MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES
IN PURE AND APPLIED SCIENCES

A MULTI-OBJECTIVE DECISION MAKING MODEL FOR RENEWABLE ENERGY PLANNING: THE CASE OF TURKEY

MUHAMMED BİLAL HORASAN

MASTER THESIS

Department of Industrial Engineering

Thesis Supervisor

Assoc. Prof. Dr. Hüseyin Selçuk KILIÇ

ISTANBUL, 2021

MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES
IN PURE AND APPLIED SCIENCES

A MULTI-OBJECTIVE DECISION MAKING MODEL FOR RENEWABLE ENERGY PLANNING: THE CASE OF TURKEY

MUHAMMED BİLAL HORASAN

(524417021)

MASTER THESIS

Department of Industrial Engineering

Thesis Supervisor

Assoc. Prof. Dr. Hüseyin Selçuk KILIÇ

ISTANBUL, 2021

ACKNOWLEDGMENT

I would like to express my deepest gratitude and appreciation to my thesis supervisor Assoc. Prof. Dr. Hüseyin Selçuk Kılıç for his valuable contributions, support and guidance throughout this thesis study.

I would also like to thank my thesis committee members, Prof. Dr. Selim Zaim and Prof. Dr. Çiğdem Alabaş Uslu for their participation, insightful comments and precious suggestions.

I am sincerely thankful to my dear family for their encouragement, support and understanding through my life and my studies. I will forever be grateful for the opportunity they have granted me.

My sincere thanks also goes to my friends who have been my side at every stage of the thesis writing process.

Finally, I am deeply grateful to my beloved wife Sümeyye, who is always being there for me. This study would not have finished without her endless support, continuous encouragement, infinite patience and devotion.

March, 2021 **Muhammed Bilal HORASAN**

TABLE OF CONTENTS

ÖZET

YENİLENEBİLİR ENERJİ PLANLAMASI İÇİN ÇOK AMAÇLI KARAR VERME MODELİ: TÜRKİYE UYGULAMASI

Çalışılan tezin konusu yenilenebilir enerji planlamasına yönelik çok amaçlı bir karar verme modeli geliştirmek, yenilenebilir enerji kaynaklarından güneş, rüzgar, jeotermal, hidroelektrik ve biyokütle olmak üzere beş enerji türü için belirlenen uygunluk kriterleri bağlamında geliştirilen modelin Türkiye özelinde uygulamasını yapmak, uygulama neticesinde ortaya çıkan sonuçları değerlendirmek, analiz etmek ve Türkiye'de yenilenebilir enerji planlamasına yönelik bir gelecek projeksiyonu sunmaktır.

Bu tez çalışmasının amacı yenilenebilir enerji planlaması ile ilgili çevresel, ekonomik, teknik ve sosyal kriterler göz önünde bulundurularak oluşturulan çerçeveye bağlı kalarak ve yenilenebilir enerji kaynaklarından güneş, rüzgar, jeotermal, hidroelektrik ve biyokütle olmak üzere beş enerji türü üzerine yoğunlaşarak, en uygun kaynak çeşitliliğine karar verilebilmesi için yenilenebilir enerji planlamasına yönelik çok amaçlı bir karar verme modeli geliştirmektir. Bununla birlikte, geliştirilen model kullanılarak Türkiye'de bölgesel bazda yenilenebilir enerji planlaması yapılırken, enerji türlerine göre en uygun ve en verimli enerji karmasının belirlenmesine katkıda bulunmak amaçlanmaktadır.

Bu tez çalışması ile birlikte doğal kaynaklar bakımından sınırlı rezervlere sahip olan ve gelişmekte olan ülkeler arasında yenilenebilir enerji bakımından yüksek potansiyele sahip bir ülke olarak anılan Türkiye için ithal edilen enerji oranını düşürmek, yerli enerji kaynağını yenilenebilir enerji alternatifleri ile arttırmak ve bunu yaparken yenilenebilir enerji potansiyelini en verimli şekilde kullanmak maksadıyla bir çözüm geliştirmek hedeflenmektedir. Ayrıca, geliştirilen model kullanılarak yenilenebilir enerji planlamasına yönelik orta vadeli bir yatırım perspektifi ile Türkiye için yenilenebilir enerji bölgesel yatırım projeksiyonu sunulması hedeflenmektedir.

Yenilenebilir enerji alanı son yıllarda özellikle gelişmekte olan ülkelerde teknolojik gelişmeler ile birlikte hızlı bir artış gösteren elektrik enerjisi talebi nedeniyle önem arz eden bir konu olarak ön plana çıkmaktadır. Benzer bir şekilde gelişmekte olan ülkelerden birisi olması, elektrik enerjisi talebinin artmakta olması ve yenilenebilir enerji potansiyeli bakımından yüksek potansiyelli bir ülke olarak kabul edilmesi gibi nedenlerden dolayı Türkiye'de yenilenebilir enerji planlaması alanında bir çalışma yapılması anlamlı

görülmektedir. Bu bakımdan literatür incelendiğinde son dönemde Türkiye'de yenilenebilir enerji konusunda yapılan çalışmalarda büyük bir artış olduğu gözlemlenmektedir. Enerji konusunun birçok farklı faktör ile bağlantılı olması dolayısıyla, araştırmacılar enerji konusunu incelerken çok amaçlı veya çok kriterli yöntemlere yer vermektedirler.

Yenilenebilir enerji konusu birçok farklı yaklaşım ve teknik kullanılarak ele alınmaktadır. Ancak bu tez çalışmasında çok amaçlı karar verme yöntemi kullanılarak geliştirilecek olan yenilenebilir enerji planlama modelinin, içerdiği amaç fonksiyonlarının ele alınış şekli ile diğer çalışmalardan ayrılması planlanmaktadır. Bunun yanı sıra, geliştirilen özgün modelin Türkiye'de bölgesel bazda uygulanacak olması çalışmayı literatürde yer alan diğer birçok çalışmadan ayırt etmektedir. Ayrıca, geliştirilen model kullanılarak Türkiye'de bölgesel olarak sunulması planlanan orta vadeli yenilenebilir enerji planlama projeksiyonu bu tez çalışmasına özgünlük katan bir diğer özellik olacaktır.

Kullanılacak olan çok amaçlı karar verme modeli ana hatlarıyla amaçlar, parametreler, bunları etkileyen kısıtlar ve karar değişkenlerinden oluşacaktır. Bu model ile yapılan uygulama sonuçlarının analizinin enerji planlaması alanında gelecekte yürütülecek akademik çalışmalara referans bir kaynak olarak katkı sağlayacağı düşünülmektedir.

ABSTRACT

A MULTI-OBJECTIVE DECISION MAKING MODEL FOR RENEWABLE ENERGY PLANNING: THE CASE OF TURKEY

The topic of this thesis is to develop a multi-objective decision-making model for renewable energy planning, to apply the developed model in the case of Turkey for the five types of renewable energy sources including solar, wind, geothermal, hydroelectric, and biomass in the context of determined suitability criteria, to evaluate the results gathered from the applied model, to make an analysis and to provide projections of future planning for renewable energy in Turkey.

This thesis aims to develop a multi-objective decision-making model for renewable energy planning in order to decide on the most appropriate resource diversity by focusing on five energy types from the renewable energy sources, namely solar, wind, thermal, hydroelectric, and biomass based on the framework structured by considering the criteria related to renewable energy planning that involves environmental, economic, technical and social issues. In addition to this, while constructing plans related to renewable energy on a multiregional basis in Turkey by using the developed renewable energy planning model, it is aimed to contribute to determining the most appropriate and the most efficient energy mix according to the type of energy.

With this thesis, it is also aimed to reduce the amount of imported energy, increase domestic energy supply with renewable energy alternatives, and develop a solution intended for using the renewable energy potential in the most efficient way for Turkey which has limited reserves in terms of natural resources while having high potential in terms of renewable energy across the developing countries. Also, with using the developed model it is aimed to provide energy investment projections in Turkey on a multiregional basis from a medium-term investment perspective for renewable energy planning.

In recent years, the field of renewable energy has become an important topic, especially in developing countries due to the rapidly increasing demand for electrical energy with the effect of technological developments. Similarly, since it is known as one of the developing countries with having high potential in terms of renewable energy and having an increasing demand for electricity, it can be considered reasonable to conduct a study

in the field of renewable energy planning in Turkey. In this regard, it can be observed from the literature review that a significant increase in recent studies on renewable energy in Turkey. On the other hand, the renewable energy field is related to many different factors, thus researchers are started to use multi-objective or multi-criteria methods when examining energy-related topics.

The field of renewable energy is reviewed and discussed by using many different approaches and techniques. However, the renewable energy planning model, which is developed in this study by considering the multi-objective decision-making method, can be distinguished from others with the originality of the objective functions it contains. This thesis can also be distinguished from many other studies in the literature with the application part since it is applied on a multiregional basis in Turkey. Moreover, it is planned to propose renewable energy planning projections on a multiregional basis in Turkey by using the developed model, which is another feature that adds to the authenticity of this thesis.

The multi-objective decision-making model to be used consists of objectives, parameters, constraints, and decision variables. It is thought that the analysis of the application results with this model will contribute to future academic studies in the field of energy planning as a reference resource.

SYMBOLS

$\boldsymbol{i}$	: Regions
$\boldsymbol{j}$	: Renewable energy types
$\boldsymbol{\lambda}$	: General satisfaction degree
$\boldsymbol{w_g}$	: Importance weights
$\boldsymbol{f_g(z_g)}$	: Membership function
$\boldsymbol{NTS_{ij}}$	: Technical score of regions and renewable energy types
$\boldsymbol{Cost_j}$	: Cost of renewable energy types
$\boldsymbol{JC_j}$	: Jobs created by renewable energy types
$\boldsymbol{NES_j}$	: Environmental score of renewable energy types
$\boldsymbol{D}$	: Demand
$\boldsymbol{mincap_{ij}}$	: Minimum required energy production
$\boldsymbol{maxcap_{ij}}$	: Maximum potential energy production
$\boldsymbol{M}$	: A big number
$\boldsymbol{x_{ij}}$	: The energy to be produced in regions concerning energy types
$\boldsymbol{y_{ij}}$	: Region i concerning energy type j is selected or not

ABBREVIATIONS

AHP	: Analytic Hierarchy Process
ANN	: Artificial Neural Network
ANP	: Analytic Network Process
API	: American Petroleum Institute
a-Si	: Amorphous Silicon
ASTM	: American Society for Testing and Materials
BEPA	: Biomass Energy Potential Atlas of Turkey
BP	: British Petroleum
C_2H_6	: Ethane
C_3H_8	: Propane
C_4H_{10}	: Butane
CdTe	: Cadmium Telluride Solar Cells
CH_4	: Methane
CIS/CIGS	: Copper Indium Gallium Diselenide
CO_2	: Carbon Dioxide
COPRAS	: Complex Proportional Assessment
CPV	: Concentrated Photovoltaic
c-Si	: Crystalline Silicon
CSP	: Concentrated Solar Power
DEMATEL	: Decision Making Trial and Evaluation Laboratory
DM	: Decision-Maker
DSİ	: State Hydraulic Works of Turkey
EAT	: Equivalent Attribute Technique
EIA	: United States Energy Information Administration
ELECTRE	: Elimination and Choice Translating Reality
EMRA	: Republic of Turkey Energy Market Regulatory Authority
ESMAP	: Energy Sector Management Assistance Program
EU	: European Union
EÜAŞ	: Electricity Generation Company of Turkey

EURACOAL : European Association for Coal and Lignite

FPSD : First Phase Satisfaction Degree

GA : Genetic Algorithm

GDP : Gross Domestic Product

GEPA : Solar Energy Potential Atlas of Turkey

GHG : Greenhouse Gas

GIS : Geographical Information Systems

GP : Goal Programming

GSA : Global Solar Atlas

GW : Gigawatt

GWA : Global Wind Atlas

GWh : Gigawatt-hour

HFCs : Hydrofluorocarbons

HOGA : Hybrid Optimization by Genetic Algorithms

ICT : Information and Communication Technologies

IEA : International Energy Agency

IF-TOPSIS : Intuitionistic Fuzzy Technique for Order Preference by Similarity to Ideal Solution

IHA : International Hydropower Association

ILP : Interval Linear Programming

IPCC : Intergovernmental Panel on Climate Change

IRENA : International Renewable Energy Agency

kW : Kilowatt

kWh : Kilowatt-hour

LCA : Life Cycle Assessment

LCOE : Levelized Cost of Electricity

MAUT : Multiple Attribute Utility Theory

MCDM : Multi-Criteria Decision-Making

MENR : Republic of Turkey Ministry of Energy and Natural Resources

MGM : Turkish State Meteorological Service Directorate

MODM : Multi-objective Decision-Making

MOLP	: Multi-objective Linear Programming
MTA	: Mineral Research and Exploration General Directorate of Turkey
MTOE	: Million Tonnes Oil Equivalent
MW	: Megawatt
MWe	: Megawatt Electric
MWh	: Megawatt-hour
N_2O	: Nitrous Oxide
NAIADE	: Novel Approach to Imprecise Assessment and Decision Environments
NIS	: Negative Ideal Solution
NREL	: National Renewable Energy Laboratory
^oC	: Celsius
OECD	: Organization for Economic Co-operation and Development
OKA	: Middle Black Sea Development Agency
OPEC	: Organization of the Petroleum Exporting Countries
OWA	: Ordered Weighted Averaging
pc-Si	: Polycrystalline Silicon
PFCs	: Perfluorocarbons
PIS	: Positive Ideal Solution
PROMETHEE	: Preference Ranking Organization Method for Enrichment of Evaluations
PTC	: Parabolic Trough Collector
PV	: Photovoltaic
PVOUT	: Photovoltaic Power Output
R&D	: Research and Development
REN21	: Renewable Energy Policy Network for the 21^{st} Century
REPA	: Wind Energy Potential Atlas of Turkey
RPS	: Renewable Portfolio Standard
SAW	: Simple Additive Weighting
sc-Si	: Single Crystalline Silicon
SDG	: Sustainable Development Goal

SF_6	: Sulphur Hexafluoride
SI-FSP	: Superiority-Inferiority-Based Fuzzy-Stochastic Programming
SMAA	: Stochastic Multi-Criteria Acceptability Analysis
SPEA	: Strength Pareto Evolutionary Algorithms
SPSD	: Second Phase Satisfaction Degree
SPT	: Solar Power Tower
SWARA	: Stepwise Weight Assessment Ratio Analysis
TEAŞ	: Turkish Electricity Generation and Transmission Company
TEDAŞ	: Turkish Electricity Distribution Company
TEİAŞ	: Turkish Electricity Transmission Corporation
TEK	: Turkish Electricity Corporation
TETAŞ	: Electricity Trading and Contracting Company
TKI	: Turkish Coal Operations Authority
TOE	: Tonnes of Oil Equivalent
TOPSIS	: Technique for Order Preference by Similarity to Ideal Solution
TSP	: Two-stage Programming
TWh	: Terawatt-hours
TWSD	: Total Weighted Satisfaction Degree
UCSUSA	: Union of Concerned Scientists
UCTEA	: Union of Chambers of Turkish Engineers and Architects
UN	: United Nations
UNFCCC	: United Nations Framework Convention on Climate Change
US	: United States
VIKOR	: Multi-criteria Optimization and Compromise Solution
W	: Watt
WASPAS	: Weighted Aggregated Sum Product Assessment
WGP	: Weighted Goal Programming
WPP	: World Population Prospects
YEKA	: Renewable Energy Zones Support Program
YEKDEM	: Renewable Energy Sources Support Mechanism

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The world population has increased significantly in the past two decades. The total population has passed the seven billion level around the world, and it is expected that the human population will continue to rise in near future. According to the United Nation's WPP2019 report, the medium-variant forecast suggests that the world population will rise to about 8.5 billion in 2030, 9.7 billion in 2050, and 10.9 billion in 2100, up from an estimated 7.7 billion in 2019 (United Nations, 2019). Rapid growth in the global population triggers serious problems related to consumption in general and implicitly sustainable development, thus it is thought that demographic trends and changes will play a critical role in the planning of governmental policies and strategies.

Simultaneously, with the effect of the rising trend of global economic growth in the last few decades, the level of global gross domestic product (GDP) per capita is expected to maintain its gradual increase. According to the 'The world in 2050' report prepared by PwC, it is also projected that the world economy to grow in the period 2014-2050 (PricewaterhouseCoopers, 2015). In order to support the idea behind the projection study, the estimated average annual real GDP growth rates for the 32 economies over the period to 2050 covered in the report as shown in Figure 1.1.

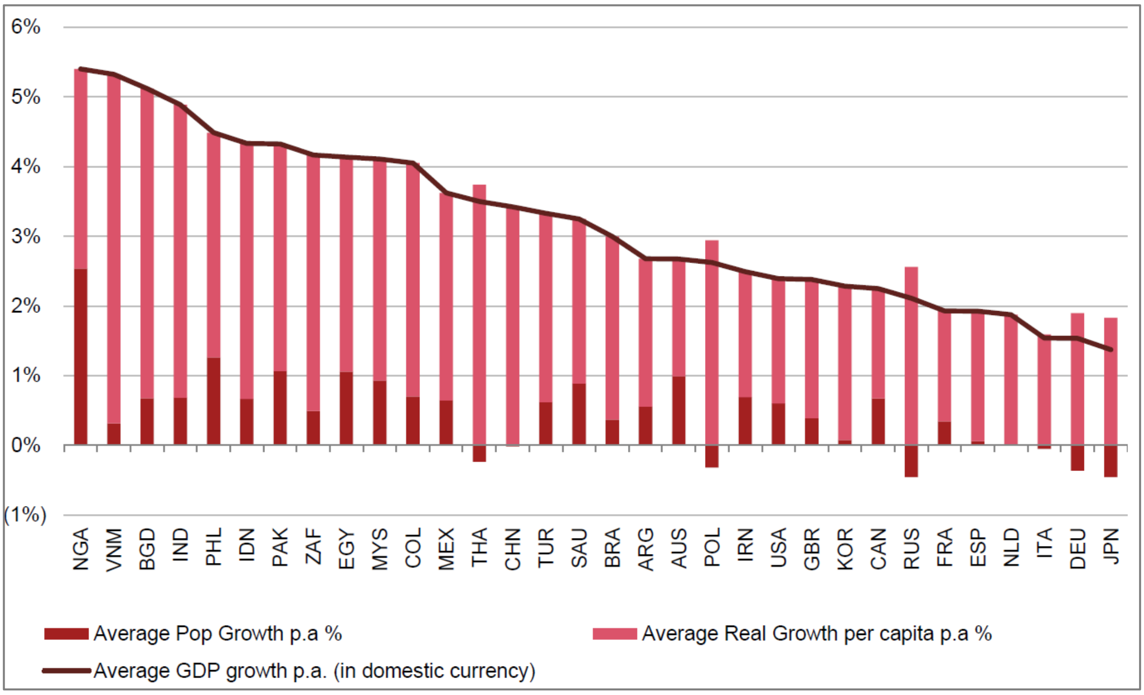

Figure 1.1 The estimated average annual real GDP growth rates

On the other hand, countries represented with GDP growth rates have to analyze the current situation efficiently to achieve their potential by developing well-planned global strategies in the process of long term policy planning.

In the meantime, the level of consumption, the most inevitable of which is the need for energy, maintains its rise in many ways despite the fact that the world's fossil resources are finite and rapidly depleting. The population growth in many of the transitional states in the world has a similar and dynamic dependency on the rate of yearly energy usage per person over the past 30 years, according to data provided by United Nations (Sheffield, 1999). On the other hand, it is also known that the electricity consumption and the economic development maintain a direct relationship. In fact, considering the rise of the income per capita and the demographic growth, it is projected that demand for electricity in developing countries will rise to unprecedented levels. In other words, it can be concluded that population growth and economic growth are the main factors leading to an increase in primary energy consumption in the world. Therefore, the issue of being largely dependent on fossil fuels in energy production is examined in the context of the ongoing global population growth and rising global income level trend, and it is expected that the energy problem will be one of the major challenges that humanity must deal with in the short term.

Since the world already has limited reserves in terms of fossil fuel resources, and the resources are not evenly distributed between countries, it is not possible to meet the energy demand only with these resources. Moreover, the damage they cause to the environment and living conditions, especially human health, animal life, and nature, is also considered as another threat. In these circumstances, decision-makers have started to find out alternative sources to meet the energy needs. Renewable energy resources are considered as the most prominent primary sources of alternative energy sources that require strategic planning in terms of sustainable development. Thereby, it can be said that these conditions have led decision-makers to carry out intensive studies on energy planning, to work on future energy projections, and to study forecasting models. In short, when all these factors are taken into account, it will be revealed that how important energy planning is today.

Energy planning, which is vital in technical, economic, socio-political, and environmental aspects, has recently become one of the most debated topics. Hence, the planning process requires special attention to determine the right energy types in an optimum way to the most appropriate regions is a very important issue. At the same time, meeting the energy demand is vital since it is projected by EIA (2019) in 'World Energy Outlook 2019' report that between 2018 and 2050, global energy consumption will increase by approximately half. For this reason, in order to meet the energy demand policymakers interested in energy planning need to give necessary importance to the issue by being aware of the seriousness of the problem particularly in regions that have limited availability in terms of natural resources or have restricted opportunities in terms of fossil fuel use. In other words, general energy planning by itself would not be sufficient in all cases, thus energy planning from a regional perspective has an important place in this process to be able to cope with the increased energy demand of each developing region. This process should also cover mainly the analysis of the needs and requirements of the specific regions in detail by considering the importance of technical conformity, financial analysis in a way that minimizing the total cost, the examination of social and employment issues, and environmental effects of energy sources.

The aim of this thesis is to analyze the current position and future potential of renewable energy sources in electricity generation and propose a multi-objective model for multiregional energy planning in Turkey. With the use of the developed model, it is aimed to contribute the decision about the most suitable renewable energy sources for the potential location. In order to decide on the most appropriate resource diversity, the main focus will be given to five energy types from the renewable energy sources, namely solar, wind, geothermal, hydroelectric, and biomass. The main reason for the selection of these five energy types is that they are the most preferred types in electricity generation. In this way, this study aims to raise awareness on the preference of renewable energy in energy consumption and so that countries will use their energy potential in the most efficient way and will benefit from many aspects, especially in economic and environmental areas.

The framework and the scope of the study will be based on significant criteria to be determined as a result of the research regarding the renewable energy planning problem. Evaluation criteria will be selected among the most crucial issues concerning environmental, political, economic, and social conditions. Since the energy planning process involves many complex criteria that are interrelated and independent of each other, multi-criteria decision-making methods (MCDM) are found to be one of the most suitable techniques for this complex process. As it is mentioned before, one of the aims of the thesis is contributing to determining the most appropriate and the most efficient energy mix according to the type of energy.

In addition, this thesis aims to propose a case application while constructing plans related to renewable energy on a multiregional basis in Turkey by using the developed renewable energy planning model. Other goals of the thesis are evaluating the results gathered from the applied model, making an analysis in detail, and providing future projections for renewable energy planning in Turkey. Moreover, this study aims to contribute reducing external energy imports, and increasing the use of domestic energy resources particularly renewable energy alternatives by developing a multi-objective decision-making model intended for utilizing the renewable energy potential in an efficient way. For the application part of the model, LINGO statistical software and other relevant programs are used by ensuring the consistency of the results.

2. LITERATURE REVIEW

2.1. Energy Planning

There is an increase in energy consumption in direct proportion to the growing population in the world, and the rise in energy demand continues with the effect of technological developments, industrialization, and urbanization. In this context, countries carry out short, medium, and long-term strategic planning for energy planning in order to meet their increasing energy needs and use existing energy resources with maximum efficiency.

It is expected that developing countries will account for a large proportion of the global growing energy demand. Thus, energy-related activities have crucial impacts on the national economy of developing countries in many aspects. The number of energy plants that a country possesses can be regarded as a significant indicator of its strong financial stability. In other words, the energy status of the country, whether it has adequate reserves to meet its energy needs from domestic resources or it has high energy import dependency, is one of the most important factors in the economic growth that presents the level of production and development.

Although fossil fuels are still known as the source of energy with the largest share of use in the energy field, it is observed that the share of renewable energy sources in the energy field is increasing day by day due to growing environmental concerns and global economic circumstances. The promising aspect of this situation is that more importance has been given to natural sources on a global basis and energy planning has become one of the most critical issues on the agenda of countries.

The excessive use of fossil fuels causes negative impacts and unfavorable results in terms of many different perspectives, such as environmental and economic. Without a well-designed energy planning mechanism, the energy industry is closely linked to environmental factors that damage the ecosystem in case of unbalanced use of fossil fuels. This situation adds further complexity to the problem since these components are extremely hard to manage or incorporate into the planning process (Hocine et al., 2020). Furthermore, the unplanned use of energy sources, in particular, fossil resources leads to the emergence of the external deficit as one of the most known negative effects from an economic perspective. Regarding this issue, Erdin and Ozkaya (2019) emphasize that rise in the natural gas and oil costs could hinder importing countries' local production, resulting in an increase in the foreign trade deficit.

Therefore, energy planning is considered as one of the leading subjects of strategic future plans, which are of great importance to developing states around the world. In particular, governments are working to use existing energy sources in the most optimal way, produce energy from these resources in the most efficient way, and meet energy demand from renewable energy sources through new policy regulations, incentive programs, and R&D investments. Especially in recent years, with the impact of economic, social, and environmental factors, future energy planning is being carried out with an aim to gradually increase the utilization rate of renewable energy sources to the highest possible level.

It is undoubtedly a clear issue that renewable energy sources generate less environmental pollution and release minor greenhouse gas emissions. Additionally, these resources are known as inexhaustible sources with having self-regenerating properties in nature. The characteristics of renewable energy sources can vary based on the natural climatic conditions of the region (Erdin and Ozkaya, 2019) and the type of energy sources. Thus, one of the key decisions related to renewable energy technologies is to determine the optimal energy alternative with the highest energy potential in the most appropriate region.

Recent studies reveal that the renewable energy field is becoming increasingly important worldwide and the number of research papers related to renewable energy sources shows an upward trend in the recent period. The growth tendency towards this subject has also resulted in a substantial increase in the studies conducted, especially in developing countries, due to rapidly increasing demand for electrical energy with the effect of technological developments. This situation proves that the renewable energy field becomes more and more important in the literature, with the expectation of an increase in renewable energy use in the future. Furthermore, this situation also provides investment opportunities for energy companies, especially for those operating in the field of renewable energy. Accordingly, these circumstances attract a great deal of attention from national and international investors that are planning to establish new energy plants.

In this regard, there are several types of energy planning problems in the literature related to renewable energy. Especially, capacity growth planning of renewable energy sources draws attention as an important but complicated topic that is becoming increasingly involved in studies. San Cristóbal (2012) states that the renewable energy industry's capacity expansion planning issue encompasses not just the determination of the most appropriate renewable energy option among various alternatives, but also the creation of enhancement plans for the generation, transmission, and distribution systems. Since renewable energy capacity growth planning is considered as a complex managerial practice involving various interrelated processes (Ervural et al., 2016), the plan need to be prepared including many different important decisions concerning the optimum diversity of different renewable energy plants, the best location alternatives for each energy facility, and capacity enhancement decisions over the planning horizon for each plant (San Cristóbal, 2012).

Overall, harmful emissions released as a result of energy conversion processes by the fossil energy sources cause serious damage to the ecosystem, while problems such as high costs of installation, unknown risk levels, and selection of the appropriate plant location in alternative energy sources cause uncertainties (Ervural et al., 2016). The level of uncertainties in the planning of renewable energy decision-making problems has a significant impact on determining model objectives and methods that will be used to solve the problem.

Although there has been a significant increase in research conducted in the field of renewable energy in recent years, it is seen that a great majority of these studies are concentrated on the Asia and the European continent (de Simón-Martín et al., 2019; Chen et al., 2020; Liu et al., 2017; Cong, 2013; Connolly et al., 2016; Knopf et al., 2015). In addition, only one of the renewable energy sources is frequently considered in the studies and the general situation of the selected type of renewable energy in a particular region or area is evaluated. However, models for energy planning are created to represent the characteristic features of a particular area or state, and they can differ dramatically based on the variety of domestic sources and regulations (Ervural et al., 2018a). Therefore, Turkey's main goal in fighting climate change is to make a major contribution to activities on an international scale in accordance with sustainable development strategies, based on shared yet separate obligations (Benli, 2013). On the other hand, Turkey is known as a country with a heavy dependence on energy imports, although it has a high potential for renewable energy sources. In order to provide a solution energy generation problem, the state is making efforts to focus on renewable energy in its future energy planning policies.

In the literature, there are a limited number of studies that evaluate different alternatives of renewable energy sources for Turkey on a multiregional basis. For this reason, since it is known as one of the developing countries with having high potential in terms of renewable energy sources and having an increasing demand for electricity, it can be considered reasonable to conduct a case study in the field of renewable energy planning in Turkey for the thesis study. Furthermore, it can be observed from the literature review that there is a significant increase in recent studies on renewable energy in Turkey. On the other hand, the renewable energy field is related to many different factors thus researchers are started to use multi-objective or multi-criteria decision-making methods when examining energy-related topics.

