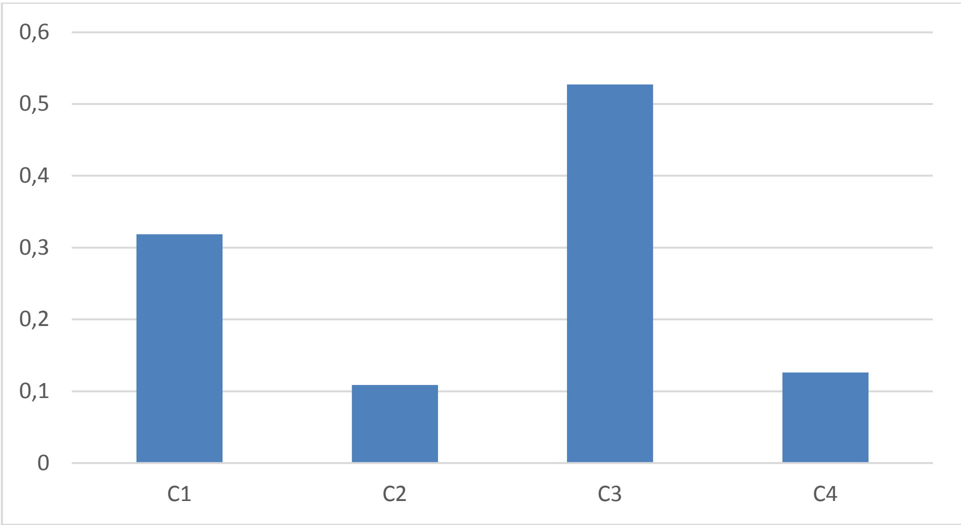
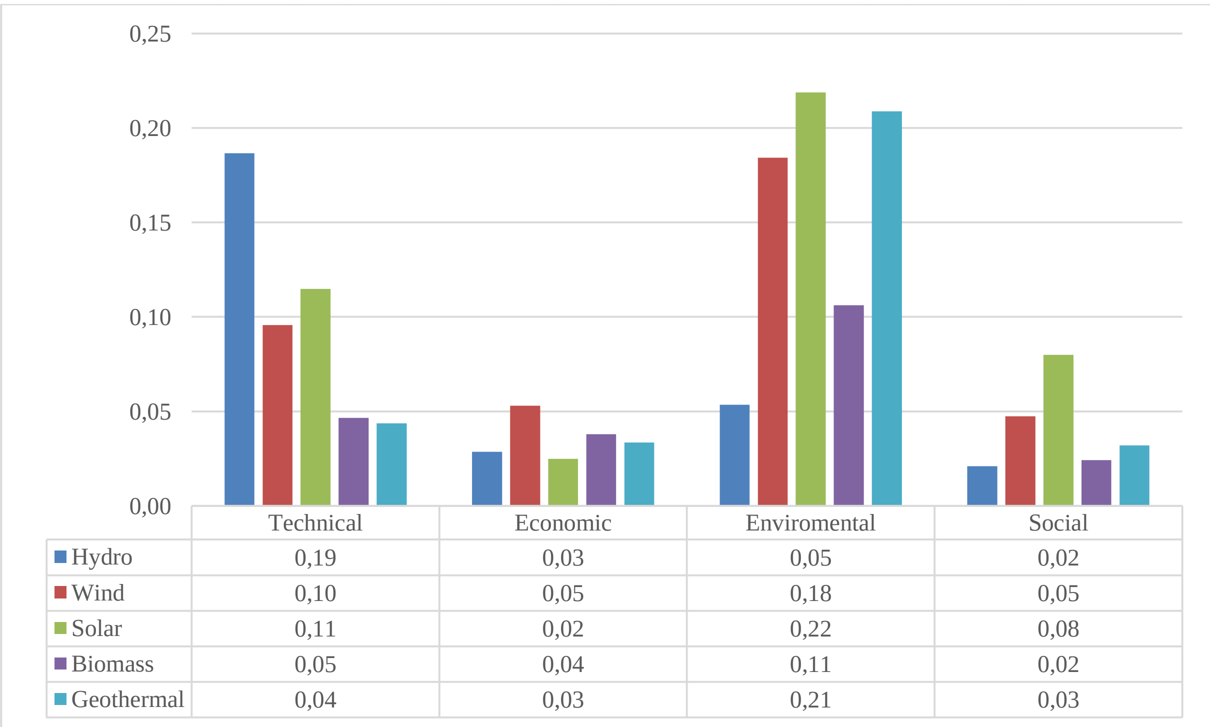


Figure 4.2. Weights of main criteria by using signed-distance value method

Separately, each alternative is affected by each main criterion by itself. Hydro energy alternative is the best alternative for technical criteria. Wind energy alternative is better than other alternatives if we consider economic criteria. On the other hand, as seen in Figure 4.3, the solar alternative is the best alternative considering the environmental and social criteria.