2.2. Decision Making Methods

At this point, it is clear that one of the most important, complex, and difficult strategic decisions that investors have to make is the determination of optimal energy type, required installed capacity, and feasible plant location which are the key factors for an energy plant to operate in an efficient way. However, the degree of eligibility of renewable energy resources for each region is not the same due to variability in regional characteristics and the potential of resources. In fact, it depends on many other different criteria including technical, economic, social, and environmental issues. Related to this subject, Karaca et al. (2017) state that it is significant to make an activity analysis considering technical, economic, environmental, and social characteristics of renewable energy resources before deciding on the source and amount of capacity in renewable energy investments.

There are many studies in the literature analyzing the energy sector from different perspectives. However, researches in the renewable energy field mostly examine five main renewable energy types including solar, wind, hydro, geothermal, and biomass, under four main criteria covering technical, economic, social, and environmental (Karaca and Ulutaş, 2018; Özcan et al., 2017). These resource types are examined in decision problems by investigating distinct characteristics of renewable energy sources which are determined based on the objective of the study. On the other hand, the number of studies evaluating all five renewable energy types and all four main criteria simultaneously is very rare in the literature. Therefore, it is aimed to present a study that addresses all the elements together as the subject of this thesis.

In general, decision-making methods are used in a wide variety of areas, particularly it is frequently used in the energy field. The most commonly used approaches in energy-related subjects are known as multi-criteria decision-making and multi-objective decision-making techniques.

Since the decision process contains several relevant and irrelevant factors which can also be time-varying, evaluation of the decision model for the problem must contain various criteria related to objectives. Farahani et al. (2010) specify that in many real-world problems, the decision-maker prefers to seek several goals or take into account multiple factors or measures. Accordingly, energy planning decisions require considering several different factors related to the category of energy resource, cost of energy type, technical features of the energy resource in the region, employment opportunities provided by the energy type, and environmental impact of the energy source. Research on planning activities in the energy industry included in the literature essentially deals with four main aspects when evaluating the determination of criteria. The typical main criteria used in energy systems involve technical, economic, environmental, and social, whereas the most frequently used sub-criteria for technical criteria include energy efficiency, installed capacity, capacity factor, energy production, reliability, safety, technological maturity; for economic criteria include levelized cost of electricity, investment cost, operation and maintenance cost, fuel cost, payback period, service life; for environmental criteria include greenhouse gas emission, land use; for social criteria include social acceptability, job creation, human health, social benefits (Şengül et al., 2015; Wang et al., 2009; Maxim, 2014; Stein, 2013). Thereby, the decision-making process involves the assessment of multiple attributes and uncertain criteria due to the complexity of the decision problem.

In general, the field of renewable energy is reviewed and discussed by using many different approaches and techniques based on the purpose of the study. In other words, when the subject of renewable energy is examined in-depth, it is observed that the topic contains many different and complex elements that are dependent and independent from each other. Therefore, the method used in the study varies depending on the objectives determined by the researcher. However, the literature review reveals that multi-criteria decision-making methods are extensively used in recent years for renewable energy related subjects due to their suitability. Briefly, it can be clearly observed that usually decision problems consist of many conflicting criteria and requires simultaneous evaluation of alternatives. For this reason, the most common approach preferred by researchers to solve this kind of problem is the MCDM method.

The MCDM techniques have a wide range of applications performed in various fields such as Chou et al. (2008), Ertuğrul and Karakaşoğlu (2008), Hanine et al. (2016) in facility location selection decision-making problems, Dey et al. (2017), Emeç and Akkaya (2018) in warehouse location selection, Kim & Chung (2013) in climate change, Franco et al. (2015), Choudhary and Shankar (2012), Akkas et al. (2017) in the energy sector, Marinković et al. (2018), Garg et al. (2018) in the ICT sector. On the other hand, the renewable energy related topics that are often studied by researchers in the literature using MCDM can be indicated as energy planning (Mourmouris and Potolias, 2013; Beccali et al., 2003), energy policy (Kaya et al., 2018), energy sources ranking (Stein, 2013; Lee and Chang, 2018), power plant location selection problems (Wang et al., 2018; Shao et al., 2020), energy project selection (Xiao et al., 2017), and selection of appropriate renewable energy types among alternatives (Deveci et al., 2020; Tasri and Susilawati, 2014).

There are different approaches applied in the literature for providing solutions to the real-world problems using MCDM methods. The well-known methods used for determining the best solution to renewable energy planning problems contain Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE), Elimination and Choice Translating Reality (ELECTRE), SAW (Simple Additive Weighting), Multi-criteria Optimization and Compromise Solution (VIKOR), Decision Making Trial And Evaluation Laboratory (DEMATEL), Complex Proportional Assessment (COPRAS), as well as hybrid methods and fuzzy techniques.

Apart from these the most widely used method for the criteria weighting process in studies observed is the AHP method. Because of its hierarchical structure and pairwise comparison property that allow assigning different importance weights for each criterion, the AHP method is a convenient method with ease of use (Ozdemir and Sahin, 2018). In decision-making problems, the AHP method is used by decision-makers in order to simplify a complex problem into the hierarchical structure in a form that they can assign weights to rank alternatives.

Saaty (1988) stated that the AHP has three parts which includes identifying and organizing decision objectives, criteria, constraints and alternatives into a hierarchy; evaluating pairwise comparisons between the relevant elements at each level of the hierarchy; and synthesizing using the solution algorithm of the result of the pairwise comparisons over all the levels. Furthermore, AHP method provides a special numerical scale format for pairwise comparisons. This scale defined by Saaty (2008) as the fundamental scale of absolute numbers which contain importance of numbers ranges from 1 to 9, where1 indicates that two activities have equal importance, and 9 implies that one activity has a superiority over another.

It is accepted by authorities that the AHP method is a powerful tool in the criteria weighting process. However, during the alternative evaluation, the ranking of alternatives, and selection of the optimal alternative processes, there are other MCDM techniques suggested that provide more efficient results. It can be clearly said that each method has advantages and disadvantages, thus determining the suitable method for a certain decision-making problem is not quite possible. Sun et al. (2010) express that there are no better or worse MCDM techniques for a given problem, therefore it is not easy to say which MCDM approach is more reasonable and reliable for a given decision making problem, as the selection of MCDM methods itself a complicated process (as cited in Wang et al., 2016). Regarding this issue, Mousavi-Nasab & Sotoudeh-Anvari (2017) and Wang et al. (2016) emphasize that using more than one MCDM method comparatively instead of a single technique for the specific problem will provide more reliable and trustworthy results. For this reason, several MCDM techniques need to be considered in the studies that will be carried out regarding energy planning to obtain more reliable results.

As one of the most widely preferred approaches for the MCDM problems, the TOPSIS method provides a set of procedures to obtain feasible alternatives among specified criteria in order to determine the best power plant location. Hwang and Yoon (1981) was developed the TOPSIS method for the first time in history and presented it as a multiple-criteria method to identify solutions from a finite set of alternatives (as cited in Kumar and Kumanan, 2012). The basic principle of the TOPSIS method is presented as the best alternative should have the shortest distance from the ideal solution and the farthest distance from the anti-ideal solution (Pamučar et al., 2017). In more details, the TOPSIS method introduces two reference points: a positive ideal solution (PIS) which maximizes the benefit criteria and minimizes the cost criteria, and a negative ideal solution (NIS) which maximizes the cost criteria and minimizes the benefit criteria (Wang et al., 2016) in order to help selecting the best choice having the shortest Euclidean distance and the farthest Euclidean distance to the PIS and from the NIS, respectively (Mousavi-Nasab and Sotoudeh-Anvari, 2017). One of the main advantages of the method is that it requires limited subjective inputs from the decision-maker and the only subjective inputs required are the weights given to the criteria (Ishizaka et al., 2013). Furthermore, the TOPSIS method draws attention to its prevalent features including simplicity in perception and use in cases when the number of alternatives and criteria is too many, suitability in cases when the data is provided as objective and quantitative (Özcan et al., 2011).

In literature, the PROMETHEE method is also accepted as one of the most frequently used outranking methods intended for solving MCDM problems. It is known that the PROMETHEE method was first developed in 1985 to propose an easily understood approach by the decision-maker and to introduce an effective outranking technique (Brans and Vincke, 1985). The main procedure for the PROMETHEE method executes a pairwise comparison of the alternatives and calculates the magnitudes of leaving or entering flows for each (Wu et al., 2016a). The PROMETHEE is quite well suited to the decision-making problems, in which a finite number of options are to be evaluated with regard to variety of criteria (Albadvi et al., 2007). The starting point of the PROMETHEE technique is the assessment matrix in which the alternatives are evaluated on the different criteria (Mousavi et al., 2013). There are also two types of information required for the PROMETHEE to be implemented: information on the relative importance value of the considered criteria, and information on the decision maker's preference function (Macharis et al., 2004). For the evaluation process, the PROMETHEE-I used for partial ranking by considering a ranking of alternatives, whereas the PROMETHEE-II provides a complete ranking of the alternatives from the best to the worst, based on the net flow to rank the alternatives (Mousavi et al., 2013). Moreover, compared with other MCDM methods, the PROMETHEE method's efficiency stems from its strong mathematical foundation, low information requirements, and ease of application, which provides more clarity and reliability to the decision-makers (Wu et al., 2016; Queiruga et al., 2008). On the other hand, the PROMETHEE does not include precise instructions for deciding these weights instead it assumes that the decision-maker is capable of correctly weighting the parameters, at least when the number of criteria is not excessive (Macharis et al., 2004). The application of the PROMETHEE method for determining the best option among possible alternatives in decision-making problems, such as renewable energy plant location selection or renewable energy project selection, could be considered as one of the most appropriate techniques since it aims to support decision-makers to understand the evaluation process and to provide the ranking of the optimal alternatives for plant installation.

For the selection process of the optimal alternative in MCDM problems, the COPRAS method is considered as another efficient approach for the most suitable solution of the decision problem in the literature. Especially, in recent years, the COPRAS method has been increasingly used for quantitative and qualitative evaluation of complicated processes in order to choose the best alternatives, ranking the alternatives in the order of their significance (Garg, 2019). Zavadskas et al. (1994) were introduced the COPRAS technique as a new method of MCDM that is used for ranking and assessing alternatives in terms of importance and benefit ratings (as cited in Büyüközkan et al., 2018). "The COPRAS method determines a solution and the ratio to the ideal solution and the ratio to the worst-ideal solution and therefore can be regarded as a compromising method" (Hajiagha et al., 2013). Furthermore, the method is based on direct and proportional dependence of significance and priority of investigated alternatives (Ustinovichius et al., 2007). Büyüközkan et al. (2018) state that the COPRAS method is "usable for both of the maximum and minimum criterion values and can be easily applied to complex criteria and problems involving multiple alternatives". In this aspect, it can be considered as one of the most powerful features of the method.

Multi-Objective Decision Making

The multi-objective decision-making method, also known as vector optimization or multi-objective programming, is considered as another efficient approach widely used in the energy field. In MODM, a collection of objective functions is optimized concerning a group of constraints instead of predetermined alternatives (San Cristóbal, 2011).

In general, the amount of investment required for a renewable energy power plant installation is considerably high, therefore decision-makers must ensure that specified criteria and objectives include a sufficient range of subjects based on accurate information for the investors before the installation process started. From this perspective, the optimal energy planning for the use of renewable energy sources also incorporates many other economic, technical, environmental, and social factors as reviewed in the literature.

The MODM models have been used in various areas including renewable energy planning (Ervural et al., 2018a; Aksoy, 2019; Deveci and Güler, 2020), electricity generation planning (Özcan and Erol, 2013; Dursun et al., 2013), energy resource allocation (Özcan and Erol, 2014), evaluation of investments on renewable energy (Dinçer and Yüksel, 2019), flexibility investment (He et al., 2011), investment optimization (Fazlollahi et al., 2012), regional optimization of renewable energy sources (Pratama et al., 2017), spatial optimization of renewable energy sources (Karakostas and Economou, 2014), and planning of distributed energy sources (Alarcon-Rodriguez et al., 2010). There are many different MODM methods applied in the studies regarding various subjects of the renewable energy sector. Cui et al. (2017) review multi-objective optimization methods in their study and provide a brief introduction about problems and algorithms. Using the multi-objective optimization approach, Mousa et al. (2019) investigate rooftop applications of specific solar energy systems, Wang et al. (2015) conduct a study evaluating a combined cooling, heating and power system driven by solar energy. Moreover, some studies in the literature related to MODM problems contain approaches consist of more than one step or level in the proposed model to find the optimal solution. Ho et al. (2014) develop a multi-objective programming model for energy conservation and renewable energy for school campuses by employing multi-objective linear programming (MOLP) and fuzzy two-stage algorithm. Prebeg et al. (2016) propose a two-level approach for long-term energy planning with a focus on renewable energy and integration of electric vehicles. Studies referring to renewable energy sources with regards to multi-objective techniques essentially involves wind energy (Montoya et al., 2014; Şişbot et al., 2010; Zhao and Huang, 2011), solar energy (Wu et al., 2016b), hydroelectric energy (Sauhats et al., 2016; Simab et al., 2018), geothermal energy (Schulte et al., 2020), and biomass energy (Samy et al., 2020; Yeo et al., 2020). Some of the studies carried out by considering different sources of renewable energy and by using different methods represented in the literature review table as following:

Table 2.1 Literature review table

Authors & Publication Year	Alternatives	Subject	Methods	Application Area
Ervural et al. (2018a)	Wind Solar Hydraulic Biomass Geothermal	Sustainable Energy Investment Planning	AHP Fuzzy TOPSIS Goal Programming (GP)	Turkey
Ervural et al. (2016)	General	Review for Optimization Models in Energy	-	-
Zografidou et al. (2017)	Solar	Designing a Renewable Energy Map	GP	Greece
San Cristóbal (2012)	Wind Solar Biomass	Location Selection for Renewable Energy Plant	GP	The North of Spain
Chang (2015)	Wind	Location Selection for Renewable Energy Plant	GP	Taiwan
Suganthi et al. (2015)	Solar Wind Bio-energy Micro-grid Hybrid	Applications of Fuzzy Logic Based Models	Fuzzy Logic	-
Mourmouris & Potolias (2013)	Wind Solar Geothermal Biomass Hydro	Decision Making for Energy Planning	REGIME	Thassos, Greece
Vafaeipour et al. (2014)	Solar	Prioritization of Regions for Solar Power Plant	Hybrid Model SWARA WASPAS	Iran
Ervural et al. (2018b)	General	Energy Planning	Hybrid Methodology ANP Fuzzy TOPSIS	Turkey
Chatzimouratidis & Pilavachi (2009)	Hydro Wind PV Biomass Geothermal	Assessment of Power Plants	AHP	

Dufo-López et al. (2011)	Hybrid System PV-Wind-Diesel	Multi-objective Optimization of Hybrid System	SPEA HOGA LCA	Spain
Jayaraman et al. (2017)	General	Evaluation of Optimal Resource Allocation	WGP	Gulf Cooperation Council Countries
Afgan & Carvalho (2002)	Solar Geothermal Biomass PV Wind Ocean Hydro	Assessment Renewable Energy Power Plants	MCDM	-
Fleten et al. (2007)	Wind	Investment Strategies for Renewable Energy Under Uncertainty	Special	Norway
Kahraman et al. (2009)	Biomass Wind Solar Geothermal Hydropower	Selection of Appropriate Renewable Energy Types Among Alternatives	Axiomatic Design Fuzzy AHP	Turkey
Kaya & Kahraman (2010)	Geothermal Solar Wind Hydraulic Biomass	Selection of Appropriate Renewable Energy Types Among Alternatives	Fuzzy VIKOR AHP	Istanbul, Turkey
Løken et al. (2009)	General	Planning of Local Energy Systems	EAT MAUT	-
Atici et al. (2015)	Wind	Site Selection for Wind Power Plant	GIS ELECTRE SMAA	Western Turkey
Kaya & Kahraman (2011)	Solar Wind Hydraulic Biomass	Energy Planning	Fuzzy TOPSIS Fuzzy AHP	-
Haralambopoulos & Polatidis (2003)	Geothermal	Group Decision-Making Framework for Renewable Energy Projects	PROMETHEE	Chios Island, Greece
Grady et al. (2005)	Wind	Placement of Wind Turbines	Genetic Algorithm	-
Gonzalez et al. (2018)	Hybrid: PV-Wind-Biomass	Optimization of Hybrid Renewable Energy Systems	Genetic Algorithm	Catalonia
Şengül et al. (2015)	Hydro Geothermal	Ranking of Renewable Energy Supply Systems	Fuzzy TOPSIS	Turkey

	Wind Regulator			
Aydin et al. (2010)	Wind	Site Selection for Wind Power Plant	GIS OWA	Western Turkey
Sánchez-Lozano et al. (2013)	Solar	Location Selection for Solar Energy Plant	AHP TOPSIS GIS	South-eastern Spain
Cai et al. (2009)	Hydropower Solar Wind	Planning of Community-Scale Renewable Energy Management Systems	ILP TSP SI-FSP	Community-Scale
Mellit et al. (2007)	PV	Sizing of Photovoltaic Systems	Artificial Neural Network Genetic Algorithm	Algeria
Korkmaz et al. (2014)	Geothermal	Assessment of Hydrothermal and Geothermal Potentials of Turkey	Probability Distributions	Turkey

On the other hand, Ervural et al. (2018a) state that problems regarding renewable energy planning have a wide scope involving capacity enhancement, the optimal mix of renewable energy options, and cost effective and sustainable utilization of resources. Moreover, renewable energy planning problems are also considered from economic, social, political, and technic aspects, under numerous objectives and constraints, simultaneously and collectively. It is clear that the optimal planning of the use of renewable energy sources requires technical analysis of energy alternatives comparatively, thus technical evaluation of selected renewable energy sources on a multiregional basis in Turkey is specified as one of the objectives in the case application of the thesis study. In addition, the average lifetime levelized cost of electricity generation used in the objective determination part in terms of the economic aspect, whereas job creation by renewable energy sources examined from a social perspective in the objective determination. Also, environmental impacts regarding renewable energy sources are considered as another key objective.

As one of the most powerful approaches towards renewable energy planning model, multi-objective decision-making method will be used in this thesis in order to develop a model to be distinguished from other studies with the originality of its objective functions. Furthermore, this thesis aims to be distinguished from many other studies in the literature with the application part since the proposed model will be applied on a multiregional basis in Turkey. The multi-objective decision-making model to be used will consist of objectives, parameters, constraints, and decision variables. It is thought that the analysis of the application results with this model will contribute to future academic studies in the field of energy planning as a reference resource.

2.3. Goal Programming

Since, there may be many different attributes involved in the decision-making process that have a vital role and huge impact on the result, determining the set of objectives for the investment decision based on renewable energy planning needs to be taken into account as a significant component. Renewable energy capacity growth planning is a complicated issue that covers the capacity increase of currently installed power plants, the capacity status of power plants under construction, and the capacity planning of new power plants to be established. Thus, a goal programming model is a useful option to provide a solution to the problem of renewable energy planning, since it is important to evaluate different objectives together and simultaneously based on determined criteria in order to obtain reasonable outputs. As Zografiodu et al. (2017) state that the goal programming (GP) methodology is a versatile kind of mathematical model that can combine several different aspects of the problem and generate a collection of feasible solutions that satisfy all constraints. Aouni et al. (2015) point out that the GP technique is a common aggregation approach that allows multiple competing goals to be considered at the same time for solving multi-objective programming problems. The GP methodology has been used in several areas in the literature including investment planning for renewable energy sources (Baysal and Çetin, 2018), renewable energy plant location selection (San Cristóbal, 2012; Chang, 2015), financial analysis of renewable energy production (Zografiodu, 2017), renewable energy portfolio optimization (Hocine et al., 2018), and resource allocation (Jayaraman et al., 2017). Although the goal programming techniques are widely applied to the renewable energy field, the two-phase goal programming method is rarely used for the regional renewable energy planning decision-making problems.

Two-Phase Fuzzy Goal Programming

There are several different techniques applied in various fields to achieve a realistic and reliable solution for the multi-objective goal programming problems in the literature. Namely, the two-phase fuzzy goal programming approach, which provides an effective solution mechanism for solving multi-objective goal programming problems, has been used by researchers in the mathematical model construction with membership functions.

Liang (2009) used a two-phase fuzzy goal programming approach for solving the multi-objective project management decision problems in a fuzzy environment. The real-life decision-making problems generally have conflicting objectives in the problem structure, therefore Arıkan and Güngör (2007) proposed a two-phase mathematical approach for multiple objective decision problems with all fuzzy coefficients, by considering fuzzy linear programming and fuzzy parametric programming. Moreover, Cavdur et al. (2019) presented a study using a two-phase binary-goal programming-based approach to solve a novel system design project-team formation problem that involves several restrictions, requirements, and the preferences of the potential team members. Furthermore, recent studies reveal that the number of studies, which combine different methods and modified versions of the two-phase concept as well as the classic two-phase procedure, show an increasing trend. In this regard, Kilic and Yalcin (2020) proposed an integrated methodology including the Intuitionistic Fuzzy Technique for Order Preference by Similarity to Ideal Solution (IF-TOPSIS) and a modified two-phase fuzzy goal programming model for green supplier selection problem.

Although the two-phase fuzzy goal programming method is rarely studied in the literature, it is observed that this approach provides a practical and satisfactory contribution for problem-solving especially in multi-objective decision-making problems. Thus, in terms of the structure of the problem examined in this study, similar studies in the literature have been reviewed before determining the most suitable method to be used for the proposed model. In this study, the two-phase fuzzy goal programming approach is used as an efficient and appropriate method to obtain the optimal solution for the proposed multi-objective mathematical model.

2.4. Originality of Study

The subject of this thesis is the energy field in general however, the main focus is specifically given to the renewable energy field in detail. A brief literature review revealed that renewable energy is a trending topic in developing countries with the effect of technological developments. In recent studies, it is also observed that researchers mostly discuss renewable energy topics from one approach or examine the subject by focusing on only one type of renewable energy source. Thus, one of the goals of this thesis is to present a broad perspective regarding five renewable energy sources together. The wide scope of the subject is one of the distinct characteristics of this study. The field of renewable energy is reviewed and discussed from many different approaches by using various methods and techniques.

Apart from these studies, the main purpose of this thesis is to develop a renewable energy planning model by keeping the scope wide in a way that incorporating many different methods simultaneously. Thereby, the model which is developed by using multi-objective decision-making methods may be similar to others in some aspects however, the final form of the model is different from others by way of handling. In parallel, the objective functions determined for the model, are distinguished from other studies with the originality of their usage in the process.

In addition to this, the thesis also aims to be distinguished from many other studies in the literature with the application part since it is applied on a multiregional basis in Turkey. Studies regarding this topic generally focused on a single country, city, or location. On the other hand, this thesis aims to provide the suitability of renewable energy sources by the case application in Turkey on a multiregional basis based on the results of the proposed model. By using the model, it is planned to form renewable energy planning projections on a multiregional basis in Turkey which will be another feature that adds to the authenticity of this thesis.

For further research, the model can be improved in a way that provides the appropriateness of renewable energy types on a provincial basis in Turkey. This thesis can produce valuable results for academic studies, decision-makers in the energy field, and policymakers in the government. Furthermore, the source of data for the research includes governmental reports gathered from related institutions and periodic reports provided by international organizations. For that reason, required information were obtained as a result of eliminating irrelevant data and compiling relevant data from comprehensive reports. The consistency of the model is checked by the data received from sources that contain information of previous, current, and coming years.

3. CLASSIFICATION OF ENERGY SOURCES

In this study, the primary focus will be given to the types of energy resources that can be used to produce electricity. In general, energy sources are categorized as non-renewable energy sources and renewable energy sources in terms of their usage.

3.1. Non-renewable Energy Sources

The main reason why these type of energy sources is called non-renewable is that non-renewable energy sources have limited reserves on the Earth. The most common types of non-renewable energy sources are fossil resources including coal, natural gas, oil, and nuclear resources such as uranium and thorium.

Throughout history, non-renewable energy sources, in their various forms, have been the main source of energy supply and have served human energy needs (Asif and Muneer, 2007). Even in the current situation, worldwide energy production is highly dependent on non-renewable energy sources. According to International Energy Association's 1973 statistics, approximately 80% of the world electricity generation is met by non-renewable sources, and 2018 statistics are revealed that around 75% of the world electricity produced from non-renewable resources (IEA, 2020a).

There are many reasons that lead to prefer non-renewable energy sources in energy generation, therefore it is necessary to analyze the subject of energy production in accordance with the technological requirements of the era by combining technological, economic, social, and environmental aspects of the period. For instance, in order to meet the growing demand for electricity, it is projected that the use of non-renewables including coal and natural gas for energy generation will continue to increase in the short term. Because, as Malhotra (2013) stated the advantages of coal as a source of energy include its widespread availability, relatively low price, and cost-effective use by mature technologies. Also, the author notes that there is still a significant increase in demand for natural gas, a renewable fuel that can be used in high-efficiency energy generation.

The demand for electricity is still increasing worldwide, thus it is not likely to replace non-renewable power plants entirely with appropriate renewable energy alternatives that can satisfy necessary technological requirements with an advantageous price as a whole in the short run. For this reason, non-renewable energy sources will continue to maintain their dominant position in terms of electricity production for a longer period, and "they are likely to continue to contribute substantially to global energy mix in future as part of energy planning" (Malhotra, 2013).

On the other hand, the Earth's energy resources are finite and rapidly depleting due to the growing consumption and demand for energy in the world. Apart from these, it is also known that non-renewable energy sources are not evenly distributed around the world. Hence, the use of fossil fuels will cause several challenging problems including depletion of fossil fuel supplies, climate change, global warming, and many other environmental issues, and most recently, an uncontrolled increase in fuel prices (Asif and Muneer, 2007). For all these reasons, there has been a great trend towards the use of renewable energy sources in recent years.

3.1.1. Coal

One of the most common types of fossil resources is coal which contains hydrocarbons and high levels of carbon. It is known as the most polluted of the three fossil fuels mentioned in this part. As the Turkish Coal Operations Authority (TKİ) (2020) defines, coal is a sedimentary rock composed of plant-based organic matter and inorganic components. It is formed as a result of the change of organic substances such as plant and tree residues in the swamp regions at the appropriate humidity and temperature values by chemical and physical effects in a process of millions of years. The formation of coal resources involves various physical events such as pressure and sedimentation, as well as chemical events such as degradation and transformation. These processes are also called carbonization.

In general, coal resources contain a large proportion of carbon elements as well as a small amount of sulfur, hydrogen, and oxygen. Hence, the carbon content it contains is considered an important criterion when classifying coal types. Although coal is classified in different ways according to its physical and chemical properties, the most commonly used and most valid classification is the ASTM classification. This classification is based on chemical analysis and thermal value (calories) (TKİ, 2020). According to this classification, coals are divided into four: anthracite, bituminous coal, semi-bituminous coal, and lignite. Lignite is described as the lowest quality coal type in the relevant standard. Anthracite is the highest quality coal type and has 86% -98% fixed carbon on a dry basis, whereas bituminous coal is another common type of coal in the world, with a fixed amount of carbon in the range of 46% to 86% (Atlı, 2018).

3.1.2. Oil (Petroleum)

Fossil fuels, especially petroleum and crude oil, remain the most important sources of energy in the world’s primary energy supply. By definition, petroleum consists of the Latin words petro (rock) and (oil). “It is a composite consisting of hydrogen and carbon, which also includes a small amount of nitrogen, oxygen, and sulfur” (Petform, n.d.). Since petroleum-derived resources consist of mainly hydrogen and carbon elements, the name hydrocarbon is also given to these resources. Petroleum exists in solid, liquid, and gaseous forms at normal pressure and temperature. In general, oil in solid form is named after asphalt or tar, whereas oil in unrefined liquid form is called crude oil, and oil in gas form is known as natural gas.

The most widely used standard for the classification of petroleum resources has been set by the American Petroleum Institute (API), which is called the API gravity. “The API gravity is nothing more than the standard specific gravity used by the oil industry, which compares the density of oil to that of water through a calculation designed to ensure consistency in measurement” (Petroleum.co.uk, n.d.). This standard classifies oils as light (API>31.1), medium (22.3<API<31.1), heavy (API<22.3), and extra heavy (API<10.0). Light (high gravity) oil is light brown, yellow or green in color, while heavy (low gravity) oil is dark brown or black (Enerjiportali, n.d.). Moreover, the portal also indicates that high-gravity oil refining mainly produces light and white products such as gasoline, kerosene and diesel, while low-gravity oil refining produces heavy and black products such as fuel-oil and asphalt.

With the development of refining techniques and technological improvements in the industry, oil-derived resources have replaced coal for a long period of time. These resources are used in many different areas such as energy, transportation, and petrochemical material production.

3.1.3. Natural Gas

Natural gas is another important type of non-renewable energy source that is a flammable gas mixture, lighter than air, colorless and odorless in its natural state (American Gas

Association, 2020). Natural gas is a product of organic matter that is formed as a result of the deposition of ancient marine microorganisms for million years (UCSUSA, 2015). It is also stated that organic matter exposed to increasing amounts of heat and pressure underwent a thermal breakdown process that converted it into hydrocarbons. The general structure of natural gas is composed of a greater amount of hydrocarbon atoms and proportionally a smaller amount of carbon atoms, such as methane (CH_4), ethane (C_2H_6), propane (C_3H_8), and butane (C_4H_{10}).

Natural gas is used in various field, mainly for heating and cogeneration, industrial use, and power generation. Since it can be used as it is extracted from the source without any processing activity, the use of natural gas resources has increased rapidly in recent period. From an environmental perspective this increase has some positive consequences in terms of reducing harmful emissions because natural gas resources emit lower amount of emissions with respect to other fossil fuel resources such as oil and coal. Yet, the use of natural gas resources still account for a high proportion of the emission generated in the world.

In brief, the classification of energy sources is summarized in Table 3.1 as follows.

Table 3.1 Classification of energy sources

Non-renewable Energy Sources	Renewable Energy Sources
Fossil Resources	Solar
Oil	Wind
Coal	Geothermal
Natural Gas	Hydropower
Nuclear Resources	Biomass
Thorium	Hydrogen
Uranium	Tidal

3.2. Renewable Energy Sources

Renewable energy by definition is the energy obtained from natural sources such as wind power, solar energy, hydropower, biomass energy, and geothermal energy in a sustainable manner (Asif and Muneer, 2007; IEA, 2014). Renewable energy sources, also known as alternative energy sources, are considered as resources that can remain without depletion for a very long time, unlike fossil resources. In other words, renewable energy resources are described as resources that are replenished at a faster rate than they are consumed (IEA, 2014). The main types of renewable energy resources can be specified as solar energy, wind energy, geothermal energy, hydroelectric power, biomass energy, hydrogen energy, tidal, and wave energy.

In recent years, the total share of renewable energy sources in electricity production is accelerated and reached over 25% of the world electricity generation as of 2018 (IEA, 2020a). This increasing trend has triggered during the early 21st century due to various types of energy-related challenges that countries encountered all around the world, Zafar et al. (2019) argue that as dependence on traditional energy sources has turned out to be a global concern. At this point, it can be clearly said that the most crucial issues regarding energy challenges stem from environmental considerations such as air pollution, global warming, climate change, and ozone layer depletion.

As one of the fundamental solutions to this problem, a tendency from non-renewable energy sources to renewable energy sources has been initiated globally as a result of global incentives and international agreements. Since locally available renewable energy resources have the potential to provide clean energy with zero or nearly zero emissions of greenhouse gases and air pollutants (Asif and Muneer, 2007), government policies towards energy planning are reshaped to increase the share of renewable energy sources. In this way, it is aimed to reduce the harmful environmental effects of using non-renewable resources for energy supply and lower the dependence on traditional energy sources. Furthermore, energy analysts proposed that consuming energy from renewable resources may contribute crucially to reducing greenhouse gas emissions and preserving the quality of the environment (Zafar et al., 2019).

From an economic perspective, a decline in the installation and material costs of renewable power plants in the recent period has led to a downward trend in the cost of electricity generation from renewable energy sources. Conversely, the cost of generating electricity from non-renewable energy sources has started to show an upward trend. Although trend changes in terms of energy generation costs have provided an output for decision-makers intended for energy planning, it is also required a detailed evaluation to guide planning activity based on the conditions of the present period.

In addition, Michaelides (2012) states that renewable energy resources provide the availability to energy production through harvesting on an indefinite basis, however, the challenge lies in developing adequate technologies to harvest the often low or varying energy densities and overcome supply intermittencies, and convert them into usable fuels. Thereby, technological maturity has a critical importance for energy production from renewable energy resources.

Briefly, the global energy demand has largely been met from non-renewable resources from the past to the present based on the circumstances of the period, however, towards the future it is likely that this growing demand will be met mostly from renewable energy sources due to environmental, social, economic and sustainability issues. Long-term scenarios and future projections state that the share of renewable technologies made up of solar, wind, geothermal, modern biomass, as well as the more traditional hydro will experience a rapid increase. It is claimed that under such scenarios, renewable energy usage could achieve up to 50% of the total share in the mid-twentieth century if sufficient policies and new technological advancements are implemented (Asif and Muneer, 2007). Similarly, the IEA has established an optimistic scenario in which renewable energy production will account for 39 percent of total electricity generation by 2050 (Zafar et al., 2019).

3.2.1. Solar Energy

In recent years, the trend of depletion of fossil resources and the environmental pollution caused by both their production and consumption have led to a turn towards solar energy with increasing importance. Solar energy is considered one of the most crucial energy sources in the world that mainly used to meet the need for electricity and heating. Since it is regarded among the renewable energy sources, solar energy contributes to energy generation as an environmentally friendly and clean energy source.

The process of obtaining solar energy is conceptually explained by Cebeci (2017) as the conversion of the element hydrogen into the element helium by fusion reactions that occur under high temperature and pressure in the solar core, and as a result of these reactions, the sun generates a significant amount of power. Solar energy is usually represented as energy in Watts per unit square meter area $(W)^2$.

Solar energy technologies are classified in different ways in different sources. In general, as shown in Figure 3.1 solar energy technologies are divided into two main groups as active and passive technologies. An active solar energy system designed to use mechanical and electrical equipment to collect solar radiation and convert it into heat and electrical power. In addition, passive technology covers the collection of solar energy without converting thermal or light energy into any other form (Dinçer et al., 2018). Active solar energy technologies are examined under three main parts including photovoltaic (PV), solar thermal, and concentrated solar power (CSP) technologies. These systems typically work with the use of solar photovoltaic panels and solar thermal collectors to harness the energy in order to generate electricity and heat.

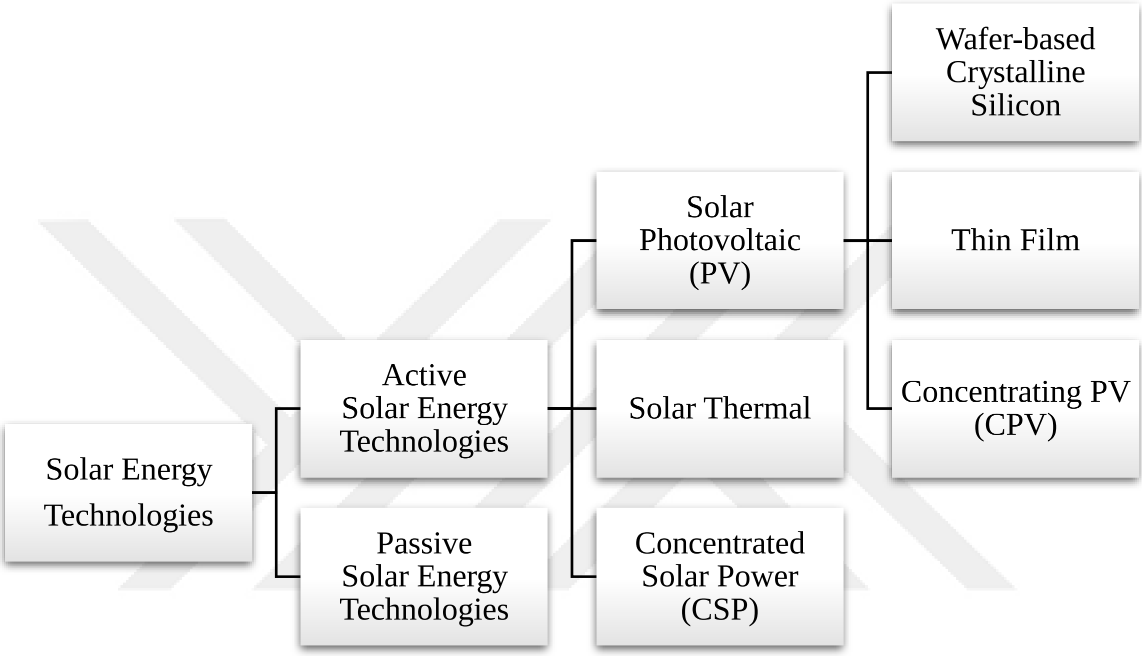

Figure 3.1 Classification of solar energy technologies

Photovoltaic technologies provide a system for converting solar energy directly into electrical energy. Solar, or photovoltaic, cells are known as the main equipment of the system. The electrical output of the PV cell is directly related to the amount of light falling onto its surface. McEvoy et al. (2012) state that the energy conversion process in solar cells starts with the absorption of light which generates an electron-hole pair. They also continue to describe the process as “the electron and hole are then separated by the structure of the device -electrons to the negative terminal and holes to the positive terminal- thus generating electrical power”.

PV technologies require detailed knowledge in the application process including solar system modeling, semiconductor material selection, and system operation. Photovoltaic energy systems are divided into three categories based on the form of raw material used and the degree of commercial maturity: wafer-based crystalline silicon (c-Si), thin-film, and emerging new PV technologies such as concentrating PV. (IRENA, 2012).

Crystalline silicon, which is a semiconductor material suitable for PV applications, is the most commonly used material in the PV industry, and wafer-based c-Si PV cells and modules dominate the current market (IRENA, 2012). It is obvious that crystalline silicon cells are more preferred than other PV technologies since it has superiority over other PV technologies in terms of technological maturity and module efficiency. Laboratory studies revealed that the crystalline silicon module efficiency varies between 14 to 19 percent as shown in Table 3.2 (IRENA, 2012).

Table 3.2 An overview and comparison of major PV technologies

		1st Generation PV		2nd Generation PV		
Technology	Units	Single crystalline silicon (sc-Si)	Polycrystalline silicon (pc-Si)	Amorphous silicon (a-Si)	Copper Indium Gallium Diselenide (CIS/CIGS)	Cadmium Telluride solar cells (CdTe)
Best research solar cell efficiency at AM1.5*	%	24.7		10.4 Single junction 13.2 Tandem	20.3	16.5
Confirmed solar cell efficiency at AM1.5	%	20-24	14-18	6-8	10-12	8-10
Commercial PV Module efficiency at AM1.5	%	15-19	13-15	5-8	7-11	8-11
Confirmed maximum PV Module efficiency	%	23	16	7.1 / 10.0	12.1	11.2
Current PV module cost	USD/W	< 1.4	< 1.4	~ 0.8	~ 0.9	~ 0.9
Market share in 2009	%	83	3	1	13	
Market share in 2010	%	87	2	2	9	
Maximum PV module output power	W		320	300	120	120
PV module size	m^2	2.0	1.4-2.5	1.4	0.6-1.0	0.72
Area needed per kW	m^2	7	8	15	10	11
State of commercialisation		Mature with large-scale production	Mature with large-scale production	Early deployment phase, medium-scale production	Early deployment phase, medium-scale production	Early deployment phase, small-scale production

With the effect of global environmental concerns, countries started to revise their energy policies in a way that increases the use of renewable energy. As a consequence of this growing importance in renewable energy technologies, studies on the solar energy field have shown an increase and therefore provided considerable development and efficiency to the solar PV system. As shown in Figure 3.2 NREL reported the highest solar cell efficiencies (NREL, 2020).

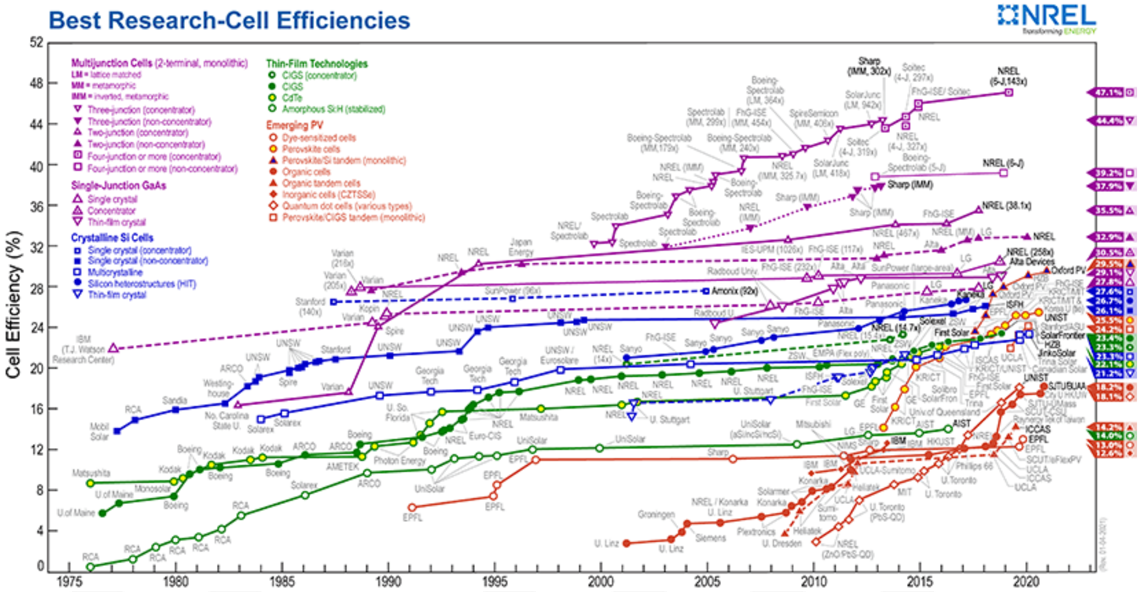

Figure 3.2 Conversion efficiencies of solar cells

Thin-film solar cells, which are accepted among second-generation PV technologies, emerged as a result of R&D studies in order to provide lower cost electricity than c-Si wafer-based solar cells. Moreover, thin-film solar cells consist of very thin layers thus it is required quite less semiconductor material production in these systems (up to 99 percent less than c-Si) to absorb the same amount of sunlight (IRENA, 2012). The types of solar cells used in thin-film technology are listed as the following: amorphous silicon (a-si), cadmium telluride (Cd-Te), and copper-indium/gallium-diselenide CI(G)S.

In brief, thin-film solar cells have many advantageous features with respect to crystalline solar cells. The low cost of energy production and the use of a lower amount of semiconductor materials can be considered as prominent properties. On the other hand, crystalline silicon PV technology still dominates the market due to the fact that thin film technology has low system efficiency compared to crystalline silicon-based PV technologies, and sufficient experience to test its service life is not yet available in the industry (Cebeci,2017).

Efforts on solar systems for increasing the efficiency of solar cells with R&D activities are gaining momentum. Regarding this issue, long-term scenarios for future module efficiency are analyzed to observe the progress in solar cell efficiencies. According to efficiency records of laboratory solar cells, after 2030, it is estimated that monocrystalline module efficiency will reach a range of 25-40 percent and polycrystalline module efficiency will be increased to 21 percent while CPV technology is expected to rise above 45 percent (Cebeci,2017).

Another criterion that is so important for renewable energy technologies, as well as system efficiency, is the economic life of the renewable systems. In the case of solar energy systems, the economic life of the system is usually projected to be 25 years, but in crystalline technology, this period can increase to 30 years (IRENA, 2018; Cebeci,2017). With ongoing studies on solar PV technologies, researchers aim to significantly extend the economic life of solar PV technologies.

In addition to solar PV technologies, concentrated solar power (CSP) systems have gained importance over the last decade. Compared to solar PV technologies, CSP systems have a particular distinctive characteristic in the way of electricity generation. The CSP system design uses mirrors or lenses to redirect sunlight in order to concentrate a large amount of sunlight onto a small area, where it is converted to heat for a heat engine or turbine connected to an electrical power generator (Barlev et al., 2011; The World Bank, 2017). In other words, the system designed to use heat provided by sunlight concentrated on a small area via mirror configuration, and generate electricity using the collected heat through a thermal energy carrier by powering a turbine (Zhang et al., 2013).

CSP technologies are classified into four different categories in terms of solar collector designs: parabolic troughs, heliostats, linear Fresnel lenses, and dish receivers. Although each of these CSP technologies presents its own advantages and disadvantages, parabolic trough collector system (PTC) and heliostats or solar power towers (SPT) are considered as the most prominent types for large installations (Dowling et al., 2017).

Ultimately, it is quite complex to determine which solar energy technologies will be preferred in order to generate electricity. For this reason, decision-makers involved in energy planning are considering many different criteria including cost of the technology, its efficiency, economic life, as well as, geographical characteristics, energy resource potential, and regional conformity analysis.

3.2.2. Wind Energy

Fluctuations in fossil fuel prices and depletion of non-renewable sources have enabled wind energy to become important as a renewable energy source in order to meet increasing energy demand. In this context, wind energy is one of the fastest developing renewable energy technologies that will help to reduce dependence on fossil fuels in electricity generation. As a domestic, clean, and inexhaustible renewable energy resource, wind energy contributes significantly to the reduction of environmental pollution in electricity generation and reduces the dependency on foreign energy supplies. Wind energy is easily available around the world, since the wind, which forms the basis for wind energy, exists in every region on Earth (Kaplan, 2015). However, wind speed and power density vary from region to region. For this reason, it is critical to specify priority criteria before the installation of a wind power plant and select an appropriate location that meets the criteria set. Basically, seasonal characteristics of wind regime in the region, material cost, maintenance cost, and feasibility assessment for the land are needed to be considered for the installation of the power plant.

According to Mathew (2006) definition, “energy available in wind is basically the kinetic energy of large masses of air moving over the earth’s surface”. Electric power generation from wind resource is obtained by transforming the kinetic energy received by the wind turbine, via rotation provided by wind blowing to wind turbines, into electrical form by means of generators. “The efficiency of converting wind to other useful energy forms greatly depends on the efficiency with which the rotor interacts with the wind stream” (Mathew, 2006).

Wind energy systems are generally classified based on the type of wind turbines used in the system design as horizontal axis and vertical axis, as shown in Figure 3.3 (Mathew, 2006).

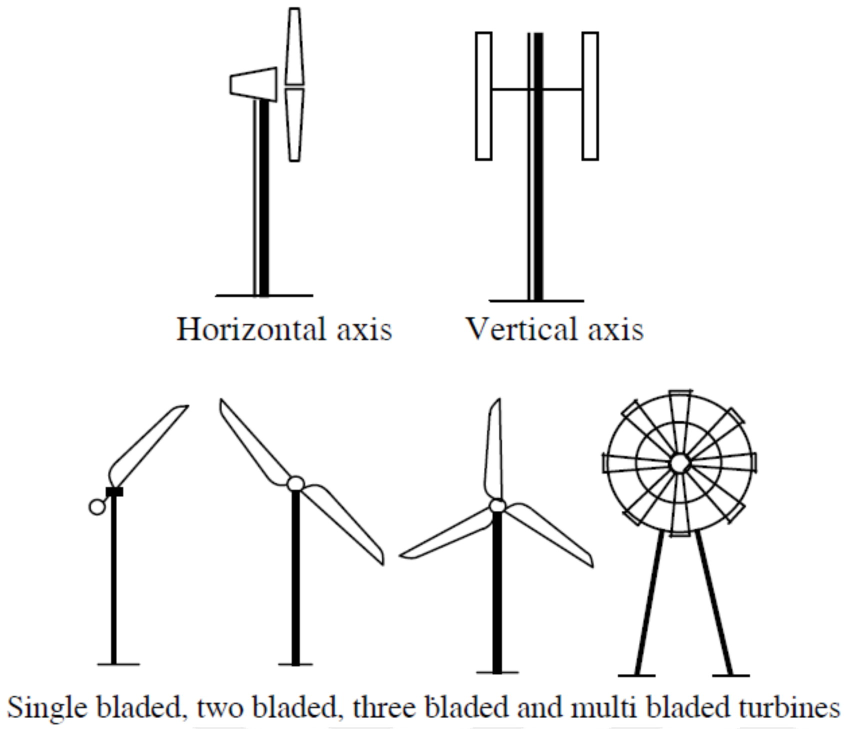

Figure 3.3 Classification of wind turbines

The horizontal axis wind turbines are built with a propeller-type rotor on a horizontal axis in order to convert the linear motion of the wind into rotational energy that can be used to drive a generator (Wagner and Mathur, 2013). As a result of this conversion process electricity is generated. In the case of vertical axis wind turbines, the axis of rotation is vertical to the ground and almost perpendicular to the wind direction to receive wind from any direction (Mathew, 2006).

In the process of determining the type of wind turbine to be used when evaluating wind energy technology, a detailed analysis covering all the bases is required from a technical point of view. In this regard, the advantages and disadvantages of the materials and equipment required for installation should be taken into consideration with the utmost importance. The main advantages of the horizontal axis are easier to design for constructing and installing, cheaper and higher total performance, while the main advantage of the vertical wind turbine is that they have less noise and law mechanism as highly reliable and visually more attractive mechanisms (Ozturk and Yuksel, 2016).

On the other hand, the main disadvantage of the horizontal axis wind turbine is that maintenance of the system is difficult due to its complex design, whereas the major disadvantages of the vertical axis wind turbine are that the system has a more expensive rotor mechanism and heavier construction process (Mathew, 2006; Ozturk and Yuksel, 2016). With the increasing use of wind technology and technological developments in this field, it is expected that studies carried out to reduce plant installation and operating costs, improve system design, and increase energy production efficiency will gain momentum in the near future.

From an environmental perspective, wind energy plays a major role in the reduction of environmental pollution and in the deceleration of climate change through releasing almost no harmful gas emissions (Stiebler, 2008). Replacing fossil fuels, which are currently consumed at a very high rate, with renewable energy sources over time, is highly likely to reduce growing concerns about future global energy demand and environmental pollution to some extent. The main environmental issues related to wind energy caused by its turbine working mechanism, land use, and system design. Negative impacts of wind turbines can be specified as wildlife safety, bio-system disturbance, noise, visual pollution, electromagnetic interference, and local climate change (Dai et al., 2015).

3.2.3. Geothermal Energy

Geothermal energy is simply described as the heat within the Earth's core. The heat is continuously produced inside the Earth therefore geothermal energy is considered as a renewable energy source (EIA, 2020a). In other words, by definition, geothermal energy is a hydrothermal mass consisting of water and steam that contains melted minerals and gases, which is found at different depths of the earth's crust and whose temperatures are produced by the accumulated heat that creates its potential with the water fed from the basins on the earth, and its temperatures change regionally (Ürün and Soyu, 2016). Based on this definition, geothermal energy sources caused by the heating of deep underground waters by magma have different temperature values depending on their location and depth.

Geothermal resources can be brought to the Earth's surface via several drilling techniques to use in a variety of applications including heating and cooling, and electricity generation depending on their characteristics. However, geothermal resources with only a temperature above a certain value can be used for electricity generation namely high and medium enthalpy geothermal resources. Although there are different classifications in the literature, geothermal resources are divided into three groups according to the commonly used temperature values. The high-temperature geothermal resources typically have a value above 150°C, whereas the medium temperature and the low-temperature geothermal resources have values between 70-150°C and 20-70°C, respectively (Akkuş and Alan, 2016).

A geothermal energy system consists of three major components: a heat source, a reservoir and a fluid, which serves as the heat carrier (Dickson and Fanelli, 2004). The geothermal fluid, which contains hot water in liquid and vapor forms, is used in the electricity generation process as an enabler that provides circulation movement besides having the required temperature value. Furthermore, the system as a whole exhibits natural features and has several advantages, such as being ready to use at any time and not being dependent on weather conditions. However, it is a clearly known fact that geothermal resources are very rare. There are very few regions in the world (area of about %5 geographically) rich in terms of these resources that are called as Ring of Fire belt by experts (Başel, 2010).

Geothermal power producing countries have different ways of applications based on the area of use of geothermal technologies. Technologies for direct uses like district heating and technologies for electricity generation purposes are widely used and can be considered as mature (IRENA, 2019a). Therefore, when examining the power plants operating today, it is seen that dry steam plants or flash plants are mostly preferred. On the other hand, emerging technologies such as enhanced geothermal systems are currently in the growth phase with having a quite high potential in the long run.

From an environmental perspective, the damage to the environment caused by geothermal power plants is very limited. In contrast with non-renewable energy processes, geothermal energy production processes do not cause high amount of harmful gas emissions. In fact, modern closed-loop power plants have reinjection systems that take non-condensing gases from steam and give them underground along with used geothermal fluid. However, geothermal energy production activities have several negative impacts on the environment including damage to the ecosystem by affecting animal and plant life negatively, damage to the atmosphere by emitting gases contained in geothermal fluids, and damage to water sources via producing chemical and thermal pollutants (Dickson and Fanelli, 2004).

3.2.4. Hydroelectric Energy

Hydroelectric energy, which is the most widely used renewable energy source in the world, is mainly obtained by using the movement of water sources. In other words, energy production is achieved by converting the kinetic energy of falling water, first to mechanical energy and then to electrical energy using a turbine and a generator (Ghosh and Prelas, 2011). The continuity of water resources substantially provided by means of nature in the forms of rainwater and melting snow. However, in hydroelectric power plants, the total amount of electricity production varies depending on seasonal changes, the number of rainy days in the region, the average total amount of rainfall, and potential drought conditions. Therefore, it is critical to plan the strategic use of water sources in order to maintain the balance of nature.

Hydropower has the greatest contribution to global electricity production among all the renewable energy resources (Ghosh and Prelas, 2011). Electricity generation from hydroelectric energy sources basically obtained by means of water turbines, taking advantage of the pressure and speed effect of water. Although hydroelectric power plants have relatively old technology, the efficiency of a hydroelectric system is quite high compared to newly emerging renewable energy technologies such as solar and wind energy. In general, hydroelectric power plants are divided into six different categories based on their size as shown in Table 3.3 (Williams and Porter, 2006). In addition, hydroelectric energy systems are classified into three groups including impoundment, diversion, pumped storage as based on their technology (EERE, n.d.; Ferreira and Camacho, 2017).

Table 3.3 Classification of hydropower by capacity

Classification	Power Output
Large	> 100 MW
Medium	10 – 100 MW
Small	1 – 10 MW
Mini	100 kW – 1 MW
Micro	5 – 100 kW
Pico	< 5 kW

Run-of-river or diversion type power plants use the flow of water from upstream without any substantial storage (Pedraza, 2015), whereas an impoundment type large hydropower system has a water storage capacity and a reservoir system such as a dam. The electricity generation process in a large hydropower system typically involves a process where water released from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity (U.S. Department of Energy, n.d.). Another type of hydroelectric technology, which is called pumped storage, differs from conventional hydropower systems in terms of operation dynamics. The system, in principle, stores energy by moving water from a lower reservoir to an upper reservoir when the demand for electricity is low. "Pumping the water uphill for temporary storage 'recharges the battery' and, during periods of high electricity demand, the stored water is released back through the turbines and converted back to electricity like a conventional hydroelectricity plant" (Zhang et al., 2015). In brief, hydropower plants consist of three main parts for electricity generation: water resource, turbine, and generator.

The power obtained from a water resource depends on several criteria, in particular the amount of water volumetric flow rate, the elevation head that water can be made to fall, and the specific weight for water (Ismail, 2017). In this regard, hydroelectric energy is not dependent on outside energy sources, as the energy production process is carried out by using natural and domestic resources. Also, hydropower systems have a minimal negative impact on the environment and climate change since they generate almost no greenhouse gas emissions in their long operating life. On the other hand, hydroelectric power plants have various negative effects on the physical, biological and socioeconomic environment (UCTEA, 2014).

3.2.5. Biomass Energy

The term biomass is described as a renewable organic material derived from plants or animals (EIA, 2020b; IRENA, 2020a). As an important non-fossil source of energy, biomass is defined in Law Number 5346 on utilization of renewable energy resources as "organic wastes as well as waste vegetable oil, agricultural harvest residues, including agricultural and forestry products, and these products resulting from the processing of by-products obtained from solid, liquid and gaseous fuels" (Official Gazette, 2005). Biomass sources including all natural substances of plant and animal origin can be replenished on a regular basis, therefore energy obtained from these biological sources is considered as renewable (Ghosh and Prelas, 2011).

In general, there are various types of biomass sources including agricultural crops and residues, such as oil, corn, seeds, sugar cane, sorghum, and wheat, forestry crops and residues, commercial, domestic, industrial and animal wastes, and municipal solid waste (Melikoglu, 2017; Baskar et al., 2012). Biomass materials are converted into different forms of fuel types, namely solid, liquid and gas, in order to meet different energy needs that involve producing electricity, fueling vehicles, heating homes, and providing process heat for industrial plants (Toklu, 2017).

Energy obtained from biomass materials called biomass energy or bioenergy is produced as a result of various conversion methods. The energy generation processes from biomass sources are generally examined in two major topics: thermochemical and biochemical conversion processes. As shown in Figure 3.4, thermochemical processes cover methods of direct combustion, gasification, pyrolysis and liquefaction, whereas biochemical processes include fermentation, anaerobic digestion, and enzymatic conversion (Deloitte, 2014; Baskar et al., 2012).