	Technical	Economic	Enviromental	Social
Hydro	0,19	0,03	0,05	0,02
Wind	0,10	0,05	0,18	0,05
Solar	0,11	0,02	0,22	0,08
Biomass	0,05	0,04	0,11	0,02
Geothermal	0,04	0,03	0,21	0,03

Figure 4.3. Effects of main criteria to alternatives separately.

All calculation process of criteria is applied to all sub-criteria and got fuzzy weights and signed distance values of sub-criteria. Investment cost sub-criteria is selected as the most important sub-criteria. Investment cost sub-criteria is more influential than other sub-criteria. And also, the alternatives are influenced by social acceptability, particle emission, exergy efficiency, efficiency, land use, and operation maintenance cost respectively. Fuzzy weights and signed distance value results of sub-criteria are shown in Table 4.5 and Figure 4.4.

Table 4.5. The weights of subcriteria and their signed distance values.

Sub Criteria	Fuzzy Weights of Sub Criteria	Signed Distance Values
C11	(0,314,0,417,0,583)	0,43275
C12	(0,438,0,583,0,748)	0,588
C21	(0,611,0,872,1,216)	0,89275
C22	(0,09,0,128,0,211)	0,13925
C31	(0,46,0,679,0,947)	0,69125
C32	(0,217,0,321,0,529)	0,347
C41	(0,595,0,852,1,188)	0,87175
C42	(0,103,0,148,0,244)	0,16075

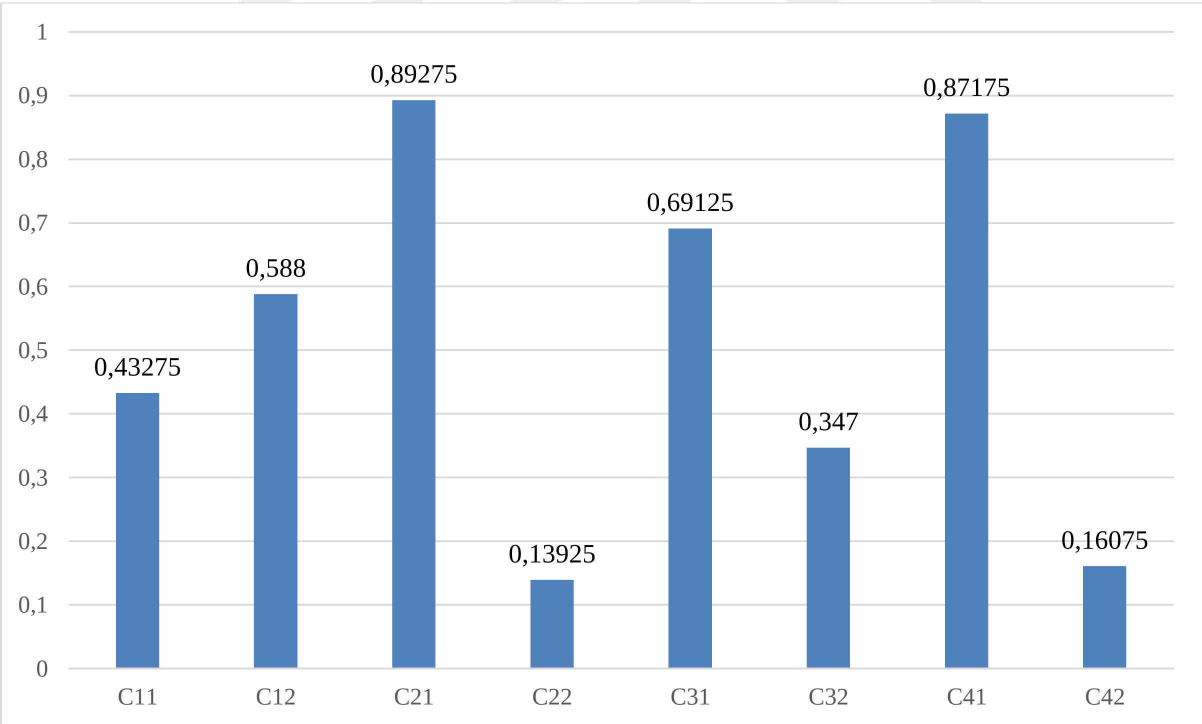


Figure 4.4. Signed-distance value graph of subcriteria.