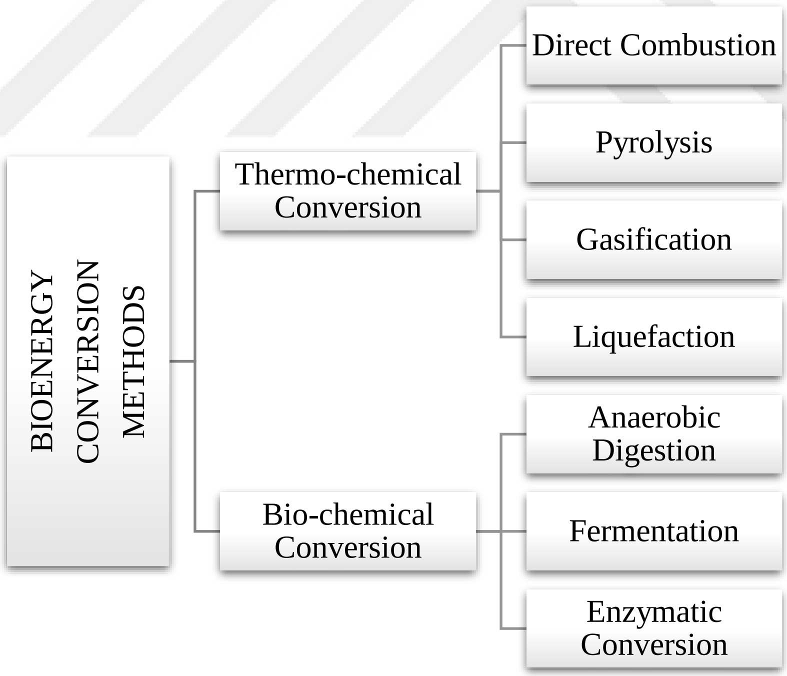

Figure 3.4 Main processes in energy production from biomass sources

Direct combustion is the most commonly used method for energy production from biomass resources. In this conversion process a variety of gases, such as carbon dioxide, can be released to the environment with the effect of burning activities. However, bioenergy generation is considered as a carbon-neutral system since the carbon emitted into the atmosphere as a result of burning biomass returns to the biomass through photosynthesis and is transformed back into carbon-rich compounds for reconversion into energy (Ghosh and Prelas, 2011). On the other hand, biomass energy has also negative impacts on human health by releasing toxic substances, on the natural environment by the emission of acidifying gases, on natural resources (Rutz and Janssen, 2014).

Although it has been known for centuries as one of the oldest traditional energy sources of humanity used in heating and cooking, biomass energy has started to be used in areas such as electricity generation and transportation with developing technology. As a result of the increase in the use of biomass resources as a substitute for fossil fuels, great progress has been made in terms of reducing environmental pollution and dependence on external sources, with contributing biological waste management and the economy of the country. It is expected that the use of biomass energy sources in the future will continue to rise with new developments in energy conversion processes.

3.3. Energy and Environment

Energy planning is a very complex process in itself as it involves many different issues that need to be evaluated at the same time, therefore it is important to analyze environmental impacts and risks before determining the most appropriate type of energy alternatives regionally. When the literature is examined in detail, it can be seen that the identification of environmental impact categories is critical in such studies. For instance, a comprehensive study conducted for the assessment of impacts and risks of renewable energy production has specified the impact categories as the following: climate change, acidification, ozone depletion, particulate matter formation, tropospheric ozone formation, eutrophication, toxicity, impacts on biodiversity, soil depletion, abiotic resource depletion, radiation, land use, water use, and plant diseases. This way the study was aimed to monitor the overall picture of the environmental consequences of renewable energy production systems with respect to all relevant environmental impact categories comparatively (Holma et al., 2018).

As a consequence of largely using non-renewable sources, especially fossil resources, in energy generation to meet growing energy demand, the world faces serious negative environmental problems such as global warming and climate change. Besides, Asif and Muneer (2007) state that generation and usage of fossil fuels and nuclear energy are explicitly related to environmental degradation, which endangers public health and wellbeing as well as the standard of living while also undermining biological diversity, and the balance of the natural ecosystem. Due to the risk of huge economic and social consequences that cannot be compensated for all these environmental negative effects, it is important to focus on studies to find solutions to the emission of pollutants and greenhouse gases, which are the biggest source of environmental problems. According to the United Nations (2016), energy consumption is the leading reason for climate change and accounting for about 60% of overall global greenhouse gas emissions (as cited in Güney, 2019). Hence, global awareness started to emerge all over the world from the beginning of the 21st century in order to limit and reduce greenhouse gas emissions.

The Kyoto Protocol has been a fundamental step forward in combating climate change (UN, 1997). In 1997, the Kyoto Protocol was adopted at the United Nations Framework Convention on Climate Change (UNFCCC) in Kyoto, Japan and entered into force on February, 2005. The main aim of the protocol is to limit and reduce emissions of greenhouse gases including carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6), and perfluorocarbons (PFCs). The Kyoto Protocol sets binding emission reduction targets for the industrialized countries and economies in transition and the European Union that are listed in its Annex B.

In order to strengthen the global efforts for reducing threats of climate change, the Paris Agreement entered into force on November, 2016 with the ratification of at least 55 Parties, which account for 55% of global greenhouse gas emissions (United Nations, 2015). The main objective of the Paris Agreement is to keep a global temperature increase below 2 degrees Celsius. In addition, this agreement for the first time brings all nations into a common cause to undertake ambitious efforts to combat climate change and adapt to its effects.

All these noticeable negative impacts of climate change affect all of the nations, therefore environmental issues associated with energy generation can be considered as a global concern. Accordingly, it is observed that policymakers started to plan a new future path for energy planning on a global scale by making required modifications to the non-renewable energy sources and encouraging them to prefer environmentally friendly energy alternatives. For instance, as part of the European Green deal, the European Commission (2020) has proposed strategic targets for 2030, which contains at least 40% cuts in GHG emissions, at least 32% share for renewable energy and at least 32.5% improvement in energy efficiency. Likewise, the UN has emphasized the actions countries should take by 2030 for sustainable development, by listing 17 Sustainable Development Goals (SDGs) including climate action (United Nations, 2020). Overall, these cases support the view that it is expected that electricity production from renewable energy sources will play a significant role in reducing environmental concerns.

4. ENERGY MARKET OVERVIEW

4.1. World Energy Market

In this chapter energy sources in the world will be reviewed in detail by analyzing past and current status, with particular emphasis on renewable energy.

4.1.1. General Overview

The need for energy is growing more and more every day in the world, accordingly considering the historical process it can be seen that there is a continuous increase in energy consumption. It is expected that by 2050, world energy consumption will rise nearly 50% and non-OECD Asia will be accounted for most of the increase in energy use (EIA, 2019). According to the British Petroleum (BP) statistical review of the world energy report (2019), the growth in primary energy consumption rate in the world between the years 2007 and 2017 was observed as 1.5%. However, primary energy consumption increased by 2.9 percent in 2018 compared to the previous year, which is noted as the fastest growth in global primary energy consumption since 2010. Nonetheless, such high rates of increase cannot continue for too long, since at a 2% increase per year, the primary energy demand would almost double by 2050 and triple by 2070 (Yuksel and Kaygusuz, 2011).

Table 4.1 World Primary Energy Consumption (Mtoe)

Countries	Million tonnes oil equivalent		Share (2018)
	2008	2018	
China	2230.4	3273.5	23.6 %
US	2258.6	2300.6	16.6 %
India	477.9	809.2	5.8 %
Russian Federation	676.6	720.7	5.2 %
Japan	517.8	454.1	3.3 %

As in the case of the distribution of energy resources in the world, there is an uneven pattern in the amount of energy consumption. An in-depth analysis of the historical process in terms of energy use in Table 4.1 (BP, 2019) shows that the two countries that have the dominant position in global energy consumption, China and America, had together more than 35% share of the world's primary energy consumption in 2008, and this figure rose to more than 40%. Global energy consumption calculations of the year 2018 reveal that natural gas with 168 million tonnes oil equivalent (Mtoe) which is accounting for almost 45% of the global increase, has the greatest change in terms of the amount of consumption as shown in Figure 4.1 (BP, 2019).

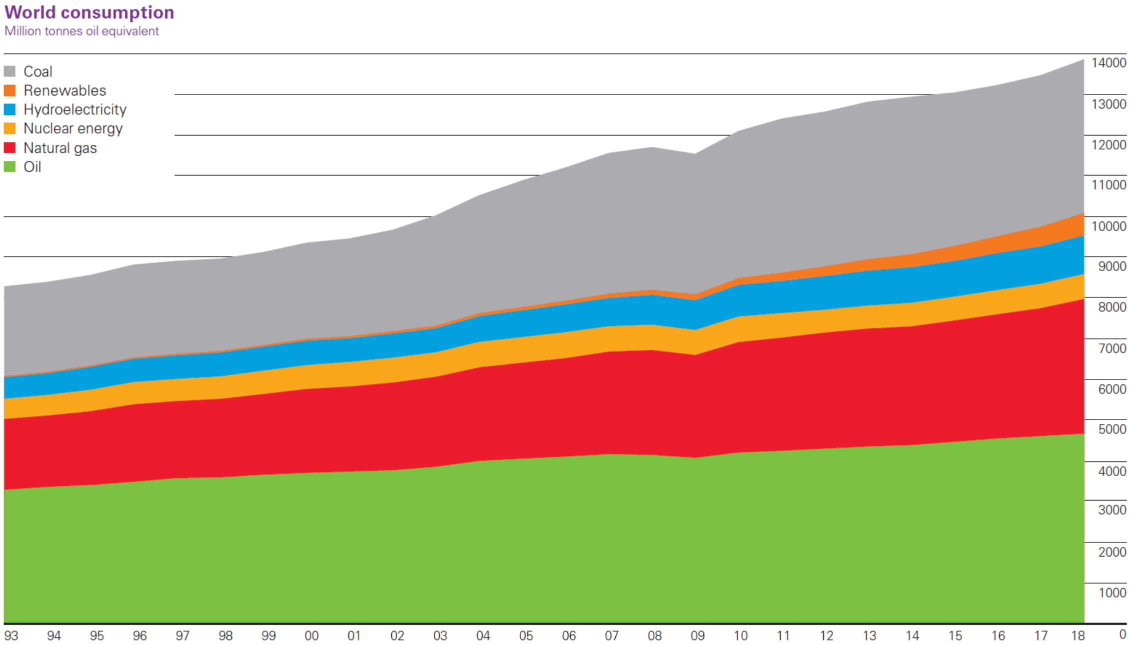

Figure 4.1 World energy consumption

In general, it is obvious that oil has the highest share in the use of energy sources, followed by coal which remains the second position, and natural gas ranked in the third place. There is a significant growth in the share of natural gas in the last 30 years. The share of natural gas increased to 24% such that the gap between coal and gas has narrowed to three percentage points, as demonstrated in Figure 4.2 (BP, 2019).

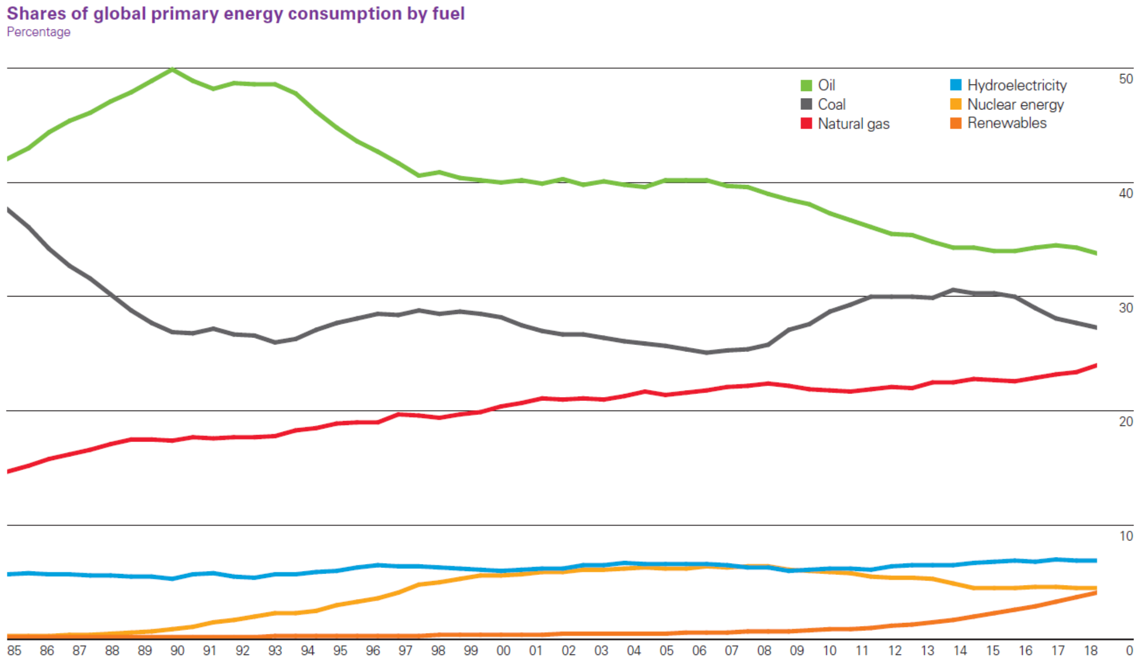

Figure 4.2 Shares of global primary energy

The reason for this change is that between 2007 and 2017, the share of natural gas consumption in the world was 2.2%, while in 2018 this rate reached a significant level of 5.3% (BP, 2019). According to the data gathered in 2018, the US ranked in the first place with 702.6 Mtoe amount of consumption that corresponds to 21.2% share of total consumption and followed by Russia with 390.8 Mtoe amount of consumption that corresponds to 11.8% share of total consumption.

World natural gas reserves stated by Turkish Petroleum (2019) as 196.1 trillion cubic meters in 2017, while in 2018 with an increase of 0.4% the total natural gas reserves reported as 196.9 trillion cubic meters. Although Russia and Iran have 19.8% and 16.2% share of total natural gas reserves in the world respectively, the US with 21.5% share of the total in terms of natural gas production has the highest share (BP, 2019). Moreover, China stands out for the increase in the Asia Pacific region. Both China and the US together account for more than 50% of the global natural gas supply (Turkish Petroleum, 2019).

The primary energy sources have an uneven distribution throughout the world. For instance, oil, the energy source with the highest utilization rate in energy consumption, has sufficient reserves only in certain countries in the world such as Saudi Arabia and Venezuela. As a member of the Organization of the Petroleum Exporting Countries

(OPEC), they account for approximately a third of the world's oil reserves. In fact, OPEC alone has more than 75% of the world's oil reserves. Furthermore, world oil reserves were declared at 1.73 trillion barrels in 2018, and the Middle East remained the region with the most oil reserves with 48.3% (Turkish Petroleum, 2019). However, it is known that fossil fuel reserves are limited and their resources are nonrenewable, for this reason, global oil reserves have a limited lifetime. Although the amount of world oil reserves is constantly rising with technological advances, it is estimated that the reserves of fossil fuels in the world are sufficient for 51 years in oil, 53 years in natural gas, and 114 years in coal (MENR, 2017).

The Middle East region, which is the richest in terms of oil reserves, is therefore known as the region with the most oil production in the world. In terms of countries, as of 2018, the United States (US) has the most oil production with 15% share of the total by producing 669.4 Mtoe, whereas with 19.7% share of total, the US also has the highest consumption rate by consuming 919.7 Mtoe (BP, 2019).

Despite the increasing environmental concerns about fossil fuel use in the world, the use of fossil fuels in the energy field is still more common. Especially, coal remains a key component of global fuel supplies, accounting for 27% of all energy used worldwide with total proven reserves of 891 billion tons (MENR, n.d.-a). is also provided that the largest part of the world's coal reserves with 237.3 billion tons is located in the United States, followed by the Russian Federation with 157 billion tons and China with 114.5 billion tons.

When the historical progress is analyzed, in the period from 2007 to 2017, the average increase in the use of coal was observed as 0.7%, whereas the growth in the production of coal was observed as 1.3% (BP, 2019). On the other hand, in 2018, both consumption (1.4%) and production (4.3%) rates of coal have increased at their fastest rates for five years. In terms of coal production, China has the highest production rate by far in the world with the total share of 46.7%. Similarly, China has ranked first with the highest share of coal consumption as 50.5%.

Nuclear energy is considered as another type of energy source, which is subject to debate in many respects, and according to figures nuclear energy appears to have an increase with a percentage of 2.4% in 2018 (BP, 2019). As of July 2020, 440 nuclear reactors are in operation in 31 countries and electricity generated in nuclear power plants is equivalent to about 10% of the world's electricity supply (MENR, n.d.-b). Top five nuclear electricity generation countries listed as the US, France, China, Russia, and South Korea with the capacity of 99.6, 63.1, 34.5, 26.1, and 22.5 million kilowatts respectively (EIA, 2020c). When regional usage rates are examined, the US ranks first with a consumption rate of 31.4%, followed by France with a rate of 15.3% (BP, 2019).

The rapid increase in global energy consumption has some negative consequences. The most important of them are environmental related issues especially the rise in carbon emissions that reached their highest rates in the recent period. With the growth in global energy demand, almost all types of energy sources used in energy production have shown an increase, particularly energy sources that cause a substantial amount of carbon emissions. In addition, as a significant source of primary energy generation, the annual average price of oil rose to $71.31 per barrel, up from $54.19 per barrel in 2017 (BP, 2019). Both environmental concerns and oil price volatility lead governments to seek energy sources that are more environmentally friendly and will reduce the external deficit. In this context, renewable energy stands out as a strong candidate that is expected to be preferred more in energy planning in the future since its resources are domestic, renewable and inexhaustible, and environmentally friendly.

4.1.2. Renewable Energy Sources in the World

The fact that these fossil fuel reserves will be depleted after a certain time has pushed countries to use renewable energy sources. For this reason, renewable energy will play a key role in the near, medium, and long-term energy planning of states in the world. In general, the use of renewable energy sources mainly concentrated in electricity generation, although development in heating and transportation has been much lower. Renewable power grew by 14.5% in 2018 contributing around a third of the growth, followed by coal with 3.0% and natural gas with 3.9% (BP, 2019). “In sharp contrast to all other fuels, renewables used for generating electricity will grow by almost 7% in 2020” (IEA, 2020b). The number of countries with growing shares of renewable energy production and consumption is increasing due to developments in renewable energy technologies and its growing position in energy planning on a global basis.

Along with the increasing energy demand worldwide, there has been an increase in the amount of electricity consumption and therefore in the rate of electricity generated from renewable energy sources. In the ten-year period, from 2007 to 2017, the global renewable energy consumption rate has grown by 16.4%, while the rate of the annualized growth of energy consumption stated as 14.5% in 2018 (BP, 2019). The amount of renewable energy consumption increased from 124.1 Mtoe in 2008 to 561.3 Mtoe in 2018. OECD countries have over half of the total share of renewable energy consumption in 2018, where the EU countries have more than a quarter of the total share of renewable energy consumption. When it is analyzed on a country basis, China, which has the largest increase in renewable energy consumption with more than 40% between 2007 and 2017, also consumed 143.5 Mtoe in 2018 with an increase of 28.8% (BP, 2019). Overall, the World Bank (2015) data regarding the share of renewable energy in total final energy consumption indicate that between 2007 and 2015, the share of renewables showed a considerable increase by reaching from 16% to 18%.

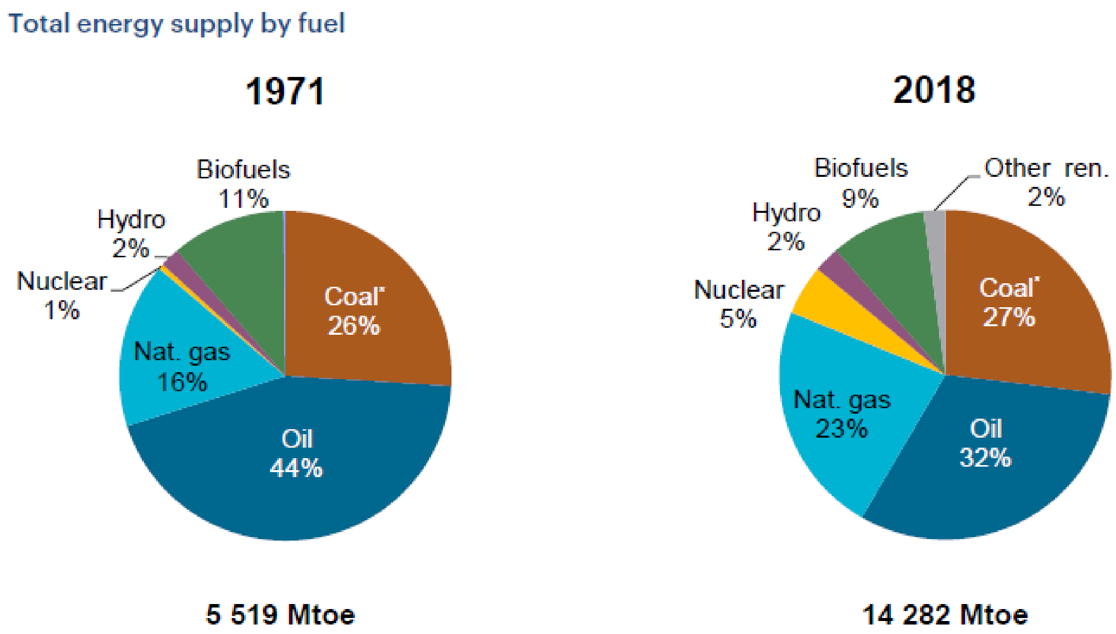

Figure 4.3 World total primary energy supply by fuel

On the other hand, the world total energy supply increased 2.6 times between 1971 and 2018, from 5519 Mtoe to 14282 Mtoe, and as of 2018, renewable energy sources accounted for 14% of the world's total primary energy supply as shown in Figure 4.3 (IEA, 2020c). The largest increase in the world renewable energy production, which increased by 14.5% in 2018, was in solar resources with 28.9% and wind resources with 12.6% (BP, 2019). However, solid biofuel/charcoal are by far the largest renewable energy source in the world renewable energy supply in 2018, with 59 percent share due to its widespread use in developing countries for heating and cooking (IEA, 2020d). Furthermore, the report also highlights that hydropower is listed as the second largest source with a rate of 19%, whereas wind is observed as the third largest with 6% share. It is observed that renewable energy generation is mostly concentrated in the Asia Pacific countries that produce a quarter of the total share in 2018 with 996 terawatt-hours (TWh) and followed by the Europe region in the second position with 761.1 TWh (BP, 2019).

According to IRENA Renewable Capacity Statistics Report (2020b), in terms of world capacity growth, approximately 179 GW of renewable power was added in total in the year 2018 and this figure slightly decreased in 2019 with 176 GW capacity addition. Besides, China and India together accounted for around half of the global capacity growth in renewable energy in 2018, although this rate has fallen slightly in 2019. Moreover, the IEA (2020b) estimates that “driven by China and the United States, net installed renewable capacity will grow by nearly 4% globally in 2020”. In total, renewable energy now accounts for over 33 percent of the global installed power generation capacity (REN21, 2019).

The total world capacity of renewables reached 2537 GW by the end of 2019, the vast majority of this capacity is concentrated in the Asian region, with a significant share of 35% (IRENA, 2020b). In the same report, renewable power capacity data represents that China ranked first by far with 759 GW generating capacity at the end of 2019, the United States ranked second in terms of renewable energy capacity with about 265 GW, and from European region countries Germany ranked third in the world with 125 GW capacity.

Renewables are mostly used in heating and cooling, transport, and power sectors. In 2016, modern renewable energy technologies account for about 10 percent of global heating and cooling need however their growth in the industry remains modest. (REN21, 2019). The share of renewable energy in transportation activities also remains low and oil sources dominate the sector. The use of renewable energy sources in the power field is relatively more common. The world electricity generation figures illustrate that renewables accounted for 19% of the global power generation in 2000, however after making great progress renewables come second in the electricity mix, as has been the case since 2013, and reached almost 26% of the mix in 2018 (IEA, 2020d). The number of countries that have built at least 1 GW of power generation capacity in 2018 exceeded 90, while more than 30 countries surpassed 10 GW of power generation capacity (REN21, 2019).

The global growth of renewable energy was dominated by solar PV with over 100 GW capacity additions in 2019, of which over a third of global PV installation deployed by China although its share in the world PV additions has decreased from a record of 55% in 2017 to less than 30% in 2019 (IEA, 2020e). In addition, the IEA (2020e) also reports that capacity enhancement of solar PV has almost doubled in Europe in the previous year, reaching 17 GW in 2019, up from just 10 GW in 2018. The top five countries in terms of total solar PV capacity sorted as China, India, the United States, Japan and Australia. As one of the fastest growing energy technologies, the cumulative capacity of solar PV increased approximately 25% to at least 505 GW in 2018 as illustrated in Figure 4.4 (REN21, 2019). It is expected that annual PV additions will increase by about 20% in 2020 (IEA, 2020e).

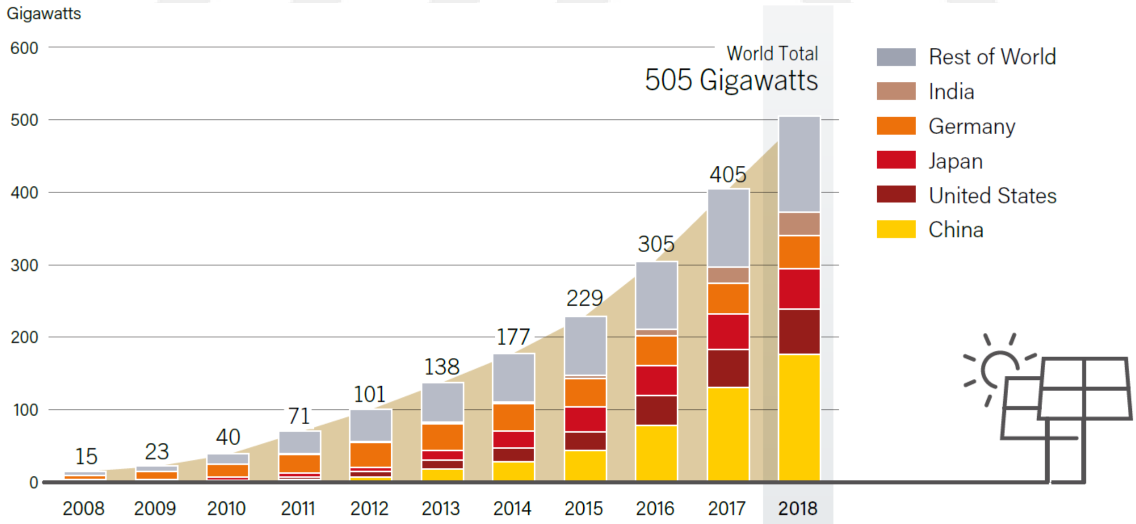

Figure 4.4 Solar PV global capacity by country and region

Wind energy has emerged as an important alternative in the energy planning of countries due to the global decline in wind energy costs, incentive policies, and legal regulations on renewable energy. There has been a significant increase in global wind energy capacity in recent years. The global wind industry has reached 591 GW of total capacity with about

51 GW of capacity addition worldwide that represent 9% increase in 2018, as illustrated in Figure 4.5 (REN21, 2019).

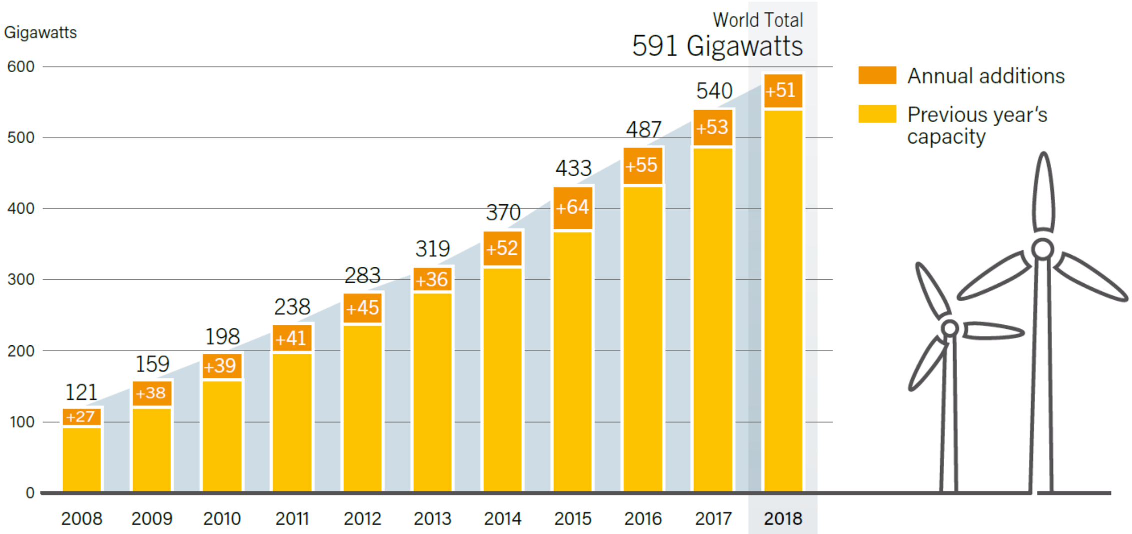

Figure 4.5 Wind power global capacity and annual additions

There has been great progress in wind energy technologies over the past decade, particularly led by China, the United States, and the European Union. As in the case of solar energy, the Asian region is the largest market in wind energy. The vast majority of capacity installations were provided by Asia with a total exceeding 262 GW by the end of 2018, representing nearly 52% of added capacity, and followed by Europe (22%) and North America (16%) (REN21, 2019). As a result of increasing expansion, China's wind capacity additions in 2019 reached 26 GW, 27% higher than in 2018, while net annual wind additions in Europe grew by 23%, reaching 14 GW (IEA, 2020e). As of 2019, after China, the United States maintained its second position in terms of new installed wind power capacity worldwide with about 9.1 GW annual additions, and the United Kingdom ranked third with 2.4 GW added capacity (Statista, 2019a).