The same steps have been followed to calculate the importance weights of the alternatives and they are shown in Table 4.6. Benchmarking of alternatives' global weights are shown in Figure 4.5.

Table 4.6. Renewable energy alternatives' global weights.

Alternative	Fuzzy Weights	Signed Distance Value
Hydro	(0.043,0.174,0.768)	0.290
Wind	(0.054,0.236,0.995)	0.380
Solar	(0.062,0.275,1.141)	0.438
Biomass	(0.028,0.122,0.588)	0.215
Jeothermal	(0.047,0.193,0.84)	0.318

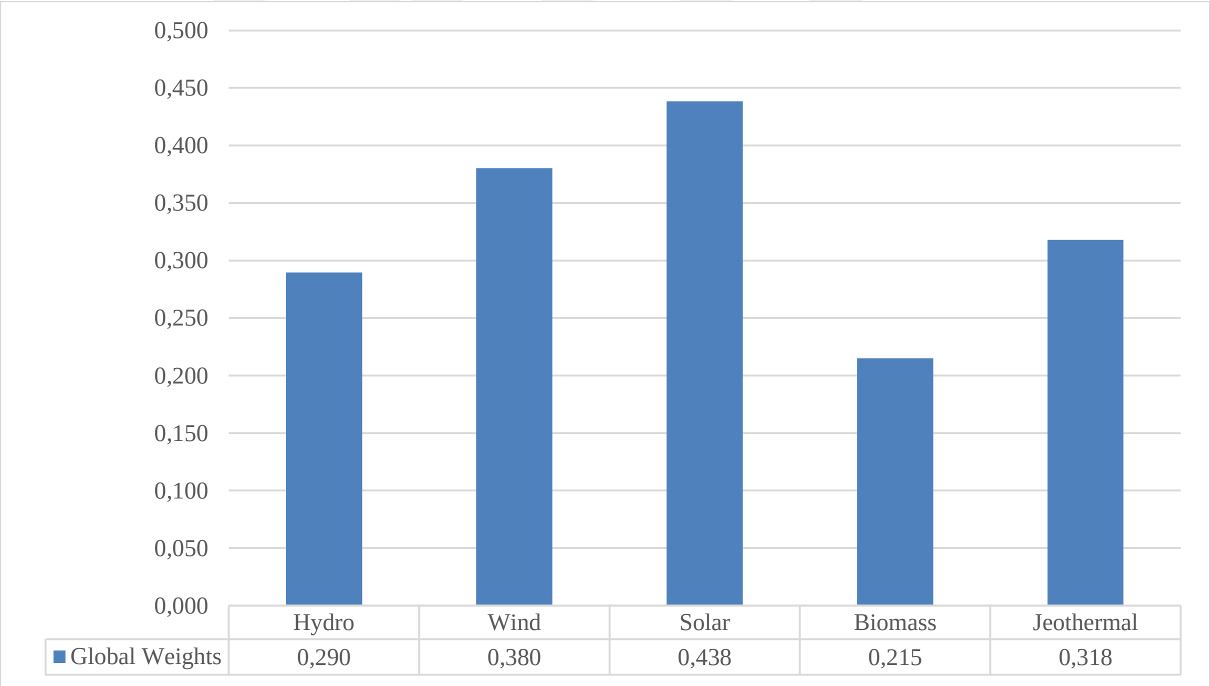


Figure 4.5. Signed-distance value graph of renewable energy alternatives.