Between 2010 and 2019, hydroelectricity increased by about 30% globally, the Asian region has played an important role in this growth, with an increase of more than 50% (IRENA, 2020b). The global hydropower market has shown a small, but noticeable increase in terms of capacity growth in 2019. With almost 12.5 GW addition, the lowest level recorded since 2001, a total installed global hydropower capacity reached around 1190 GW (IRENA, 2020b; IEA, 2020e). Especially, it is stated by IRENA (2020b) that China has reached 326 GW of capacity in 2019, with an almost 64 percent increase in the last decade, and had a share of 27% of total world hydropower capacity. Brazil ranked second with 109 GW installed capacity, equivalent to 9% share of global hydropower capacity, and followed by Canada and the United States.

In general, hydroelectricity is still known as a dominant and growing renewable energy source, although "its share in the power mix has decreased since the 1970s from 23% to slightly less than 16% in 2018" (IEA, 2020c). In 2020, the total annual capacity growth of the hydroelectricity industry is projected to reach more than 18 GW (IEA, 2020b). The main reason for this growth is that hydroelectric is a critical source of renewable energy that can be used to meet the growing global electricity demand. Hydroelectricity produces a significant proportion of renewable electricity, accounting for 15.8% of global electricity, and 62.9% of total renewable electricity (IEA, 2020d).

Another renewable energy source, geothermal energy, showed a gradual increase in 2019 by five percent and reached 13.9 GW in terms of power capacity (REN21, 2020). However, "global geothermal capacity additions are projected to amount to 0.3 GW in 2020" (IEA, 2020b), with a sharp decrease compared to the previous year. Although there has been a slight decline in the global growth rate, the total installed capacity of geothermal energy has continued to grow steadily over the last decade. Between 2010 and 2019, the world geothermal energy installed capacity has grown about 40% (IRENA, 2020b). According to Renewables 2020 Global Status Report, the top five countries ranked by geothermal power capacity as the following: United States, Indonesia, Philippines, Turkey, and New Zealand (REN21, 2020). On the other hand, Indonesia and Turkey have remained the leaders for new installations and these two countries are accounted for more than two-thirds of the new capacity installed (IEA, 2020b; REN21, 2019). In fact, Turkey has the most capacity installed during the last five years, with over 1 GW, became the global leader in terms of geothermal energy installed capacity by a wide margin and followed by Indonesia and Kenya (Huttrer, 2020).

Biomass is the fifth renewable energy source included in this study that has significant contributions to the fields including heating and cooling, transport and electricity for sustainable development plans of the nations. Bioenergy has the highest renewable share in the world total energy supply with 9% in 2018, accordingly, it has the largest proportion in world renewable energy supply with a share of about 65% (IEA, 2020d). The total capacity of biomass energy, which has a global capacity of 121 GW in 2017, increased by 6.5 percent to 130 GW in 2018 (REN21, 2019). Likewise, global bioenergy capacity grew by almost 8 GW in 2019, achieving "a stable level of deployment compared to 2018 (IEA, 2020e). China is the world leader having a bioelectricity capacity of 17.8 GW as of the end of 2018, with 21% capacity increase (REN21, 2019). The United States had the second-highest national levels of bioenergy capacity in 2018, with 16 GW, and Brazil had the third with 14.7 GW. Moreover, IEA (2020e) states that China ranked first in terms of bioenergy capacity additions globally, which accounted for 60% of new capacity in 2018, whereas Japan and Turkey were the next largest markets.

4.2. Turkish Energy Market

The main policy of Turkey in energy planning is to provide energy in a timely and reliable manner, with an adequate amount, at competitive prices, and with considering all environmental impacts. In this context, it is important to consider significant factors such as ensuring resource diversification by giving top priority to the development and use of domestic and renewable energy sources, enabling the use of alternative clean energy sources, providing regional cooperation and integration, and structuring the energy sector based on transparency and competition (Ayan and Pabuçcu, 2013). For this purpose, in this section, the energy subject, which has an important role for the sustainable development of countries, will be discussed by analyzing the past and current status of the energy market within the framework of historical progress.

4.2.1. General Overview

In energy planning, one of the main criteria for establishing a sustainable development structure is to make an in-depth analysis of the past and current energy situation while achieving the goals of increasing the use of renewable energy sources and reducing external dependence and the use of non-renewable fossil energy sources in order to meet growing energy demand. In this regard, Turkey has dynamic progress with its ongoing developments in the energy sector by having an important position among the developing countries. Therefore, changes and trends related to the development of energy activities will be discussed in this section by analyzing the milestones associated with energy in Turkey's historical process.

The increase in energy consumption has gained momentum due to population growth, industrialization, and technological developments in Turkey in the last thirty years. Especially in the last decade, there has been a much faster increase in consumption figures. Between 2008 and 2018, the total amount of primary energy consumption in Turkey has increased by over 50%, and reached 153.5 Mtoe (BP, 2019). As a consequence of this situation, Turkey is listed among the top 20 countries in primary energy consumption in the world. Moreover, in 2018, the most used sources in primary energy consumption by fuel type were ranked in descending order of amount as an oil (48.6 Mtoe), coal (42.3 Mtoe), natural gas (40.7 Mtoe), hydroelectricity (13.5 Mtoe), and other renewables (8.5 Mtoe) (BP, 2019). In other words, as of 2018, the share of fossil fuel use in primary energy consumption in Turkey is over 85% in total including oil, coal, natural gas with the total share of 31.7%, 27.5%, and 26.5%, respectively. As in the case of many countries worldwide, energy consumption in Turkey is highly dependent on fossil fuels. However, it is obvious that Turkey does not have sufficient reserves in terms of oil, natural gas, and coal resources, therefore the primary energy supply of the country consists largely of imported sources inevitably.

It is stated by UCTEA (2020) that the share of imports in Turkey's primary energy supply has been over 70% since 2005, which proves that Turkey's primary energy supply is largely dependent on external energy sources. Total imports in energy raw materials reached their peak in 2012 with a figure of 69 billion dollars, import figures showed a falling tendency in the following years and reached a total of 41.6 billion dollars in 2019 (UCTEA, 2020). Total imports of oil resources increased by around 18% in 2019 with respect to the previous year (EMRA, 2019a). Analysis of oil import figures in 2018 shows that Russia ranks first with a share of 25%, followed by Iran with a share of 18%, and Iraq with a share of 17% (Turkish Petroleum, 2019). The ranking of the countries changed in 2019 with the effect of the dynamism in the energy market, Russia took first place with 35% share in Turkey's oil import, followed by Iraq with 21% share and Kazakhstan with 7% share (EMRA, 2019a). Furthermore, in 2019, Turkey's dependence on imports in oil increased compared to the previous year and reached a rate of 91.2%, while dependence on imports in natural gas decreased compared to the previous year and fall to the rate of 98.9% (Turkish Petroleum, 2019). The use of natural gas in the country has increased significantly over the past decade, taking a critical place in the country's energy production. Although natural gas imports decreased by about 10% compared to 2018, however, large amounts of natural gas imports are still being imported, and the majority of imports with a share of 33.6% provided from Russia, followed by Azerbaijan (21%) and Iran (17%) (EMRA, 2019b). Moreover, coal is another source that Turkey uses in energy production and largely dependent on external sources. Although coal imports of the country decreased by 2.8% in 2019 to 36 million tons, according to the report published by European Association for Coal and Lignite (EURACOAL) Turkey is known as the second largest coal importer in Europe after Germany and is likely to become the top importer in the coming years. The coal import values provided by the report indicate that Russia ranked in the first position, followed by Columbia.

When the energy market in Turkey is examined in terms of energy production, it is seen that primary energy production continues to increase. In this regard, the rate of meeting primary energy demand through production using domestic resources was 27.6% in 2018, which was 12% higher compared to 2017 (TKİ, 2019a). In other words, Turkey's external dependence on energy was decreased by approximately 3.3% compared to the previous year and recorded as 72.4% (Turkish Petroleum, 2019). In 2019, the amount of domestic production increased by 10,62% compared to 2018 (EMRA, 2019b). As of the end of 2018, Turkey's domestic primary energy production increased by 12.21% compared to the previous year and amounted to about 40 Mtoe, of which coal has 41.7% of the total share with 16.5 Mtoe energy production, oil has 7.5 % of total share with 2.9 Mtoe and natural gas has around 1% of total share (TCOA, 2019a). In spite of the increase in energy production is significantly behind the increase in energy consumption, this difference is gradually closing as the studies carried out on energy production gain momentum. However, imports of energy sources are expected to continue inevitably, as long as this difference continues.

Although a significant downward trend has been observed in coal usage rates all over the world, there is an upward change in Turkey in terms of coal production growth rate, with 13% in 2018, which is approximately 17 Mtoe coal production (BP, 2019). The reason for this matter stems from newly discovered sources of lignite. In contrast with the state of scarcity in terms of natural gas and oil reserves, the situation is a little more optimistic for Turkey in terms of coal, particularly lignite resources. In accordance with the policy aimed at increasing the use of domestic energy sources, lignite reserves of the country reached 19.32 billion tons with an increase of 10.82 billion tonnes as a result of intensive coal exploration activities launched in 2005 (TKİ, 2019b). The total proved coal reserves at the end of 2018 were declared as 11526 million tonnes, with estimates at current production rate those remaining reserves would last 139 years (BP, 2019). Considering the current production amount, as of 2018, the remaining oil reserves have a life span of about 18 years and the remaining natural gas reserves have a lifetime of approximately 9 years unless new discoveries are made (Turkish Petroleum, 2019).

From an environmental perspective, Turkey maintains its efforts through reducing carbon emissions in line with its environmental goals. Carbon dioxide emissions in Turkey between 2008-2018 grew by 3.6% on average annually, however, in 2019, with the effect of environmental policies towards energy field, the annual growth rate noted as -2.2% which is equivalent to 383.3 million tonnes of carbon dioxide (BP, 2020). In brief, BP (2020) provides that Turkey accounted for 1.1% of global carbon dioxide emissions according to recent figures.

Overall, it should be noted that the concept of energy planning is becoming increasingly important. Hence, studies in this field have an important role in reducing external dependence and the current account deficit. For that purpose, it is important to create new incentive mechanisms and develop energy policies that intend for increasing the use of domestic resources in order to support the goal of reducing external dependence on energy. Efforts to increase the use of domestic resources are expected to gain more momentum in the coming years.

4.2.2. Renewable Energy Sources in Turkey

Turkey is known as a rich country in terms of the potential and diversity of renewable energy sources. Accordingly, the strategic plan of the country aims to increase the share of renewable energy in electric power generation. In this regard, the Eleventh Development Plan (2019) of Turkey revealed that the energy sector targeted to increase the share of renewable energy resources in total electricity generation from 32.5 percent in 2018 to 38.8 percent by the year 2023. In order to realize the necessary investment and energy planning to increase renewable energy share in electricity generation, experts need to make a multi-dimensional analysis for each type of renewable energy source to exhibit main differences, key requirements, and specifications before installation of the power plant in regions. Hence, first of all, it is critical to identify and examine types of renewable sources in detail. Law No. 5346 on the use of renewable energy sources for electricity generation under regulation on certification and support of renewable energy sources contains that renewable energy sources cover non-fossil energy sources such as wind, solar, geothermal, hydraulics, biomass, gas derived from biomass (including landfill gas), wave and tidal (Official Gazette, 2005). The renewable energy sources to be evaluated in this study are solar, wind, geothermal, hydroelectric, and biomass.

Turkey's demand for energy has grown rapidly within the last ten years, therefore the share of renewable energy sources in total final energy consumption has increased significantly since it is one of the most advantageous energy sources as domestic and inexhaustible. Renewable energy consumption (excluding hydro) has 40% growth rate per annum between 2008 and 2018, consequently reached a total consumption of 0.41 exajoules (BP, 2020). Moreover, this figure grew by 30% in 2018 and total renewable energy consumption reached 8.5 Mtoe (BP, 2019). And besides, Turkey's hydroelectricity consumption was noted as 2.1% share of the world total in 2019, with a dramatic growth rate of about 48% (BP, 2020). The amount of hydroelectricity used in the country increased from 7.5 Mtoe to 13.5 Mtoe, between the years 2008 and 2018 (BP, 2019).

The amount of renewable power generation (excluding hydro) increased from 2.2 TWh to 45.3 TWh between 2009 and 2019, having around 40% growth rate per annum (BP, 2020). There has been a tremendous increase in the use of solar energy and wind energy technologies in Turkey in the last few years with the impact of the increasing popularity of these sources worldwide. According to values revealed in 2018, renewable energy generation is mostly provided by solar and wind, with growth rates of 173% and 11% respectively (BP, 2019).

Domestic resources are strategically important for the energy planning of Turkey, thus major breakthroughs have been made in renewable the energy field in the last decade. In this context, Turkey is ranked among the top 20 countries in the world in terms of renewable energy investments. In 2018, the country's investment amount was above 2 billion US dollars, and as a reflection of investment made the installed capacity of renewables increased by 75% in the 2016-2019 period (KPMG, 2020). It is expected that the increase in installed capacity of renewable energy sources will continue in parallel to the continuation of the investment trend considering environmental, social, and economic criteria.

As of 2019, Turkey's total installed power network of 91.3 GW consists of 8589 power plants, of which wind power plants have 8.3% of the total share and solar power plants have 6.6% of the total share (KPMG, 2020). IRENA Renewable Energy Capacity Statistics report indicates that the total renewable energy capacity of Turkey increased by 27219 MW from 2010 to 2019, and reached a total of 44588 MW including hydroelectric (28503 MW), wind (7591 MW), solar (5996 MW), geothermal (1515 MW), and bioenergy (983 MW) (IRENA, 2020b).

Furthermore, it is known that the resource potential in terms of renewable energy in Turkey is quite high. Therefore, government policies carried out for energy planning in recent years particularly focus on developing incentives to increase the level of utilization of the country's renewable energy potential. In this way, the government designs a support mechanism for energy investments in line with the country's 2023 goals by guaranteeing the purchase of the produced energy at certain prices and for a certain period to increase the share of renewable energy sources in energy production. On the other hand, unit costs of renewable energy investments continue to decline in line with technological developments and the support provided by the state in this area is an important assurance that this growth trend will continue (KPMG, 2020).

4.2.3. Renewable Energy Potential of Turkey

Turkey's energy potential by types of renewable energy sources is analyzed in this section. In this way, the current situation is first examined, and then the energy potential of the country is presented for future energy planning.

Thanks to its geographical location, Turkey is in a very advantageous position in terms of solar energy potential. However, it has not yet reached an expected level of utilization in relation to its high energy potential. Besides various obstacles for this issue, the commercial use of solar energy is restricted mainly due to the high cost of installation (Asif and Muneer, 2007). Electricity generation from solar energy, on the other hand, is gaining momentum due to the decreasing trend of solar power plant installation costs and the increase in renewable energy incentive policies in recent years.

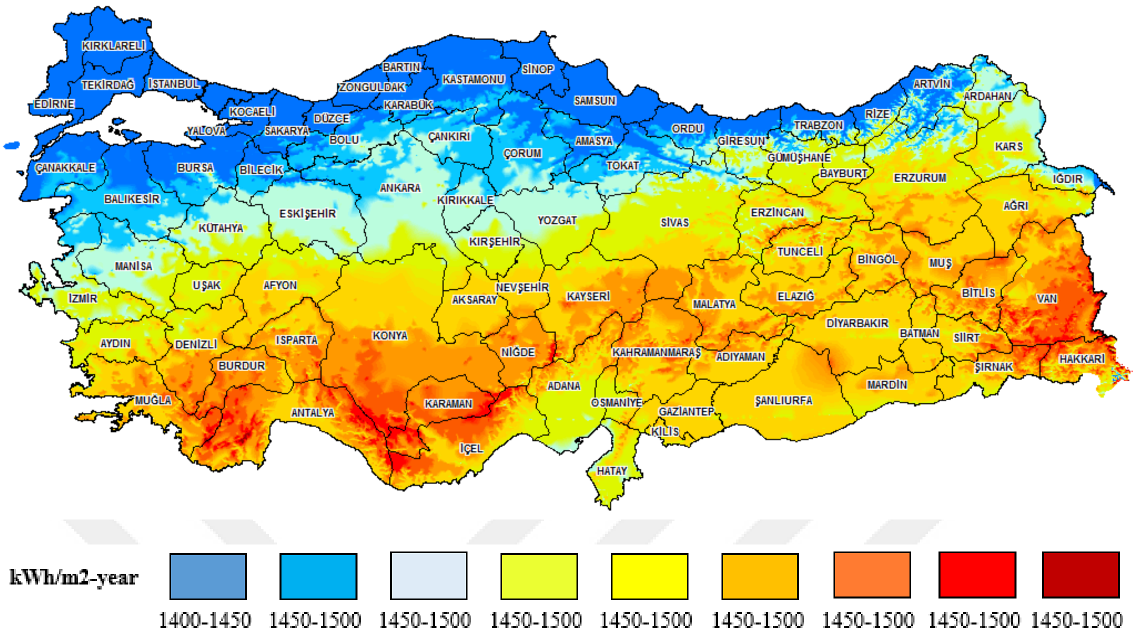

Figure 4.6 Turkey solar energy potential map

According to Turkey's Solar Energy Potential Atlas (GEPA) prepared by the Republic of Turkey Ministry of Energy and Natural Resources (2006), the average annual total sunshine duration was calculated as 2741 hours/year, whereas the average daily total was 7.5 hours/day and the average annual total irradiance was calculated as 1527 kWh/m2-year, whereas average daily total irradiance was 4.18 kWh/m2-year as seen in Figure 4.6, 4.7 and 4.8 (MENR, 2006).

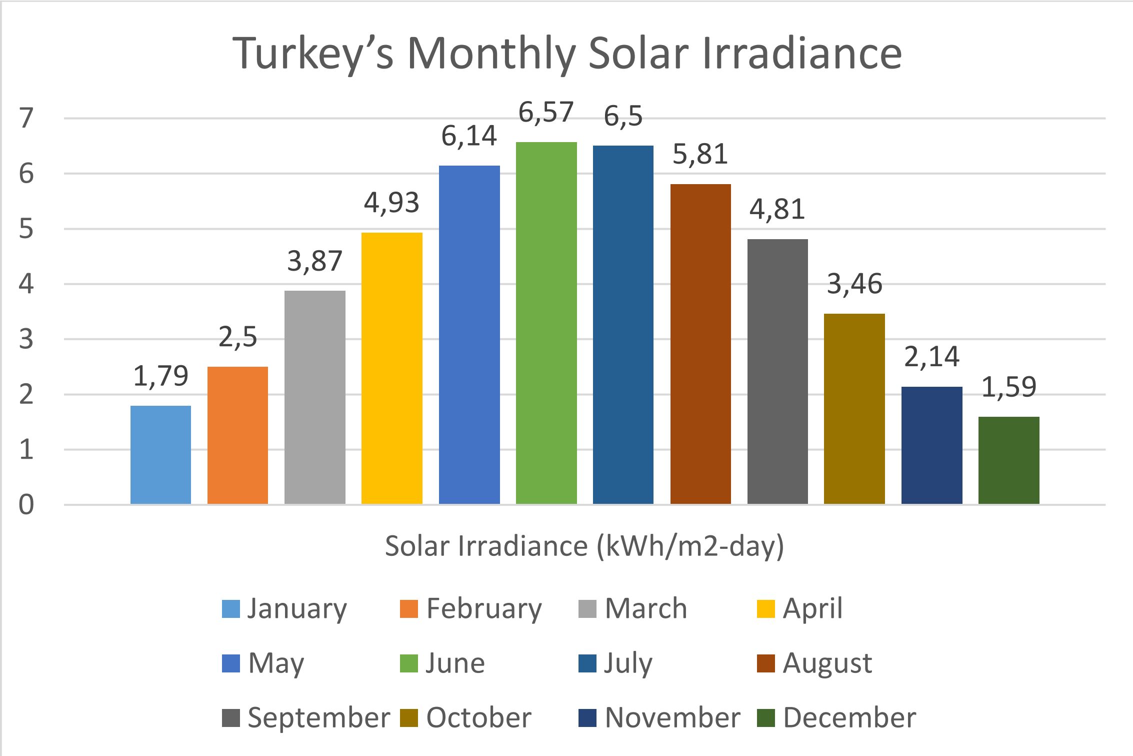

Figure 4.7 Monthly solar irradiance of Turkey

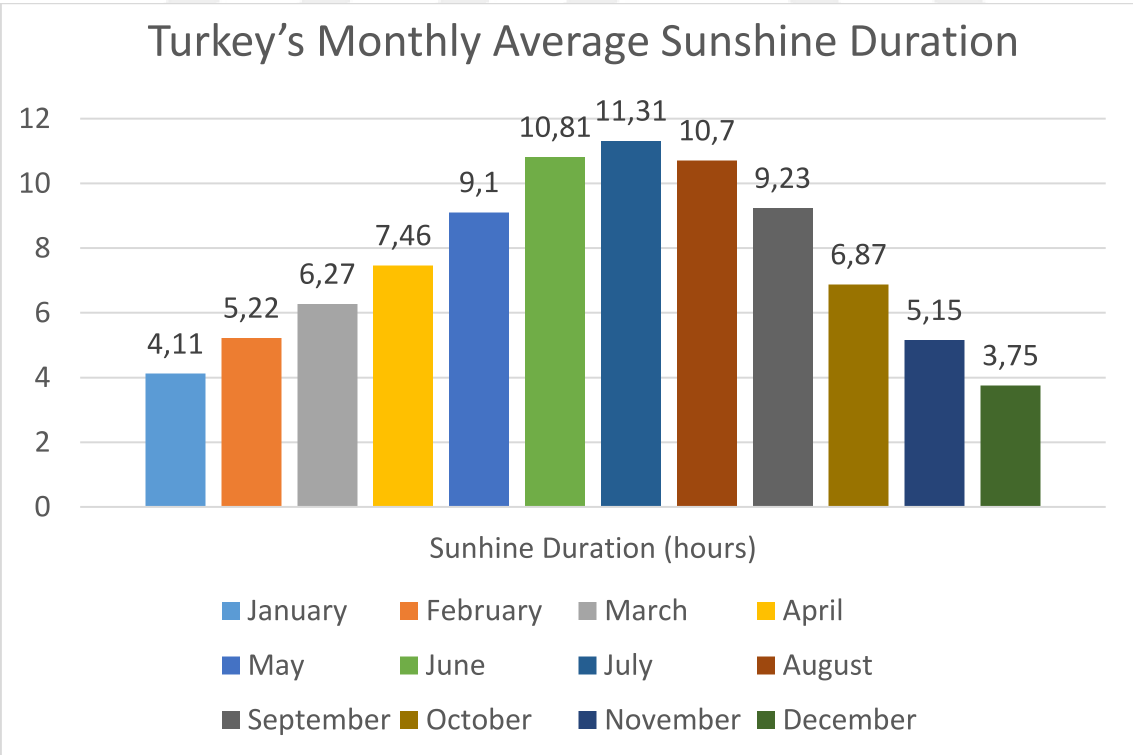

Figure 4.8 Monthly average sunshine duration of Turkey

The general potential view and monthly average global radiation distribution contained in GEPA are presented. From here, it is seen that July is the most optimal month in terms of solar power production in Turkey, whereas December is the least optimal month. Also, Southern Anatolia is observed as the region with the highest sunshine duration.

Furthermore, it has been calculated that if the solar energy potential in Turkey is put into operation, it will be possible to produce about 405 million MWh of electrical energy per year (Yalçın, 2016). Technical developments and R&D studies, which intended for using solar energy potential more efficiently, are accelerated in recent years with a focus on the application of solar energy systems.

Turkey has a significant level of wind potential in terms of its large area and climate characteristics due to its geographical location. As a result of studies conducted by the General Directorate of Renewable Energy, the Wind Atlas of Turkey was prepared to provide information about wind speeds in each province. Although provided values in the energy field vary depending on many different criteria, the most reliable values are presented and included in this study. For instance, “the wind velocity varies with the height above ground, influenced by the surface roughness” (Stiebler, 2008). Considering these factors, wind source information was produced using a medium-scale numerical weather forecast model and a micro-scale wind flow model for Turkey, and with the help of this information, the Turkish Wind Energy Potential Atlas (REPA) was prepared (MENR, n.d.-d). The distribution maps show the potential for wind energy for Turkey which is created for an altitude of 100 meters above ground level, as shown in Figure 4.9.

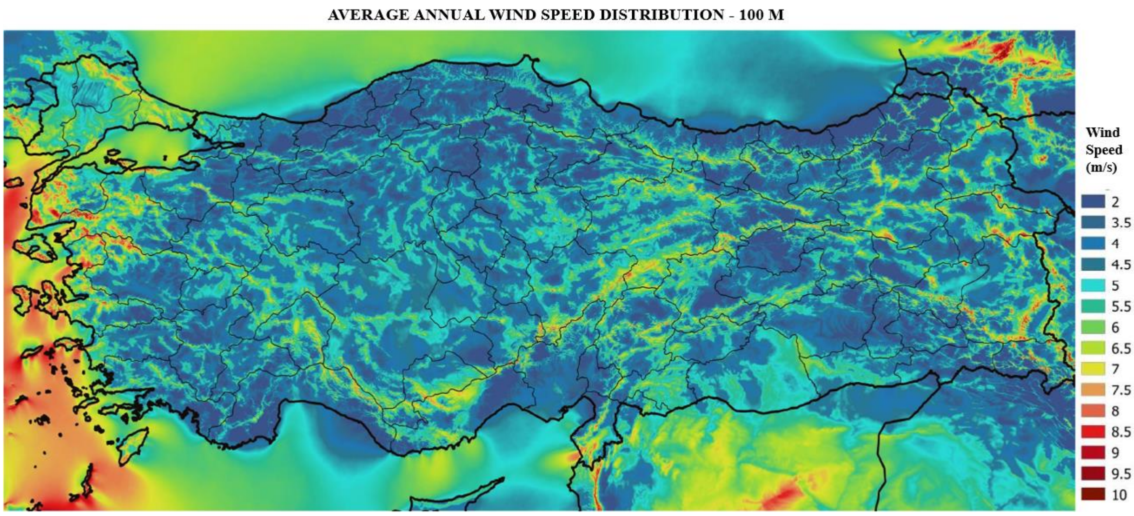

Figure 4.9 Annual average wind speed

At a height of 50 meters from the ground level and above a 7 m/s annual average wind speed areas can be considered appropriate for the installation of a wind power plant in Turkey. In the “Tenth Development Plan” adopted by the Grand National Assembly of Turkey on July 2, 2013, Turkey's total wind potential is stated as 48000 MW (as cited in Dinçer et al., 2019). The maximum amount of electricity that could be produced from current wind potential with 40% capacity factor specified by EMRA is 168192000 MWh per year. From a regional perspective, coastal parts of Turkey and wind transition zones in Central Anatolia are fertile areas for obtaining electricity from wind energy (Karagöl and Tür, 2017).

Turkey has a strategic position in the world in terms of its geographical location which is positioned on the tectonic fault lines. Areas located close to volcanic regions and on the tectonic belt where fault lines cross are known as rich in geothermal energy resources. Therefore, Turkey has a high geothermal energy potential region as a result of its strategic position which is located on the Alpine-Himalayan Tectonic Belt. The geothermal potential of Turkey is theoretically 31500 MW, and 79% of the potential areas in Turkey are located in Western Anatolia, 8.5% in Central Anatolia, 7.5% in the Marmara region, 4.5% in Eastern Anatolia, and 0.5% in other regions (Karagöl and Tür, 2017). However, the energy policies of Turkey contain significant future targets to develop existing resources and discover new resource areas with the ongoing search efforts. The country also aims to increase its total heat capacity with newly discovered geothermal sites, and thus, provide suitable geothermal sources for electricity generation via wells drilled. As illustrated in Figure 4.10 (MTA, n.d), 94 percent of geothermal resources are low and medium temperature and suitable for indirect applications such as heating and thermal tourism, whereas approximately 6 percent is suitable for electricity generation (Karagöl and Tür, 2017).

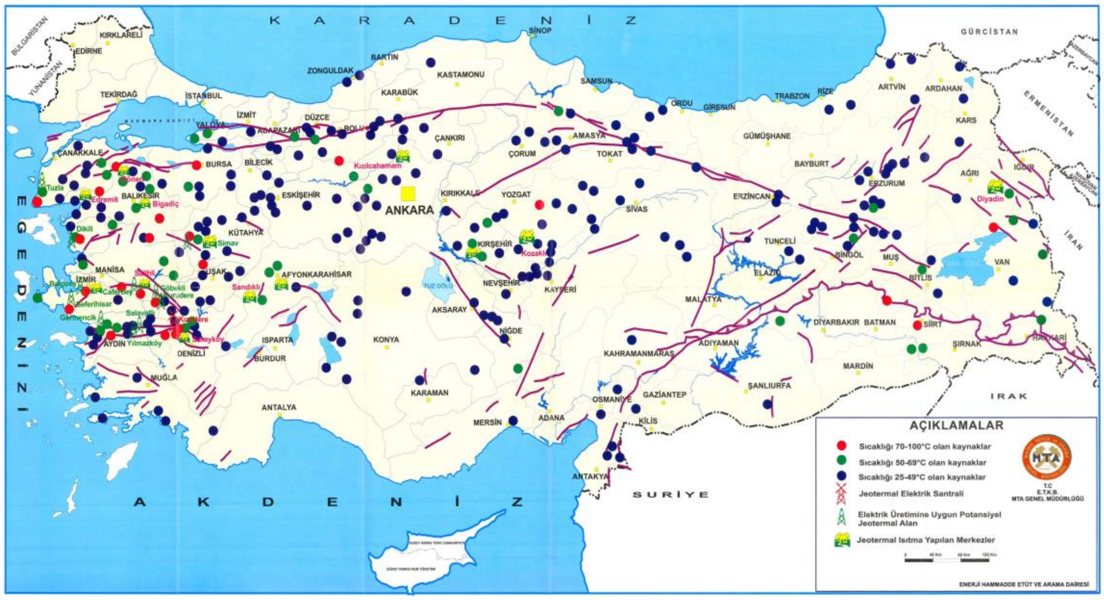

Figure 4.10 Distribution map of geothermal resources in Turkey

As a result of studies carried out by MENR (2016), approximately 2000 MW of Turkey's total theoretical geothermal heat potential was identified as suitable for electricity generation. The maximum amount of electricity that could be produced from the current geothermal potential with 92% capacity factor specified by EMRA is 16118400 MWh per year. This situation provides that Turkey with high potential for geothermal energy is ranked in the seventh place in the world and in the first place in Europe (Ürün and Soyu, 2016).

The demand for water resources in the world is increasing every day, as the most basic element of need in many different areas. In this regard, the use of water resources needs to be planned very well and utilized in the most efficient way. According to the Turkish State Meteorological Service Directorate (2020), Turkey has an average annual rainfall value of 574 mm, where the highest amount of precipitation is observed in the Black Sea region and the lowest amount of precipitation is observed in the Central Anatolia region.

In accordance with today's technical and economic conditions, the potential for above-ground water that can be consumed for various purposes is an average of 94 billion cubic meters per year, and the underground water potential is about 18 billion cubic meters (UCTEA, 2018). In other words, the total consumable water potential of Turkey is 112 billion cubic meters per year.

On the other hand, the gross theoretical hydroelectric potential in Turkey is stated as 433 billion kWh/year, of which 216 billion kWh/year can be evaluated technically, whereas about 160 billion kWh/year can be developed economically, and along with the potential of new projects this potential is expected to reach around 180 billion kWh/year by the end of 2023 (UCTEA, 2018). Furthermore, the annual report of the General Directorate of State Hydraulic Works (DSİ) (2019) indicated that there were 683 hydraulic power plants in operation at the end of the year, and the average annual production was 99.7 GWh, which corresponds to 62% of the total developed potential.

According to Turkey's Biomass Energy Potential Atlas (BEPA) prepared by the Republic of Turkey Ministry of Energy and Natural Resources (2020), the total biomass energy potential of the country is calculated as about 30.6 million tonnes of oil equivalent (Mtoe) per year. Biomass resources contain plant and animal wastes, wood and forest residues, municipal solid waste, and these resources account for 86%, 3%, and 11% of the total biomass energy potential respectively. The maximum amount of electricity could be produced from the current biomass potential calculated as 356601227 MWh. The IEA (2020f) unit converter used for the energy conversion process, which specifies that 1 tonne of oil equivalent (toe) is a quantity of energy equal to 11.63 MWh. It is expected that the share of biomass used for transportation and electricity production, called modern biomass, will increase in the short term (Deloitte, 2014).

4.2.4. Future Projections and Targets

Turkey has a high potential in terms of renewable energy sources including solar, wind, geothermal, hydro, and biomass. However, it is known that renewable energy sources in the country cannot be used at the desired level. If the current potential is evaluated effectively by making proper energy planning in terms of capacity additions, and making the necessary investments, the country could have an important place among countries worldwide. In addition, Turkey can increase its capacity to meet electricity demand from renewable energy sources at higher levels. In this context, it is expected that the share of renewable energy sources used for electricity generation will increase in the short term.

The presidency of the Strategy and Budget of the Republic of Turkey declared renewable energy targets for 2023 in the Eleventh Development Plan (2019). According to the report, the electricity demand is estimated to become almost 376 TWh, whereas the share of renewable energy resources in total electricity generation is expected to reach about 39 percent by the end of 2023. Moreover, in the report, the energy sector targets for 2023 are projected that the total amount of electricity produced from domestic sources will be approximately 220 TWh. On the other hand, the target share of renewable energy production for 2023 has been exceeded in the current situation. According to the Electricity Market Development Report (2019c), the share of renewable energy sources in total electricity production was 42.1 percent in Turkey.

2019-2023 Strategic Plan published by MENR (2019) contains a revised set of targets for renewable energy sources in terms of capacity increases. The strategic plan introduced the installed capacity target of 10 GW for solar energy, 12 GW for wind energy, 32 GW for hydropower, and 3 GW for geothermal and biomass energy combined by the end of 2023. In order to create the most appropriate energy planning strategy by taking into account the growing demand for electricity, the state always needs to update its goals, considering economic, technological, and social factors, as well as global changes.

5. ELECTRICITY MARKET OVERVIEW

Electricity is known as one of the most important forms of energy, also known as a secondary energy source, derived from primary energy sources as a result of energy conversion processes. Electric energy has extensive usage in various fields including industry, transportation, agriculture, and healthcare. Moreover, there is an increasing demand for electricity worldwide since it is a green energy source that does not harm the environment. Therefore, efforts to increase the use of renewable energy sources in electricity generation are of great importance. In this context, the electrical energy sector in the world and the electrical energy sector in Turkey will be analyzed in this section.

5.1. World Electricity Market

It is fundamental to benefit from studies including publications, reports, and regular forecasts of globally recognized organizations in the process of sector analysis since there are several organizations that follow the world energy sector closely. In this regard, the electricity sector analysis section is prepared as a result of examinations from reliable sources by considering this issue.

The world's population is constantly growing and consequently, the need for energy is steadily increasing as well. It is expected that the world's population will rise to 9.2 billion by 2040, and the urbanization rate of the world's population will also increase from 55% in 2018 to 64% in 2040 (EÜAŞ, 2019a). In addition, demand for electricity is expected to grow at a faster pace than overall energy demand, thus it is necessary to benefit also from other energy sources for electricity production in order to supply the required energy electricity demand, and that is vital for social welfare (Malhotra, 2013). These factors combined with the other related parameters will form the basis of demand forecasts and thus become a crucial part of future planning for electricity generation. In this context, World Energy Outlook report, published by IEA (2019a), involves energy projections to 2040 under different scenarios (stated policies, sustainable development, current policies) which provide an in-depth look at the future of the energy sector. The report states that the increasing role of electricity among energy end-uses is a common feature of projections for final energy consumption. "The global share of electricity rises from 19% today to 23% in the Current Policies Scenario, to 24% in the Stated Policies Scenario in 2040, and to more than 30% in the Sustainable Development Scenario" (IEA, 2019a).

The main contributors to the increase are developing economies with the largest share of the world's electricity demand growth. It is also estimated that electricity, with the effect of the direct use of renewables, will overtake oil around 2040 and become the largest component of final consumption.

Electricity Information Overview 2020 report indicates that world electricity final consumption increased rapidly from 5000 TWh level in the 1970s to 22315 TWh in 2018, of which OECD has approximately 44% of the total consumption with 9728 TWh (IEA, 2020g). The report provided that the total final consumption of non-OECD countries was 12587 TWh, and four countries including China, India, Russia, and Brazil accounted for about 67% of all non-OECD electricity final consumption in 2018. In recent years, countries with a high amount of electricity consumption launched various initiatives in parallel with their sustainable development policies in a way to increase the total share of renewable energy sources. For instance, China raised the country's renewable portfolio standard (RPS) in 2019 to 35% of electricity consumption by 2030, while the EU's revised Renewables Energy Directive (2018/2001) established a new binding 2030 renewable energy target of at least 32% of gross final consumption of energy from renewable sources (IEA, 2019a). In other words, renewable energy technologies having lower or no carbon emissions are expected to account for a higher share in new capacity additions. In the stated policies scenario, nearly 8500 GW of new power capacity is added globally by 2040, of which two-thirds is renewables (IEA, 2019a).

According to the Key World Energy Statistics 2020 report, the world's total electricity generation was 6131 TWh in 1973, of which 71.8% belongs to OECD countries. In 2018, the world's electricity generation reached a total of 26619 TWh, of which OECD accounted for 41.7%, China 27%, and the United States 17%. The amount of total electricity generated from renewable energy sources rose to 6700 TWh in the same year (IEA, 2020a). In this period, world gross electricity production increased with an average annual growth rate of 3.3% (IEA, 2020g). IEA estimations indicate that global electricity generation will grow by around 55% (14.800 TWh) between 2018 and 2040 in the stated policies scenario, and this growth will mostly lead by Asia particularly China, followed by India (IEA, 2019a).

Currently, renewables provided an estimated more than 26% of global electricity generation (EÜAŞ, 2016). In terms of contribution to the electricity generation by source, the world's total hydroelectricity production was 1296 TWh in 1973 (IEA, 2020a), which increased gradually to 4222 TWh in 2019, of which OECD accounted for 34%, while China accounted for about 30% of the world total with 1270 TWh production (BP, 2020). It is clear that hydroelectricity maintains its leading position among renewable energy sources in electricity generation. Furthermore, the increasing share of renewables in electricity production triggers the domestic use of renewable energy sources more and more in power generation. For instance, according to International Hydropower Association (2017), Norway is a prominent country with around 95% share of hydroelectricity in total domestic power production.

The world's wind electricity production increased from 104 TWh in 2005, to 1273 TWh in 2018, of which OECD has 58.5% of the world total, while China has 28.7% with 366 TWh production. Spain has a crucial position among countries with 18.5% share of wind in total domestic electricity generation (IEA, 2020a). Another important progress observed in solar PV technology in the last decade. The world's solar PV electricity production increased from 32 TWh in 2010, to 720 TWh in 2019 (IEA, 2019b). OECD accounted for more than half of the world's total electricity generation, whereas China accounted for over a third. The highest contribution of solar PV in total domestic electricity generation was observed in Italy with 7.8% of share (IEA, 2020a). Although there have been significant improvements in electricity generation from renewable energy sources, the share of fossil fuels in the world's gross electricity generation is still very high. As shown in Figure 5.1 (IEA, 2020g), coal and natural gas remain the dominant fuel in electricity production, and these two sources account for more than half of the world's total electricity generation. On the other hand, a significant acceleration is expected in the capacity increase of renewable electricity generation technologies as the downward trend of costs in renewable energy plants continues. Therefore, it is estimated that the role of renewable energy sources in meeting global electricity demand will increase in the coming years due to technological developments, cost reductions, and growing environmental concerns.

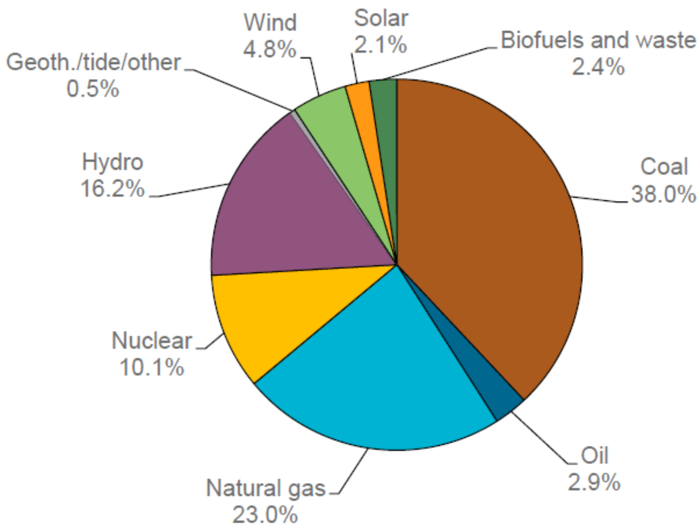

Figure 5.1 World gross electricity production by source, 2018

5.2. Turkish Electricity Market

Electrical energy first began to be used in order to perform the function of lighting in daily life. Along with technological developments, the use of electrical energy has gradually expanded to a variety of different fields, the most important of which is its use for electricity generation purposes. The first electricity generation power plant in Turkey was a hydroelectric power station of 60 kW power established in Tarsus in 1902 (Yumurtacı and Asmaz, 2004). After this date, there has been a steady increase in the amount of installed power for a long period, and in fact, as a result of the country's restructuring strategy in the energy field, the total amount of installed power has gradually accelerated in the last decade.

According to the annual report of EÜAŞ (2019b), the total installed power capacity was below 5000 MW in 1978, however, there was a sharp increase in the total installed power to reach over 50000 MW in 2011 from 5119 MW in the thirty-year period (EÜAŞ, 2019b). The report also states that between 2013 and 2019, the amount of growth in the total installed power has risen dramatically, it was about 10000 MW on average in every two-year period. In the current situation, by the end of 2019, Turkey's total installed capacity has reached 91267 MW including 47663 MW of thermal, 28503 MW of hydroelectric, 7591 MW of wind, and 5995 MW of solar, and 1515 MW of geothermal (TEİAŞ, 2019a). The licensed installed capacity of energy sources, its share in total installed capacity for the period 2017-2019 are given in Table 5.1 (EMRA, 2019c;

EMRA, 2018). The table represents that the licensed installed capacity of electricity generation sources was 81506.42 MW in 2017, it increased by 2.06% and reached 83187.05 MW in 2018, and this figure reached a total of 84957.72 MW in the following year.

Table 5.1 Licensed installed capacity by source

Resource Type	2017 (MW)	Share (%)	2018 (MW)	Share (%)	2019 (MW)	Share (%)
NATURAL GAS	26,311.80	32.28	25,731.93	30.93	25,935.41	30.53
HYDRO DAM	**19,746.05**	**24.23**	**20,534.80**	**24.69**	**20,642.51**	**24.30**
LIGNITE	9,267.12	11.37	9,597.12	11.54	10,101.03	11.89
IMPORT COAL	8,936.35	10.96	8,938.85	10.75	8,966.85	10.55
RUN OF RIVER	**7,509.98**	**9.21**	**7,748.90**	**9.32**	**7,851.85**	**9.24**
WIND	**6,482.12**	**7.95**	**6,942.27**	**8.35**	**7,520.33**	**8.85**
GEOTHERMAL	**1,063.73**	**1.31**	**1,282.52**	**1.54**	**1,514.69**	**1.78**
FUEL OIL	702.77	0.86	709.21	0.85	305.93	0.95
HARD COAL	616.15	0.76	616.15	0.74	810.77	0.85
BIOMASS	**439.72**	**0.54**	**590.92**	**0.71**	**725.92**	**0.48**
ASPHALTITE COAL	405.00	0.50	405.00	0.49	405.00	0.36
SOLAR	**17.90**	**0.02**	**81.66**	**0.10**	**169.70**	**0.20**
NAPHTA	4.74	0.01	4.74	0.01	4.74	0.01
LNG	1.95	0.00	1.95	0.00	1.95	0.00
DIESEL	1.04	0.00	1.04	0.00	1.04	0.00
Total	**81,506.42**	**100.00**	**83,187.05**	**100.00**	**84,957.72**	**100.00**

According to Table 5.1, renewable energy sources with an installed capacity of 35,259.50 MW correspond to the share of 43.26% in total installed power in 2017, while the share increased to 44.70% in 2018 by having 37,001.07 MW installed capacity. This figure increased to 45% in 2019, slightly above last year's increase. When the rate of change between years is analyzed, it is seen that solar energy resources grew at a substantially higher rate. Moreover, the unlicensed installed capacity of energy sources and change for the period 2017-2019 are given in Table 5.2 (EMRA, 2019c; EMRA, 2018).

Table 5.2 Unlicensed installed capacity by source

Resource Type	2017		2018		2019	
	Installed Capacity (MWe)	Share (%)	Installed Capacity (MWe)	Share (%)	Installed Capacity (MWe)	Share (%)
Solar	2,979.84	93,90	5,017.49	94.47	5,825.46	92.33
Natural Gas	85.88	2,71	153.04	2.88	328.66	5.21
Biomass	66.72	2,10	79.18	1.49	75.67	1.20
Wind	32.20	1,01	51.95	0.98	70.83	1.12
Hydraulic	8.69	0,27	8.91	0.17	8.65	0.14
Total	**3,173.32**	**100,00**	**5,310.57**	**100.00**	**6,309.27**	**100.00**

According to Table 5.2, the unlicensed installed capacity of renewable energy sources showed a rapid growth rate of 67.35% in 2018 and the total unlicensed installed capacity reached 5,310.57 MW, compared to the previous year. Solar energy is observed as the prominent category within the unlicensed capacity of renewable energy sources by having a relatively higher share of 94.47%. The unlicensed capacity ranking of resource types remains unchanged in 2019, the highest share belongs to solar power, followed by natural gas, biomass, wind, and hydraulic power.

When the development of Turkey's installed power in terms of primary energy sources is analyzed over the past decade, it can be seen that renewable energy sources account for more than half of the country's installed power growth thanks to regulations and incentives for renewable energy. Accordingly, there was no installed capacity of wind energy in 2007 and solar energy in 2013, however, as a consequence of efforts to increase the use of renewables in electricity generation, the total installed capacity of wind power plants reached 7591 MW and solar power plants reached 5995 MW at the end of 2019 (TEİAŞ, 2019b). Figure 5.2 (KPMG, 2020) illustrates the relative percentage contributions made by renewable energy sources to Turkish electricity sector between 2010 and 2019. It demonstrates that Turkey's installed power capacity relies on renewable energy sources for about half of its total installed power capacity as of the end of 2019.

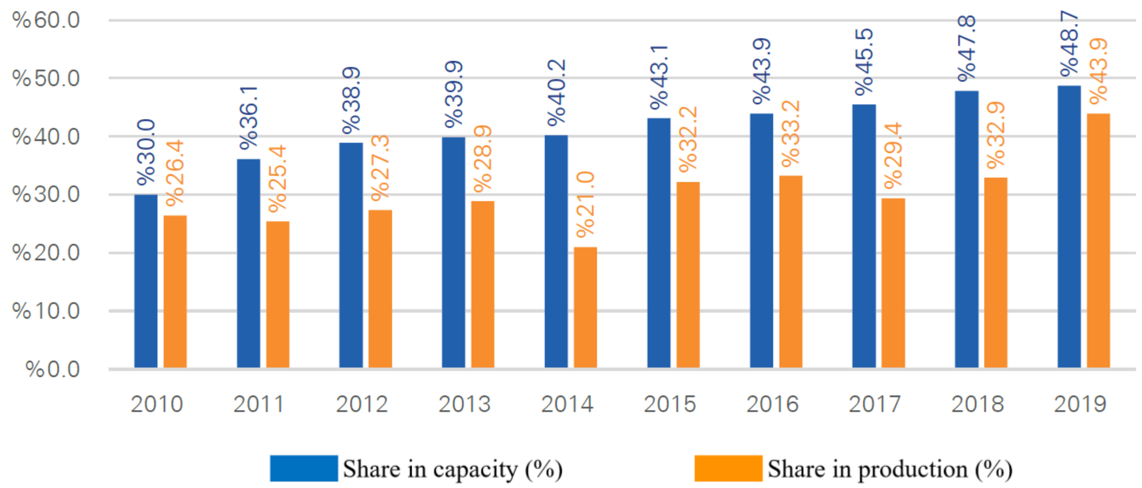

Figure 5.2 Share of renewable energy in Turkish electricity volume

In the recent period, a new transition process has started with the impact of new structural arrangements and regulations in the energy policies of Turkey. The main goal of regulatory actions was to encourage the use of renewable energy sources in electricity production in order to reduce foreign dependency. It is essential to examine official market development reports published in recent years to highlight the change in figures while analyzing the position of electricity generation in the current electricity market. In 2019, the current system produced a total of about 304 billion kWh, of which 157.1 billion kWh from thermal, 88.8 billion kWh from hydroelectric, 21.7 billion kWh from wind, 9.3 billion kWh from solar, and 9 billion kWh from geothermal power plants (TEİAŞ, 2019a). According to the EMRA's Electricity Market Development Report (2018), the share of renewable energy sources in total electricity generation was 29.5 % in 2017. It is also observed from the report that similar to the increase in the use of renewable energy resources in energy production, which has recently become more preferred, the share of renewable energy sources in total electricity generation is increased to 32.32% in 2018. The upward trend is maintained in 2019, and renewable energy sources are accounted for 42.10% of the total electricity generation in the country (EMRA, 2019c). Overall values of electrical data for the years 2017, 2018, and 2019 are listed in Table 5.3 (EMRA, 2019c; EMRA, 2018).

Table 5.3 Overall values of Turkish electricity data

	Unit	2017	2018	Change (%)	2019	Change (%)
Licensed Installed Capacity	MW	81,506.42	83,187.05	2.06	84,957.72	2.13
Unlicensed Installed Capacity	MW	3,173.32	5,310.57	67.35	6,309.27	18.81
Licensed Generation	GWh	292,595.42	296,003.71	1.16	294,251.32	-0.59
Unlicensed Generation	GWh	3,031.33	8,212.77	170.93	9,829.45	19.68
Consumption	GWh	292,003.54	302,772.30	3.69	301,982.70	-0.26
Import	GWh	2,729.06	2,466.01	-9.64	2,211.51	-10.32
Export	GWh	3,300.10	3,073.60	-6.86	2,788.67	-9.27

Historical progress figures reinforce that the development of Turkey's gross electricity generation has shown a rapid rise over the last decade. The amount of electricity production was almost 195 billion kWh in 2009, which shows that the national electricity generation grew dramatically by 56% increase in the last ten years (TEİAŞ, 2019c).

Unlicensed electricity generation by resource type and the share in total unlicensed electricity generation for the period 2017-2019 are given in Table 5.4 (EMRA, 2019c; EMRA, 2018).

Table 5.4 Unlicensed electricity generation by source

Resource Type	2017		2018		2019	
	The amount of energy given to the system as surplus (MWh)	Share (%)	The amount of energy given to the system as surplus (MWh)	Share (%)	The amount of energy given to the system as surplus (MWh)	Share (%)
Solar	2,836,173.49	93.56	7,859,766.42	95.71	9,425,965.29	95.90
Biomass	138,657.08	4.57	205,901.95	2.51	255,486.79	2.60
Wind	36,954.64	1.22	111,990.43	1.36	113,558.01	1.16
Hydraulic	19,546.21	0.64	34,750.58	0.42	34,437.65	0.34
Total	**3,031,331.42**	**100.00**	**8,212,409.37**	**100.00**	**9,829,447.73**	**100.00**

According to Table 5.4, the unlicensed electricity generation has risen sharply to 9,425,965.29 MWh between the years 2017 and 2019. In terms of share, there was an increase of 324% in the amount of unlicensed electricity generation over the same period. Among the energy sources, solar energy has the majority of share with a rate of 95.90% in 2019.

Licensed electricity generation by resource type and the share in total electricity generation for the period 2017-2019 are given in Table 5.5 (EMRA, 2019c; EMRA, 2018).

Table 5.5 Licensed electricity generation by source

Resource Type	**2017 (GWh)**	**2018 (GWh)**	**2019 (GWh)**	**Share (%)**
NATURAL GAS	108,837.19	91,227.14	56,522.71	19.21
IMPORT COAL	51,172.22	62,949.64	60,381.27	20.52
HYDRO GAM	**41,269.59**	**40,961.45**	**88,850.17**	**30.20**
LIGNITE	40,581.02	45,055.29	46,893.73	15.94
WIND	**17,859.86**	**19,891.37**	**21,636.28**	**7.35**
RUN OF RIVER	**17,124.40**	**18,975.98**	**-**	**-**
GEOTHERMAL	**5,969.48**	**7,611.58**	**8,929.73**	**3.03**
HARD COAL	3,453.87	3,005.55	3,518.87	1.20
ASPHALITE COAL	2,394.64	2,328.50	2,323.95	0.79
BIOMASS	**1,939.72**	**2,410.00**	**4,266.32**	**1.45**
DIESEL	1,008.83	0.98	1.00	0.00
FUEL OİL	957.86	957.98	732.92	0.25
SOLAR	**24.56**	**65.56**	**194.37**	**0.07**
LNG	2.20	1.12	0.00	0.00
Total	**292,595.42**	**295,442.15**	**294,251.32**	**100.00**

According to Table 5.5, in 2018, licensed electricity generation reached 295,442.15 GWh with an increase at a rate of 0.97% compared to the previous year. However, this figure decreased by 0.59% in 2019, and the amount of licensed electricity generation became 294,251,318.65 MWh. Renewable energy sources with licensed electricity generation of 84,187.61 GWh correspond to the share of 28.77% within the total licensed electricity generation in 2017. The share of renewable energy sources within the licensed electricity generation was 30.67% in 2018 by having the licensed electricity generation of 90,786.84 GWh. In 2019, renewable energy sources accounted for 42.1% of the total licensed electricity generation. It can be seen that the share of hydroelectric sources in electricity generation is by far higher than other renewable energy sources.

On the other hand, electricity imports of Turkey peaked in 2014 reaching 7.9 billion kWh, however, it then dropped in steady decrements to well below 2.5 billion kWh by 2019, as shown in Figure 5.3 (TEİAŞ, 2019d). In this period, electricity export figures fluctuated steadily and were noted as 2.7 billion kWh in 2019 with a slight decline compared to the previous year. Import and export activities were mainly carried out with countries in the nearby geographies including Bulgaria, Greece, Azerbaijan, Georgia, and Iran (TEİAŞ, 2019c).

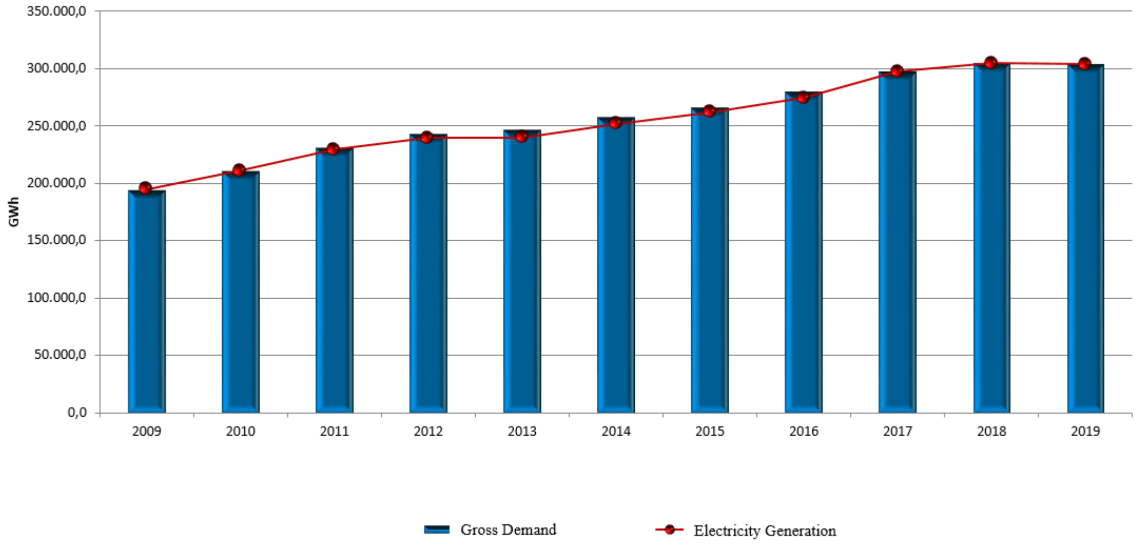

Figure 5.3 Gross electricity generation and development of demand in Turkey

Turkey is known as one of the developing countries hence, the ongoing increase in the country's population, continuous growth in many areas such as industry and technology, and significant participation in the global market as consequences of its emerging economy caused a considerable increase in energy consumption. The need for a definite plan of action in energy policies has become inevitable. According to Turkey's electric energy 5-year production capacity projection (2019-2023) report prepared by the Turkish Electricity Transmission Corporation (2019e), the country's gross electricity energy consumption increased by 6.2% in 2017 to 296.7 billion kWh, and in 2018 to 304.2 billion kWh with a 2.5% increase. Furthermore, the demand estimation study involved in the report reveals that Turkey's gross electricity consumption in 2020 will be around 329 TWh in the base case scenario, and this figure expected to reach about 451 TWh by the end of 2028. The ongoing increase in the consumption of electrical energy continues due to factors such as the developing status of the country, the growing population and the increase in demand for energy. However, after nine consecutive years of growth, the net amount of electricity consumption of the country decreased by 0.4% in 2019 to 257 billion kWh (TEİAŞ,2019f).