As can be seen in Table 4.6 and Figure 4.5., the best alternative solar energy is followed up with wind, geothermal, hydropower and biomass. Biomass energy has been found to be the worst alternative among the other options. The similar results were also presented in the research conducted by Erol and Kilkis (2012) and Celikbilek and Tuysuz (2016). There are various advantages of solar energy. Carbon dioxide, nitrogen dioxide, and sulfur oxide emissions are eliminated by solar energy. The initial setup cost of a solar energy system is relatively high however, the maintenance cost of the system is considerably low when compared with the other energy systems. Nanotechnological innovations are also greatly affecting the development of solar energy. This kind of technological developments will increase the effectiveness and decrease the initial setup and investment costs of the solar energy systems. According to the findings in this study and the research conducted by earlier researchers, it can be stated that the most important RES in Turkey is solar energy. Balat (2005) stated that, when compared to the other countries harnessing solar power, Turkey has more chance to effectively use solar energy as a result of its geographic position. To keep up with the growing energy demand, the study shows that solar energy is the best suitable RES alternative. Wind energy, on the other hand, is the next best RES option after solar energy. The wind energy is environmentally friendly as there is no possibility for it to cause CO2 emissions, atmospheric warming and acid rains (Erdogan and Kaya, 2015). Like solar energy, wind energy may also play a significant role to decrease energy dependence on other countries and to strengthen the energy security of Turkey. On the contrary to the finding to this study, some of the researchers have concluded that wind energy alternative is the most excellent RES and the solar energy alternative comes after the wind energy as the second-best alternative (Kahraman et al., 2009; Kahraman et al., 2010; Kaya and Kahraman, 2011a; Ertay et al., 2013; Çolak and Kaya, 2017). In any case, both solar and wind energy are significantly important to achieve Turkey's RER energy target.

When the economic potential of renewable resource is considered, wind and solar power's utilization rates are significantly low. As it was stated earlier in this thesis, there are 3616 solar power plants in Turkey with a 3421 MW total installed capacity. This capacity corresponds to only 4% of the total potential. Also, installed wind power reached a total of 6516 MW by the end of 2017 which is 7.6% of the total potential. These total potential equivalents indicate that both solar and wind energy utilization rates are significantly low compared with their total potential. Ozcan (2018) stated that Turkey has achieved 21.41% and 4.52% of its 2023 RES target in the wind and solar energy, respectively.

The third-best energy alternative is geothermal energy. Even though it is the third-best option, it is quite close to the wind energy when their scores are considered. Geothermal energy alternative’s economic potential is nearly14665 GWh/yr with 2000 W (Ozcan, 2018). There are 40 geothermal power plants with 1064 MW total installed capacity which corresponds to 1.2% of the total potential (http://www.enerji. gov.tr/en-US/Pages/Geothermal, 02.07.2018). Ozcan (2018) stated that the Turkish government aimed to construct 1000 MW installed geothermal energy plant by the end of 2013, however, the government achieved its aims in geothermal energy by the end of 2017. Like solar and wind energy, the utilization rate of geothermal energy is low compared to its total potential. Hence, it might be better for the government to increase its 2023 geothermal energy target and increase the utilization rate of geothermal energy.

5. CONCLUSIONS

Regarding environment and energy security, attention of renewable energy source importance has been increasing for Turkey. On the other hand, the target of Turkey will begin to supply 30% of Turkey's requirement till 2023 by using renewable energy sources. Thus, investigation of the most suitable renewable energy source is a vital subject to invest in the renewable energy sector. In this thesis, a modified fuzzy AHP methodology which is suggested by Aydın and Kahraman (2011; 2018) is used to investigate renewable energy source alternatives for Turkey. This method uses positive fuzzy numbers at the same time negative fuzzy numbers, and this makes the model easy to understand. This methodology is a new one and not familiar.

Hydropower, solar energy, biomass, wind energy, and geothermal energy sources are taken into account to investigate which one is the best renewable energy source for Turkey. Four main criteria and eight sub-criteria are used to evaluate Turkey's renewable energy alternatives. The criteria are selected regarding the literature review. According to the result of the case, the most important criteria is "environmental". Also, the second one is "technical" criteria. This shows that technical and environmental issues are more important than other issues. After global weights are computed, the ranking of alternatives are found out as solar, wind, geothermal, hydropower and biomass in descending order. According to the literature review, the result of the case is similar to other studies. Generally, wind energy and solar energy alternatives are the most favorable renewable energy source according to the literature review. Because of the usage of wind and the solar energy source is small, using wind and solar energy sources help to reach Turkey's 2023 targets.

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