In general, the main goal of Turkey's energy policy is to reduce the country's external dependence and make the highest contribution to the country's prosperity by evaluating energy and natural resources in an efficient, effective, safe and environmentally sensitive way (OKA, 2011). Turkey makes significant efforts in energy planning to meet the growing energy demand in the most appropriate way. In this context, the state is developing new policies and making considerable investments in the energy field. Kok and Benli (2017) state that Turkey invested around $ 60 billion in 2015 for meeting the national energy demand and the cost of energy continues to increase. Moreover, their study indicates that investments from 193 to 225 billion Turkish Lira will be needed by 2030 according to technical evaluation regarding energy demand after 2020. Therefore, authorities aim to increase the use of domestic and renewable energy sources by establishing a strong incentive mechanism. In this way, it is aimed to reduce energy production costs and minimize external dependence.

For this purpose, the government declared YEKDEM (Renewable Energy Sources Support Mechanism) and YEKA (Renewable Energy Zones) support programs. As described in the report prepared by Presidency of the Turkey Investment Office (2018), YEKDEM provides feed-in-tariffs to power plants that use renewable energy sources for electricity generation, which is valid for the first ten years of the operation. Renewable energy facilities up to 1 MW of energy will be able to benefit from the unlicensed model, while renewable energy plant investments over 1 MW of capacity will be subject to the licensed model. According to Law No. 5346 both types of models that meet necessary requirements and operational currently or will be in operation before December 31, 2020 will be eligible for purchasing guarantee to electricity generated from renewables and benefit from the tariffs. In addition, the law provides local content support for five years to facilities that utilize locally manufactured equipment during the construction of the power plant (PricewaterhouseCoopers, 2020). Another significant incentive mechanism introduced by the state was the YEKA system which provides an auction model for investors. The main purposes of the YEKA auctions are to provide a model that includes both the public and private sectors to improve local production capacity, transfer technology, and build a competitive domestic market for low-cost renewable energy (Sari et al., 2019). The details of the legislation and fixed purchase prices of renewable energy sources are indicated in Table 5.6 and Table 5.7 (Law No. 5346).

Table 5.6 Feed-in-Tariffs

SCHEDULE I (Provision of the law dated 29/12/2010 and numbered 6094)	
Type of Production Facility Based on Renewable Energy Resources	Prices Applicable (US Dollar cent/kWh)
a. Hydroelectric production facility	7.3
b. Wind power-based production facility	7.3
c. Geothermal power-based production facility	10.5
d. Biomass-based production facility (including landfill gas)	13.3
e. Solar power based production facility	13.3

Table 5.7 Local Content Support

SCHEDULE II (Provision of the law dated 29/12/2010 and numbered 6094)		
Type of Production Facility	Local Production	Local Content Contribution (US Dollar cent/kWh)
A- Hydroelectric production facility	1- Turbine	1.3
	2- Generator and power electronics	1.0
B- Wind power-based production facility	1- Blade	0.8
	2- Generator and power electronics	1.0
	3- Turbine tower	0.6
	4- All of the mechanical equipment in rotor and nacelle groups (excluding payments made for the blade group and the generator and power electronics.)	1.3
C- Photovoltaic solar power-based production facility	1- PV panel integration and solar structural mechanics production	0.8
	2- PV modules	1.3

	3- Cells forming the PV module	3.5
	4- Invertor	0.6
	5- Material focusing the solar rays onto the PV module	0.5
D- Intensified solar power-based production facility	1- Radiation collection tube	2.4
	2- Reflective surface plate	0.6
	3- Sun tracking system	0.6
	4-Mechanical accessories of the heat energy storage system	1.3
	5-Mechanical accessories of steam production system that collects the sun rays on the tower	2.4
	6- Stirling engine	1.3
	7- Panel integration and solar panel structural mechanics	0.6
E- Biomass-based production facility	1- Fluid bed steam tank	0.8
	2- Liquid or gas fuel steam tank	0.4
	3- Gasification and gas cleaning group	0.6
	4- Steam or gas turbine	2.0
	5- Internal combustion engine or stirling engine	0.9
	6- Generator and power electronics	0.5
	7-Cogeneration system	0.4
F- Geothermal power-based production facility	1- Steam or gas turbine	1.3
	2- Generator and power electronics	0.7
	3- Steam injector or vacuum compressor	0.7

When the institutional structure in the Turkish electricity sector is analyzed, it is seen that there is a management approach that is shaped according to the dynamics of the current period and keeps up with innovations. The first step was taken as a result of the First Consultative Energy Conference organized in 1953, it was decided to establish the Turkish Electricity Corporation (TEK) as a central authority in order to manage electricity-related operations and the corporation was founded in 1970 (TEDAŞ, 2018). Although the electricity sector in Turkey was managed by TEK as a regulatory authority in the early stage of the electricity market, later, electricity generation, transmission, and distribution responsibilities were assigned to different institutions in accordance with restructuring efforts and privatization policies as represented in Figure 5.4 (PricewaterhouseCoopers, 2020).

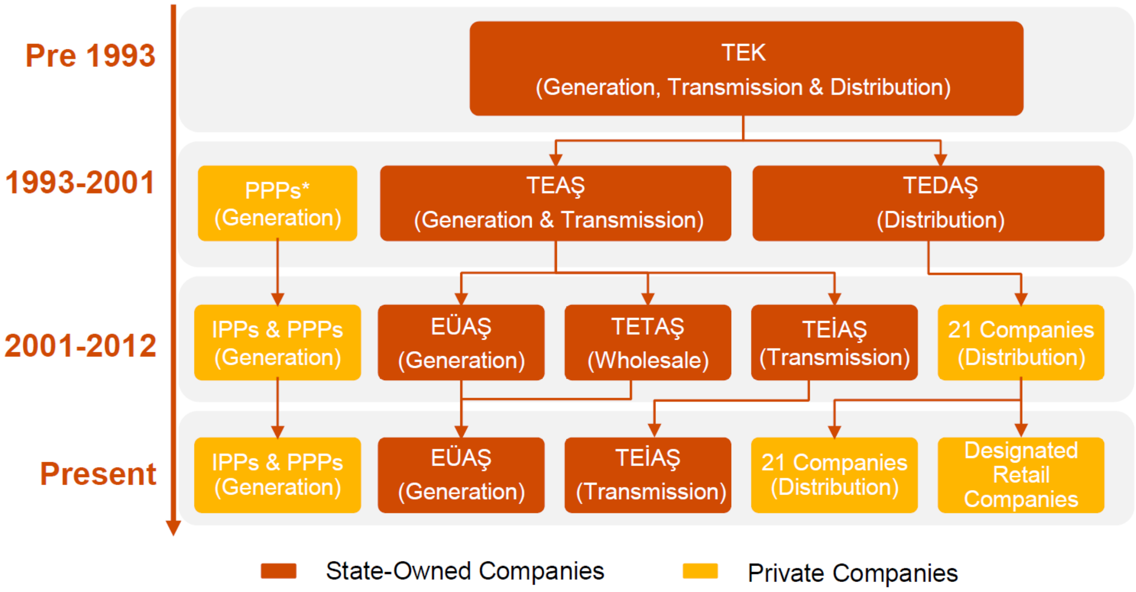

Figure 5.4 Privatization timeline of the electricity market

Until the beginning of the 2000s, the generation and transmission activities were held by the Turkish Electricity Generation and Transmission Company (TEAŞ), while the Turkish Electricity Distribution Company (TEDAŞ) was responsible for the distribution functions. In the following period, between 2001 and 2012, TEAŞ divided into three distinct organizations including Electricity Transmission Company (TEİAŞ) which was responsible for developing, maintaining, and operating electricity transmission system, Electricity Generation Company (EÜAŞ) which was responsible for operating state-owned electricity generation capacity and Electricity Trading and Contracting Company (TETAŞ) which was responsible for wholesale electricity trade. In the case study involved in this thesis, the regional distinction is modeled by using 21 regional subsidiaries determined by TEDAŞ as shown in Figure 5.5 (TEDAŞ, 2018).

Figure 5.5 Electricity distribution regions

6. MATERIAL AND METHOD

In this chapter, the methodology of the model and the proposed multi-objective decision-making model were analyzed in four sections. In Section 6.1, the methodology of the proposed model is described in detail. In Section 6.2, the proposed model is identified covering all the bases within the main framework. In Section 6.3, the formulation of the proposed model is presented, and in Section 6.4, the data sources used in the model are examined and the application of the model is explained.

6.1. Methodology

Renewable energy planning is critically important for developing countries to achieve sustainable development goals in terms of development strategies, energy policies, environmental and climate change policies. In the context of this study, in particular, renewable energy planning of Turkey, which has known as having a high potential of renewable energy resources, and multidimensional assessment of renewable energy resources in electricity generation from a multiregional perspective have been examined in detail. In this respect, it is observed from the literature that renewable energy as a subject interacts with many different factors such as political, environmental, economic, and social factors simultaneously. Thereby, in order to make a reasonable suggestion for renewable energy planning, it was found an appropriate method to use an efficient mathematical model. Since renewable energy planning as the main subject of this study was required to evaluate many different dimensions together, this thesis aimed to develop a multi-objective model using a two-phase goal programming method.

The process of model construction was the most crucial part therefore the study was conducted in accordance with a well-prepared methodology to be able to create a well-designed model by analyzing the energy sector from a broad perspective in the context of a macro plan. At this point, determining criteria was an important issue when creating a multi-objective model. It was just as important to ensure that the data is provided correctly. For that reason, comprehensive preliminary research was made to specify reasonable decision criteria, obtain reliable data for the model, and determine appropriate methods to be applied related to objectives. In order to obtain accurate data from reliable sources, the most important sources were taken into consideration during the literature review process. Some of these sources are listed below.

- European Commission Reports
- OECD Environmental Performance Reviews
- International Energy Agency World Energy Statistics
- Turkish Statistical Institute
- Republic of Turkey Ministry of Energy and Natural Resources
  - Periodic Budget Reports
  - Annual Reports
  - Strategic Plan Reports
  - Performance Program Reports
- Renewable Energy General Directorate
  - National Energy Efficiency Action Plan
- General Directorate of Energy Affairs
  - Market Monitoring Reports
  - Energy Statistics Reports

Evaluation, analysis, estimation, and projection data to be generated as a result of the studies carried out in the field of renewable energy were collected from domestic and foreign sources. Therefore, the data related to renewable energy sources used in the developed model by obtaining the data from sources that are found to be the most suitable for the study. The data presented in these reports used as a part of the developed model by identifying regional appropriateness criteria for renewable energy types.

Moreover, in the preliminary research part, the data related to purpose-specific parameters collected in accordance with the purpose of the model. For necessary situations, missing information was obtained by using expert opinions included in similar studies. In the next step, the developed model was tested with the collected data of parameters. Since the model is based on multiple objectives and involves complicated decision-making processes, different types of decision-making methods and techniques were analyzed and the most appropriate methods were determined and used for the model. For the application part of the model, required statistical software and programs were determined and applied under different scenarios. In this study, as a comprehensive solver tool for model optimization LINGO software has been used for the two-phase goal programming model application to obtain the optimal solution for the problem.

The Two-Phase Fuzzy Goal Programming Methodology

In this study, a two-phase fuzzy goal programming methodology is employed to determine the suitable renewable energy types among alternatives, and the allocated amount of capacity for power plant installation that corresponds to specified renewable energy sources. There are four objectives involved in the proposed multi-objective model, unlike classic decision-making models with a single goal for planning problems. The first objective is maximizing the normalized technical score of regions based on energy type, whereas the second objective is minimizing the cost of energy types. The third objective is maximizing the number of jobs created regarding energy types, and the fourth one is maximizing the normalized environmental score concerning energy types. Since the decision-making model involves various objectives related to different areas and exhibits a complex structure, it is reasonable to use a problem-specific methodology. In this case, the two-phase approach is utilized as an appropriate solution method. The related information about the two-phase fuzzy goal programming methodology is provided in detail in the following sections.

- ***The First Phase (Max-Min Approach)***

The two-phase method used in this study has five main parts. The ideal and anti-ideal solutions for each of the objective functions are computed in Part I (Guu et al., 2011). Accordingly, in the first place, it is necessary to find the best (z_{best}) and worst (z_{worst}) values for each of the objective functions. By running the related part of the proposed mathematical model separately for each objective, the best and worst values are obtained. Then, in Part II, those values are characterized by membership functions to measure the degree of achievement of the desired goal levels in the decision case (Balasubramaniam, 2011). According to the approach adapted from Tuzkaya et al. (2016), the membership functions as illustrated in Figure 6.1 and 6.2 are constructed for minimization and maximization based on Equations (1) and (2), respectively.

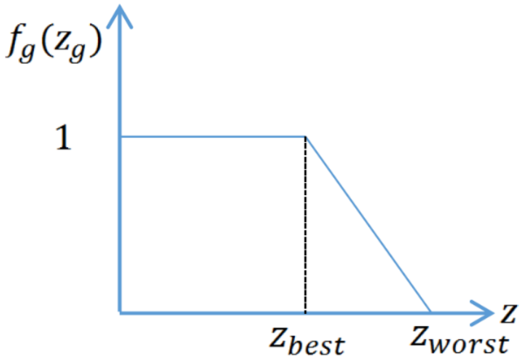

Figure 6.1 Membership function for a minimization function

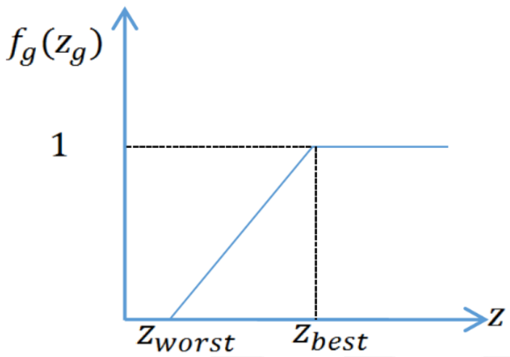

Figure 6.2 Membership function for a maximization function

$$f_g(Z_g) = \begin{cases} 1, & Z_g \leq Z_{best}^g \\ \frac{Z_{worst}^g - Z_g}{Z_{worst}^g - Z_{best}^g}, & Z_{best}^g \leq Z_g \leq Z_{worst}^g \\ 0, & Z_g \geq Z_{worst}^g \end{cases} \tag{1}$$

$$f_g(Z_g) = \begin{cases} 1, & Z_g \geq Z_{best}^g \\ \frac{Z_g - Z_{worst}^g}{Z_{best}^g - Z_{worst}^g}, & Z_{worst}^g \leq Z_g \leq Z_{best}^g \\ 0, & Z_g \leq Z_{worst}^g \end{cases} \tag{2}$$

In the first phase, in Part III of the methodology, the max-min operator is used in order to improve the satisfaction degree of the objective function having the minimum degree of satisfaction. From the membership functions, it is understood that bigger $f_g(z_g)$ values reflect the higher objectives' satisfaction for maximization, whereas smaller $f_g(z_g)$ values provide the higher satisfaction for minimization (Arıkan and Güngör, 2007). In Part IV, introducing a new variable λ such that $\lambda = f_g(z_g)$, the general satisfaction degree, also called threshold satisfaction degree, is tried to be maximized and for each objective function, the value of satisfaction degree ($FPSD$) should be more than or equal to λ value as seen in Equations (3) and (4) (Tuzkaya et al., 2016; Arıkan and Güngör, 2007; Kilic and Yalcin, 2020).

$$Maximize\ \lambda \tag{3}$$

$s.t.$

$$\lambda \leq FPSD_g \qquad \forall_g \tag{4}$$

- ***The Second Phase (Weighted Sum Approach)***

In particular cases regarding multiple objective problems, using the max-min operator as in the first phase of the method is considered inefficient. However, the second phase of the two-phase method forces the solution yielded to be at least better than the solution obtained in the first phase, and the efficient solution obtained guarantees to achieve better utilization (Guua and Wu, 1999). In the second phase, the main goal is to maximize the composite satisfaction degree at least as good as the degrees obtained by phase one (Mahdavi et al., 2009). In other words, in the second phase, the development of optimal solutions obtained in the first phase is investigated. Thus, the main aim of the second phase is to improve the first phase satisfaction degrees.

The second phase of the method involves the weighted sum approach and uses optimal solutions gathered in the first phase. In more detail, within this phase, all of the goals' first phase satisfaction degrees are used as minimum bound values, and the goal is to maximize the total weighted satisfaction degree (*TWSD*) by calculating the values of each goal's Second Phase Satisfaction Degrees (*SPSD*) as shown in Equations (5) – (9) (Kilic and Yalcin, 2020).

$$Max\ TWSD = \sum_{g=1}^{K} w_g * SPSD_g \tag{5}$$

$s.t.$

$$FPSD_g \leq SPSD_g \qquad \forall_g \tag{6}$$

$$0 \leq SPSD_g \leq 1 \qquad \forall_g \tag{7}$$

$$\sum_{g=1}^{K} w_g = 1 \tag{8}$$

$$0 \leq w_g \leq 1 \qquad \forall_g \tag{9}$$

The general framework of the two-phase fuzzy multi-objective goal programming method is provided in the above as Part V, however the weight determination part is skipped since the importance weights of objectives are assumed equal in the proposed methodology.

6.2. Problem Description

In this part, the proposed model is identified in detail by describing the objectives of the study and providing an extensive evaluation of the determined criteria. In this study, a multi-objective model was developed in order to contribute decision-makers for renewable energy planning on a multiregional basis in Turkey. Researches focused on energy planning in the literature revealed that environmental issues, economic analyses, socio-political evaluations, sustainability considerations, and energy efficiency of energy types were the most common criteria considered related to renewable energy technologies. In this regard, the proposed decision model constructed in this study considered many aspects mainly technical, economic, social, and environmental align with the studies conducted in the literature.

One of the most critical steps in the proposed mathematical model was to determine the objectives properly. For this reason, the objective functions in the model were specified as a result of a detailed literature review in accordance with the intended purpose.

In this study, technical characteristics of regions concerning energy types, used as a distinctive feature by giving a technical score to the regions regarding the types of renewable energy sources. In the process of multiregional evaluation and analysis of renewable energy sources, regional distinctions were made based on the classification specified as electric distribution zones. According to the classification, Turkey was divided into 21 distribution zones by the Turkish Electricity Distribution Corporation (TEDAŞ), after the privatization of the electricity distribution system. Determined electric distribution zones cover different cities within themselves. The number of cities included in the distribution zones is not fixed. The number of cities covered by different electric distribution regions is different from each other. For instance, Sakarya electric distribution region covers the cities of Kocaeli, Düzce, Sakarya and Bolu, while the electric distribution region named as Trakya covers cities of Edirne, Tekirdağ and Kırklareli. In brief, the average values of the cities involved in a specific electric distribution region, regarding technical criteria of renewable energy alternatives assigned as the overall value for the region. The normalization process was performed before the technical score of the determined renewable energy sources for each region used in the model. Accordingly, one of the main objectives of this study was to maximize the normalized technical score of regions concerning renewable energy types.

In addition to this, the cost of each renewable energy type per energy generation was considered as another important factor in energy planning and minimization of the levelized cost of electricity per renewable energy type depending on the power capacity of the renewable energy plant was evaluated as another aim of the study. The average lifetime levelized cost of electricity generation (LCOE) was used in the model since it was calculated by considering many different elements such as investment expenditures, operations and maintenance expenditures, fuel expenditures, and the life of the system. However, "the LCOE of renewable energy technologies varies by technology, country and project, based on the renewable energy resource, capital and operating costs, and the efficiency/performance of the technology" (IRENA, 2019b). For this reason, this study aimed to obtain the real data for Turkey for the model application part.

Since energy planning was considered to be a comprehensive and interrelated subject with different elements, the issue of employment as a part of planning activity has been expressed in the literature as a prominent social aspect. In this regard, the number of jobs created from renewable energy types per installed capacity was evaluated as one of the parameters discussed in the study. Furthermore, the maximization of the total number of employment for specified renewable energy sources per installed power capacity was determined as one of the main objectives of this thesis.

The ongoing growth in the human population and the impact of the latest technological developments led to an increase in energy consumption. Therefore, decision-makers gave great importance to the development of comprehensive energy planning strategies to meet increasing energy needs. It was known that fossil fuels have been the most widely used resource in electricity generation in the world. However, not every country has sufficient resources in terms of fossil fuel resources, and yet fossil fuel reserves were running out day by day. And besides, fossil fuel usage causes serious negative impacts on the environment. Thus, increasing the use of renewable energy sources in electricity generation became a critical issue for energy planning in many aspects, such as sustainability, climate change, and the health of living beings through pollution. In this study, environmental impacts of the selected renewable energy sources were evaluated as producing a normalized environmental score for each renewable energy type.

It is observed that the environmental impact of renewable energy sources varied according to the different evaluation criteria. Hence, the environmental evaluation criteria for the study determined by considering many alternatives in the literature in order to provide originality. In this respect, life-cycle greenhouse gas emissions of renewable energy types represented as grams of carbon dioxide equivalent per MWh, included in the study. Land requirements required for renewable energy plants, which were expressed in units of a square meter per MWh, were also taken into consideration in this thesis by taking the average of the selected studies in the literature after the normalization process. By considering all the criteria briefly mentioned in this part, the final normalized environmental score for renewable energy technologies was formed in accordance with the literature. Thereby, maximization of the normalized environmental impact score of the renewable energy sources was identified as one of the objectives of this study.

After the model objectives were specified, the process of defining the model continued with the determination of the maximum and minimum capacity limits. Moreover, in this study, the most prominent renewable energy sources are taken into consideration namely, solar, wind, geothermal, hydropower, and biomass. The data collection process related to renewable energy sources will be analyzed in detail in the next section. Also, the parameter data will be explained thoroughly in the data description part.

It is expected that the proposed model covering the criteria determined would provide a useful contribution in renewable energy planning by producing consistent outputs on a regional basis including what kind of energy plant should be installed and in what amount of electricity should be generated from the renewable energy plant.

The electric distribution regions to be used during the regional evaluation process of Turkey have different characteristics since each city has different characteristic features with respect to each renewable energy resource. Hence, as part of the study, evaluation of regions by considering related parameters has an important place in terms of determining the technical suitability of renewable energy sources in Turkey on a multiregional basis. To obtain accurate results for regional renewable energy planning using the model, it is critical to reveal the distinguishing differences between regions prior to case implementation.

6.3. The Proposed Model

Indices

i : Region $(1 \dots m)$

j : Energy Type $(1 \dots n)$

Sets

I : The set of regions

J : The set of renewable energy types

Parameters

NTS_{ij} : Normalized technical score of region "i" concerning energy type "j"

$Cost_j$: Cost of energy type "j" per MWh

JC_j : Number of jobs created for energy type "j" per MWh

NES_j : Normalized environmental score of energy type "j"

D : Total renewable energy production demand

$mincap_{ij}$: Minimum required energy that must be produced in region "i" concerning energy type "j" in case it is selected

$maxcap_{ij}$: Maximum energy capacity that can be produced in region "i" concerning energy type "j"

M : A big number

Decision Variables

x_{ij} : The energy that will be produced in region "i" concerning energy type "j"

y_{ij} : Region "i" concerning energy type "j" is selected or not (0/1 binary variable)

Objective Functions

$$Max\ Z_1 = \sum_{i=1}^{m}\sum_{j=1}^{n}(x_{ij} * NTS_{ij}) \qquad (10)$$

$$Min\ Z_2 = \sum_{i=1}^{m}\sum_{j=1}^{n}(x_{ij} * Cost_j) \qquad (11)$$

$$Max\ Z_3 = \sum_{i=1}^{m}\sum_{j=1}^{n}(x_{ij} * JC_j) \qquad (12)$$

$$Max\ Z_4 = \sum_{i=1}^{m}\sum_{j=1}^{n}(x_{ij} * NES_j) \qquad (13)$$

Constraints

$$\sum_{i=1}^{m}\sum_{j=1}^{n}x_{ij} = D \qquad (14)$$

$$M * y_{ij} \geq x_{ij} \qquad \forall_{i,} \forall_j \qquad (15)$$

$$x_{ij} \leq maxcap_{ij} \qquad \forall_i, \forall_j \qquad (16)$$

$$x_{ij} \geq mincap_{ij} * y_{ij} \qquad \forall_i, \forall_j \qquad (17)$$

$$x_{ij} \geq 0, y_{ij} \in \{0,1\} \qquad \forall_i \qquad (18)$$

The model developed in this thesis indicated different regions and several energy types for energy planning. In the proposed model, two indices were defined as i and j in line with planned work where i denotes electricity distribution regions and j denotes types of renewable energy sources. This study focused on five renewable energy types including solar, wind, geothermal, hydroelectric and biomass. Moreover, energy regions of Turkey used in the study identified by TEDAŞ as 21 electricity distribution zones, namely, Dicle, Aras, Vangölü, Çamlıbel, Çoruh, Toroslar, Fırat, Meram, Akdeniz, Başkent, Gediz, Trakya, Uludağ, Sakarya, Anatolian Side, Bosphorus, Osmangazi, Kayseri, Göksu, Yeşilırmak, and Menderes. Hence, the regions used for the model ranges from 1 to 21, while the types of renewable energy sources range from 1 to 5 accordingly.

The model parameters identified in the model contain NTS_{ij} which represents the normalized technical score of the regions concerning different energy alternatives, where the cost of renewable energy types per megawatt-hour (MWh) indicated as $Cost_j$. Another parameter, JC_j used to demonstrate the number of jobs created for each energy type per megawatt-hour (MWh), while the normalized environmental scores of renewable energy sources were represented as NES_j. The total electricity production demand from renewable energy sources described as D. Moreover, the parameter symbolized as $mincap_{ij}$ expressed the minimum required energy that must be produced in regions correspond to renewable energy types in case it is selected. On the other hand, $maxcap_{ij}$ was another parameter in the model which represents the maximum energy capacity that can be produced in regions concerning the types of renewable energy sources. To include a parameter that corresponds to a big number, the symbol M was used.

One of the aims of this study was to determine what kind of energy plant should be installed and in what amount of electricity should be generated from the renewable energy plants on a multiregional basis. For this reason, the decision variable x_{ij} specified represents the amount of energy that will be produced in regions concerning the types of renewable energy sources. The other decision variable y_{ij} was identified to show if the regions are selected or not for the electricity generation concerning renewable energy types.

The proposed multi-objective decision-making model was built in order to provide a consistent solution for a multiregional renewable energy planning problem. Equations (10) – (13) correspond to the objective functions of the proposed multi-objective decision-making model. The objective function (10) is incorporated into the model to maximize the normalized technical score of regions concerning renewable energy types. In order to minimize the levelized cost of electricity of energy types depending on the power capacity of the renewable energy plant, the objective function (11) is integrated into the model. The objective function (12) is included in the model for maximization of the total number of employment for specified renewable energy sources per installed power capacity. Furthermore, the maximization of the normalized environmental impact score of the renewable energy sources, which is considered one of the most important elements of the model, used in the model as listed in the objective function (13).

Constraint (14) is a demand constraint and ensures that the total electricity generated from renewable energy sources under any scenario is equal to the sum of the amount of the total energy demand of the regions. In this way, the proposed model aims to satisfy the total demand of the regions from the sum of the electricity generated through renewable energy sources.

Constraint (15) is intended to be used as a selection control mechanism constraint in the model in order to guarantee that the selection of the regions if electricity production activity from renewable energy sources exists in the region.

Constraint (16) and (17) are capacity constraints of the proposed multi-objective model. The constraint (16) ensures that the sum of the electricity produced in regions that correspond to renewable energy types would not exceed the maximum energy capacity of each region concerning the types of renewable energy sources. On the other hand, constraint (17) provides that the sum of the electricity produced in regions that correspond to renewable energy types would be greater than or equal to the minimum required energy to be produced in regions concerning renewable energy types in case it is selected.

Constraint (18) included in the model in order to ensure that the energy produced in regions concerning energy types must be positive while the constraint also expresses that the y_{ij} is binary value only corresponds to 0 or 1 values.

6.4. Data Description

In order to produce reasonable outputs from the developed model, the provided data have to be consistent and reliable. Therefore, the data used in this study was obtained from the most reliable data source possible to achieve consistent results. For this study, the renewable energy-related data sources including books, publications, reports, journals, and other related documents provided by international institutions, agencies, associations, global organizations, government units, and non-governmental organizations have been examined in detail.

In this study, mainly five renewable energy alternatives were considered and different data sources for each renewable resource were thoroughly reviewed. Renewable energy sources considered for the energy planning problem can be specified as solar, wind, geothermal, hydroelectric, and biomass respectively. Besides, the data used in the proposed model will be analyzed in this section for each aspect separately.

Technical Aspect

- ***Solar Energy***

In this study, the Global Solar Atlas (GSA) was used as the main data source for solar energy in the calculation process of the technical scoring. The GSA tool has been developed collectively by the World Bank, Energy Sector Management Assistance Program (ESMAP), and the Solargis in order to provide quick and easy access to solar resource and photovoltaic power potential data globally (GSA, 2020). The specific photovoltaic power output (PVOUT) data provided by GSA that consider many factors together, such as insolation time and solar radiation, were used when determining the technical suitability criteria for solar energy. Another strength of the data gathered from the platform was area analysis. The process of technical analysis of solar energy resources on a multiregional basis for Turkey has become easier to achieve through this feature.

In more detail, the PVOUT value is defined in the unit kWh/kWp and indicates the kWh of electricity that would be generated by a PV system with 1kW peak installed capacity, and this value also represents the long-term yearly average of daily totals of photovoltaic power potential (World Bank, 2019). The general visualization of the global solar photovoltaic output map is shown in Figure 6.3 (GSA, 2020).

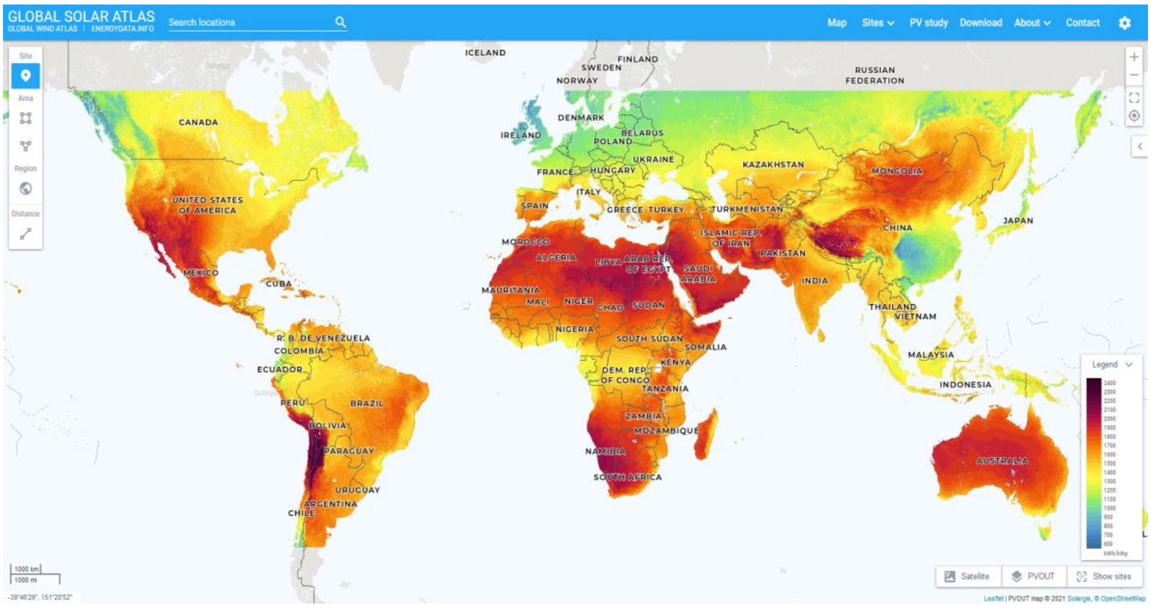

Figure 6.3 Global solar photovoltaic output map

PV power simulation model calculates the PVOUT value for a selected location based on several criteria. The most significant one is the amount of solar radiation falling on the tilted surface of the PV modules, which depends on the local climatic conditions as well as the mounting of the modules, inclination angle, air temperature, instantaneous sun position, terrain features, and losses due to environmental factors (World Bank, 2019).

Also, the data obtained from other sources were not directly used in the study but to guarantee and control consistency. For instance, the GEPA platform prepared by MENR as a domestic database involves solar radiation and insolation time values on a provincial basis. However, these data were used as a supportive element in the study due to reasons such as the website being outdated and not having sufficient explanatory documents regarding the requested resources.

In brief, the PVOUT value can be considered as a significant indicator that analyzes the solar photovoltaic potential of specific regions based on the local technical and environmental conditions. For this reason, average PVOUT values were gathered from the GSA and arranged by determined multiregional format. Then, the technical score for solar energy was calculated by applying the linear normalization procedure.

- ***Wind Energy***

In this study, the data related to wind resources were gathered from the Global Wind Atlas (GWA) (2020) which is the product of a partnership between the Department of Wind Energy at the Technical University of Denmark and the World Bank Group. The platform helps policymakers, planners, and investors identify high-wind areas for wind power generation virtually anywhere in the world. The GWA uses large-scale atmospheric data and microscale wind climate data under different models, using proper methodologies and calculations to provide local wind climate estimations on specific heights. The general visualization of the global wind atlas map is shown in Figure 6.4 (GWA, 2020).

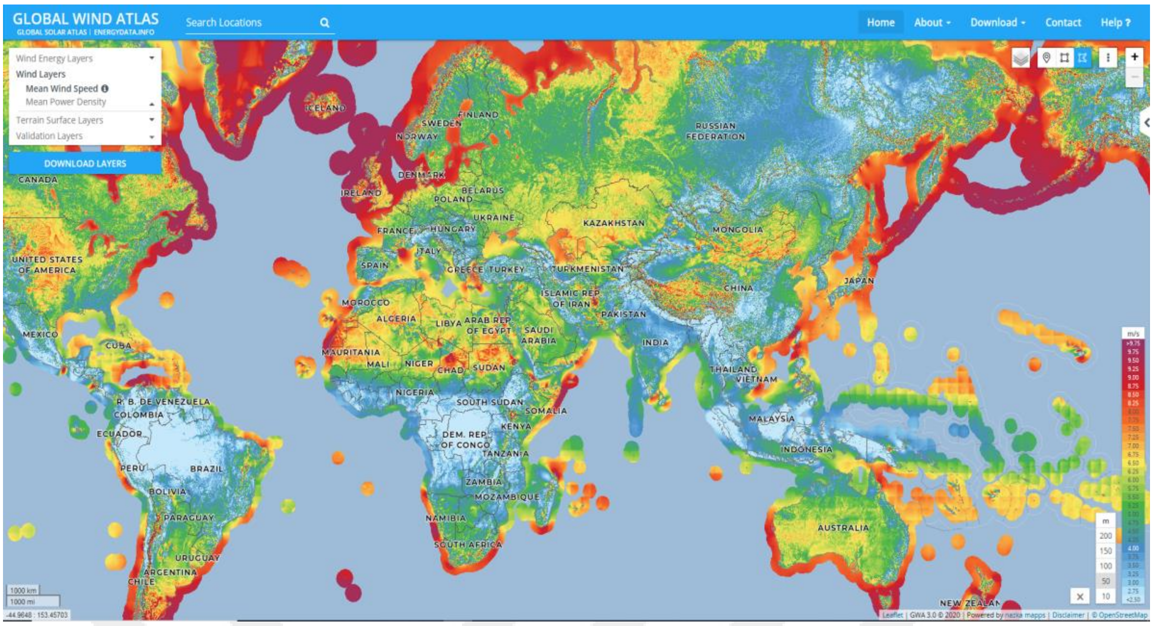

Figure 6.4 Global wind atlas mean wind speed map

From the GWA website, mean wind speed and mean power density values at a height of 50 meters were obtained for each city in Turkey. It is clear that regions with higher mean wind speed and mean power density have better wind resources. Thus, the data gathered from the GWA database was used in the proposed model to support the multiregional technical assessment process before the installation planning.

First of all, the regional values for 21 sites were calculated by taking an average of cities with grouping by region. Mean power density (W/m^2) at height 50 m above ground and mean wind speed (m/s) at height 50 m above ground were taken into consideration as equally important criteria. Therefore, before using the data in the model equal weight assigned and the linear normalization operation was applied. Hence, as a second step, the linear normalization process was applied by assigning equal weights to the data of the selected criteria. In this way, a normalized technical score of the wind energy resource on a multiregional basis was obtained.

- ***Geothermal Energy***

An in-depth literature survey has been conducted on geothermal energy. Studies have shown that geothermal resource potential is high in provinces located in dense fault lines and volcanic zones. At this point, local studies were reviewed to obtain reliable data for regional analysis and for the parameter used in the proposed model.

First, geothermal resource potential values by provinces were analyzed (Akkuş and Alan, 2016). Since the geothermal energy potential data was used to determine the maximum capacity constraint, it was not evaluated in the model. However, it has been used as an important source of information while checking the consistency of regional data. Furthermore, provinces were evaluated considering the temperatures of geothermal fields where electricity is generated (UCTEA, 2016). These studies indicated that the geothermal resources with high temperature values are considered to be more efficient in terms of electricity generation.

On the other hand, this study focused on the number of wells drilled in the relevant provinces as an important criterion for the model parameter. Since the government in line with the state policy concentrated on search activities for geothermal resources in the regions where the potential is high, this study was evaluated the technical feasibility of regions in terms of the number of wells drilled according to Mineral Research and Exploration General Directorate (MTA). The data were provided from the report prepared by Akkuş and Alan (2016) for the Union of Chambers of Turkish Engineers and Architects. The average values based on the province were distributed according to the electricity distribution regions. Moreover, the technical score of the geothermal energy resources by region was obtained after the application of the linear normalization procedure.

- ***Hydroelectric Energy***

The most important factors for hydroelectric power are the annual average number of rainy days and the monthly average total amount of rainfall. Therefore, related multiregional data associated with these two criteria gathered from the Turkish State Meteorological Service (MGM, 2019). Before calculating the technical score of the hydropower resources, primarily the data belongs to each province were arranged on a multiregional basis according to the electricity distribution regions by taking an average. Afterward in this study, equal weights were assigned to the data of the selected factors, and the linear normalization procedure was performed in order to calculate the normalized technical score of the hydroelectric energy resources.

- ***Biomass Energy***

The data regarding biomass energy type were obtained from the Biomass Energy Potential Atlas (BEPA) provided by the General Directorate of Energy Affairs (MENR, 2020). For each province, the amount of plant and animal waste, the amount of municipal waste, the amount of forest waste (tons/year) have been obtained from the BEPA. Then, the tons of oil equivalent (toe/year) of these wastes were calculated for each province. Here, the total amount of waste for each province and the total energy equivalent of the wastes belonging to that province were proportioned, and the tons of oil equivalent per waste of the province were calculated. Later, these data were arranged on the basis of electricity distribution regions, and after linear normalization operation, the multiregional evaluation score for biomass energy was created.

Ultimately, all technical score values calculated for selected renewable energy alternatives on the specified regions were added to the final table. Thus, an overall technical score table was created as seen in Table 6.1.

Table 6.1 Normalized Technical Score Table

REGIONS	ENERGY TYPE (Normalized Technical Score)				
	SOLAR	WIND	GEOTHERMAL	HYDRO	BIOMASS
1-DİCLE	0.991	0.580	0.096	0.541	0.706
2-VANGÖLÜ	0.969	0.739	0.022	0.715	0.201
3-ARAS	0.921	0.762	0.056	0.597	0.159
4-ÇORUH	0.756	0.773	0.014	1.000	0.341
5-FIRAT	0.962	0.771	0.022	0.629	0.273
6-ÇAMLIBEL	0.909	0.812	0.174	0.590	0.592
7-TOROSLAR	0.985	0.809	0.051	0.589	0.890
8-MERAM	0.983	0.754	0.346	0.469	0.771
9-BAŞKENT	0.852	0.557	0.188	0.697	0.569
10-AKDENİZ	0.986	0.735	0.003	0.606	0.720
11-GEDİZ	0.953	0.934	1.000	0.601	0.601
12-ULUDAĞ	0.854	0.940	0.374	0.646	0.595
13-TRAKYA	0.837	0.919	0.008	0.611	1.000
14-ANATOLIAN S.	0.402	0.392	0.014	0.405	0.588
15-SAKARYA	0.800	0.574	0.110	0.800	0.718
16-OSMANGAZİ	0.916	0.711	0.767	0.564	0.614
17-BOSPHORUS	0.402	0.392	0.014	0.405	0.928
18-KAYSERİ	0.979	1.000	0.017	0.542	0.536
19-MENDERES	0.982	0.740	1.000	0.662	0.497
20-GÖKSU	1.000	0.899	0.017	0.612	0.676
21-YEŞİLIRMAK	0.810	0.641	0.087	0.740	0.621

Economic Aspect

From an economic perspective, the literature reveals that the levelized cost of energy/electricity (LCOE) is an important metric for the energy industry, in particular for the renewable energy field (REN21, 2019; IRENA, 2019b). In many cases, the evaluation of the project cost of a renewable energy system was considered a complicated and uncertain issue. The LCOE of renewable energy alternatives changes depending on many different factors such as country, installation cost, operation cost, material cost, and renewable energy technology. Therefore, it was difficult to determine specific cost values for Turkey, besides there was not any study or report that present the cost values for renewable energy technologies on a multiregional scale. For this reason, the LCOE value of the nearest region was used in cases where the cost data of the renewable energy type for Turkey was not accessible.

The value of LCOE for the model was calculated as a result of a complicated process by considering investment expenditures (I_t), operations and maintenance expenditures (M_t), fuel expenditures (F_t), electricity generation in a given year (E_t), discount rate (r) and the economic life of the system (n). The formula used by IRENA for calculating this parameter is given in Equation (19) (IRENA, 2019b).

$$LCOE = \frac{\sum_{t=1}^{n} \frac{(I_t + M_t + F_t)}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \tag{19}$$

The comprehensive LCOE value was used in the model instead of considering each component of the formulation individually. Thus, the LCOE value for each renewable energy type was used as a significant parameter data in the cost minimization part of the model. The weighted average LCOE value for solar energy and wind energy for Turkey obtained from IRENA Power Generation Costs (2019b) report as \$85 and \$65 per MWh, respectively. For geothermal and hydroelectric energy technologies, the LCOE values obtained as \$60 and \$55 per MWh, respectively (REN21, 2019; IRENA, 2019b). These values belonged Eurasia region which also included Turkey. For biomass energy, the LCOE value of Europe was taken into consideration that was \$80 per MWh (IRENA, 2019b). As a result, the final version of the cost table was constructed as shown in Table 6.2.

Table 6.2 Levelized cost of electricity by source

ENERGY TYPE	COST ($/MWh)
SOLAR	85
WIND	65
GEOTHERMAL	60
HYDROELECTRIC	55
BIOMASS	80

Social Aspect

Since renewable energy planning is taken into account in this study, the subject of job creation was evaluated as a social aspect that cannot be ignored. Due to growing interest in the field of renewable energy in recent years, the issue of employment has become one of the crucial topics on the agenda of the countries. For this reason, job creation was considered as a significant goal in the proposed model.

According to reports published by IRENA (2019c) regarding renewable energy capacity and employment statistics, the value of jobs created per renewable energy type was determined. The value of job creation per installed capacity (MW) was found as 7.505 for solar energy, 2.147 for wind energy, 7.052 for geothermal energy, and 6.800 for biomass energy (IRENA, 2019d). Using the same approach for the case of Turkey, the value of job creation was obtained as 6.103 for solar energy, 1.899 for wind energy, 4.677 for geothermal energy, 1.216 for hydroelectric energy, and 5.944 for biomass energy (IRENA, 2019c; Statista, 2019b). From evaluating the job creation values, it can be concluded that the values for Turkey were almost completely consistent with the calculated values of the world. The only difference stems from geothermal energy resources, which is because Turkey has significant potential in terms of geothermal energy. Moreover, it is clear that solar energy technologies are observed as more labor-intensive, and the positive aspect of this situation is that solar energy technologies are developing relatively more business opportunities (Dinçer et al., 2018).

In the last step, the job creation values of Turkey were transformed into the unit of "Jobs/MWh". For this process, the conversion operation was performed using the capacity factors of 22.8% for solar, 40% for wind, 92% for geothermal, 42% for hydroelectric, and 80% for biomass energy (EMRA, 2013; MENR, n.d.-b), under the assumption that the plant operates for 24 hours in 365 days in the year. The calculated values as given in Table 6.3 were used as parameter data in the proposed model.

Table 6.3 Job creation by source

ENERGY TYPE	**JC (People/MWh)**
SOLAR	0.003056
WIND	0.000542
GEOTHERMAL	0.000580
HYDROELECTRIC	0.000330
BIOMASS	0.000848

Environmental Aspect

The most prominent environmental aspect of the renewable energy field is the potential of reducing greenhouse gas emissions. It was decided to consider life cycle assessment (LCA) of greenhouse gas emissions as one of the parameters in the study since this process evaluates the environmental impacts of GHG emissions as a whole. Using this approach for the evaluation of renewable energy sources in terms of environmental aspect, the parameter data regarding the life cycle GHG emissions per electricity production (gCO_2eq/kWh) were obtained from Intergovernmental Panel on Climate Change (IPCC) reports (Bruckner et al., 2014; Schlömer et al., 2014). By taking an average of the obtained data and completing the necessary unit conversion process, the data were prepared for the next step.

As part of the environmental aspect, the impact of renewable energy technologies in terms of land requirements (m^2/MWh) was analyzed. As a result of the literature review, five sources including books, research articles, working papers, and a special report, were selected as appropriate for data collection related to land requirements (IRENA, 2017; Cucchiella and Koh, 2015; Cheng and Hammond, 2017; Evans et al., 2010; Trainor et al., 2016; GEA, 2012). These sources contain land requirements data in the desired format in units of m^2 per kWh. The data were organized by taking an average, and then unit conversion was applied to the data obtained to use the same unit for parameters. In the final step, the data were normalized by using the linear normalization method. Moreover, the final version of the values obtained by taking an average of the LCA GHG emissions and land requirements since these criteria equally important. The normalized environmental score of renewable energy types, as shown in Table 6.4, was used in the proposed model.

Table 6.4 Normalized environmental score by source

ENERGY TYPE	NES (NES/MWh)
SOLAR	0.236
WIND	0.583
GEOTHERMAL	0.654
HYDROELECTRIC	0.365
BIOMASS	0.030

Other Parameters

- ***$Mincap_{ij}$***

The minimum required energy capacity to be produced for each region per energy type was calculated as a result of the following formulation (Installed Capacity x Capacity Factor x 24 hours x 365 days). The relevant data including the licensed and unlicensed installed power capacities were obtained mostly from the final YEK list for 2020 and Electricity Market Development Reports prepared by Energy Market Regulatory Authority (EMRA, 2020a; EMRA, 2020b, Enerjiatlası, 2019). In the cases where there was not any installed capacity in the region related to the specific energy type, the minimum licensed capacity of this energy type in the country was considered for determining the minimum required energy that must be produced in that region concerning relevant energy type. Thus, the final version of the data used in the model is seen in Table 6.5.

Table 6.5 Minimum required energy by source and region

REGIONS	ENERGY TYPE (mincap) (MWh)				
	SOLAR	WIND	GEOTHERMAL	HYDRO	BIOMASS
1-DİCLE	17975.52	2803.20	22203.10	43907.57	18697.34
2-VANGÖLÜ	19872.94	2803.20	22203.10	11405.52	9902.30
3-ARAS	9786.67	2803.20	22203.10	6780.77	8409.60
4-ÇORUH	4473.91	2803.20	22203.10	1821.20	29706.91
5-FIRAT	15978.24	35040.00	22203.10	2722.61	9916.32
6-ÇAMLIBEL	17975.52	35040.00	22203.10	5905.12	9916.32
7-TOROSLAR	4473.91	31536.00	22203.10	3587.22	6993.98
8-MERAM	4473.91	24528.00	22203.10	6460.68	5606.40
9-BAŞKENT	4473.91	2803.20	22203.10	4856.54	7029.02
10-AKDENİZ	4473.91	210240.00	22203.10	6291.43	3504.00
11-GEDİZ	4473.91	10512.00	80592.00	846.22	16118.40
12-ULUDAĞ	4473.91	2803.20	60444.00	6990.48	14955.07
13-TRAKYA	4473.91	10512.00	22203.10	846.22	8409.60
14-ANATOLIAN S.	4473.91	2803.20	22203.10	846.22	24528.00
15-SAKARYA	4473.91	35040.00	22203.10	846.22	2312.64
16-OSMANGAZİ	4473.91	95308.80	22203.10	1802.81	10519.01
17-BOSPHORUS	4473.91	10512.00	22203.10	846.22	256541.86
18-KAYSERİ	4473.91	42048.00	22203.10	1140.55	10519.01
19-MENDERES	9986.40	39244.80	30681.37	11276.75	4450.08
20-GÖKSU	4473.91	87600.00	22203.10	3826.37	8409.60
21-YEŞİLIRMAK	4473.91	31536.00	22203.10	7479.81	9916.32

- ***$Maxcap_{ij}$***

The maximum energy capacity that can be produced for each region per energy type was calculated in a few steps. First of all, the total renewable energy potential of Turkey concerning solar, wind, geothermal, hydroelectric, and biomass energy obtained as 405,000,000 MWh, 168,192,000 MWh, 16,118,400 MWh, 160,000,000 MWh, 356,601,227 MWh, respectively (MENR, 2016; Yalçın, 2016; MENR, 2020). As a result of the literature review, Ervural's (2018) study, which represents renewable energy potentials of the regions based on energy types, was used as a suitable source for determining the renewable energy potential of regions in Turkey according to selected renewable energy alternatives. Using the total renewable energy potential of the country and the obtained potentials of renewable energy alternatives for each region, the modified potential values of each region by sources were calculated. Next, the necessary calculations were made using the obtained potential data, and the maximum amount of energy that can be generated from the corresponding energy type was provided in each region. The values of regions 14 and 17 in terms of geothermal and hydropower energy potential were revised to prevent inconsistencies between upper and lower boundaries. In the next step, making necessary calculations the final table was constructed that shows the maximum amount of energy that can be produced from the existing potential of renewable energy resources. The data included in Table 6.6 were used in the proposed model.

Table 6.6 Maximum amount of energy to be produced by source and region

REGIONS	ENERGY TYPE (maxcap) (MWh)				
	SOLAR	WIND	GEOTHERMAL	HYDRO	BIOMASS
1-DİCLE	22622713.82	1709482.43	359829.89	34524092.81	33069717.56
2-VANGÖLÜ	20757848.68	148569.60	935557.42	1641636.38	10899886.56
3-ARAS	18232993.42	607390.36	899574.48	8414053.02	17224512.10
4-ÇORUH	13223782.89	294563.75	179914.69	24108756.90	5214451.90
5-FIRAT	20235345.39	3655688.08	107948.81	15491479.59	4978960.53
6-ÇAMLIBEL	18767220.39	8373018.07	935557.42	4579501.72	13322083.57
7-TOROSLAR	21768217.11	12920589.76	251880.57	20767459.77	31555844.43
8-MERAM	21541470.39	4437167.67	1007523.29	4543433.98	44777003.13
9-BAŞKENT	17665460.53	1588131.90	1043506.23	3199365.00	21396073.62
10-AKDENİZ	22136713.82	3880592.32	35982.94	6410002.29	14196765.83
11-GEDİZ	21189226.97	25107820.37	2734705.86	411482.28	22270755.87
12-ULUDAĞ	18728851.97	45739599.70	2482824.78	1316027.73	24726594.51
13-TRAKYA	17131233.55	16355592.43	23988.46	71562.53	13927632.83
14-ANATOLIAN S	19050720.39	3056377.95	23003.40	4999.69	5180810.28
15-SAKARYA	15587970.39	835802.09	647693.40	1544788.43	10597111.93
16-OSMANGAZİ	19371523.03	2132474.79	1691199.63	2201431.38	20857807.62
17-BOSPHORUS	19050720.39	3056377.95	23003.40	4999.69	5180810.28
18-KAYSERİ	20289967.11	2759007.49	359829.38	1492005.73	7300232.67
19-MENDERES	21043213.82	11609929.10	1979063.13	3700061.70	20252258.36
20-GÖKSU	21091973.68	4784414.06	35982.94	8888796.34	7535724.04
21-YEŞİLIRMAK	15512832.24	15139410.12	359829.89	16684063.04	22136189.37

7. RESULTS AND DISCUSSION

In this study, a multi-objective decision-making problem is considered for 21 regions and 5 renewable energy types. In the beginning, the normalized technical score of each region for selected renewable energy types is found as shown in Table 6.1. The cost values associated with renewable energy types per MWh are constituted as given in Table 6.2. The data that indicates the information regarding job creation for considered renewable energy technologies per MWh are generated as introduced in Table 6.3. The normalized environmental scores of renewable energy types per MWh are formed as shown in Table 6.4.

There were four objective functions presented in the proposed multi-objective model as Z_1, Z_2, Z_3, and Z_4 to represent the technical score of regions by renewable energy types, the unit cost of renewable energy technologies, job creation by renewable energy types, and the environmental score of renewable energy resources.

As an initial step, the linear membership functions were used for preparing the objection functions included in the proposed model to find the positive and negative ideal solutions. Hence, the range of objective functions was determined by calculating the lower and upper bounds. The membership functions for the objective functions were established by maximizing the normalized technical score, job creation, and normalized environmental score, whereas minimizing the cost-related objective function as shown in the following Equations (20) – (23).

$$f_1(Z_1) = \begin{cases} 1, & Z_1 \geq 99641640 \\ \dfrac{Z_1 - 31386600}{68255040}, & 31386600 \leq Z_1 \leq 99641640 \\ 0, & Z_1 \leq 31595560 \end{cases} \tag{20}$$

$$f_2(Z_2) = \begin{cases} 1, & Z_2 \geq 5500000000 \\ \dfrac{8500000000 - Z_2}{3000000000}, & 5500000000 \leq Z_2 \leq 8500000000 \\ 0, & Z_2 \leq 8500000000 \end{cases} \tag{21}$$

$$f_3(Z_3) = \begin{cases} 1, & Z_3 \geq 305570.6 \\ \dfrac{Z_3 - 33048.88}{272521.72}, & 33048.88 \leq Z_3 \leq 305570.6 \\ 0, & Z_3 \leq 33048.88 \end{cases} \tag{22}$$

$$f_4(Z_4) = \begin{cases} 1, & Z_4 \geq 59434690 \\ \dfrac{Z_1 - 3008018}{56426672}, & 3008018 \leq Z_4 \leq 59434690 \\ 0, & Z_4 \leq 3008018 \end{cases} \tag{23}$$

The ranges indicating the best and worst values of each objective function were given in Table 7.1.

Table 7.1 The worst and the best values of each objective function

	Z_g^{worst}	Z_g^{best}
Z_1	31386600	99641640
Z_2	8500000000	5500000000
Z_3	33048.88	305570.6
Z_4	3008018	59434690

The next step of the two-phase fuzzy multi-objective goal programming method were described in the following equations.

$$Maximize\ \lambda \tag{24}$$

$s.t.$

$$\lambda \leq \frac{(Z_1 - 31386600)}{(99641640 - 31386600)} \tag{25}$$

$$\lambda \leq \frac{(8500000000 - Z_2)}{(8500000000 - 5500000000)} \tag{26}$$

$$\lambda \leq \frac{(Z_3 - 33048.88)}{(305570.6 - 33048.88)} \tag{27}$$

$$\lambda \leq \frac{(Z_4 - 3008018)}{(59434690 - 3008018)} \tag{28}$$

$$\lambda \in [0,1] \tag{29}$$

As a solver program, the LINGO computer software was used to run the proposed model. As a result, the general first phase satisfaction degree (λ) was obtained as 0.49862455. Moreover, the first phase satisfaction degrees $FPSD_1$, $FPSD_2$, $FPSD_3$, and $FPSD_4$ were obtained as 0.53233915, 0.49862467, 0.49862455, and 0.49862469, respectively. According to the applied method, the value of λ must be less than or equal to membership function values of the goals. In this case, its value was found equal to the value of the third objective function.

In the second phase solution procedure, the weighted sum approach was used in this study. It was assumed that all objectives have equal importance weights as 0.25. Accordingly, the mathematical model revised in accordance with the second phase as shown in Equations (30) - (35). Also, Phase II aims to improve the total weighted satisfaction degree as well as the values of the second phase satisfaction degrees of the objective functions. In this phase, the *FPSD* values obtained in the first phase were used as lower limits. The objective function and constraints of the proposed model for the second phase were presented as follows.

$$\text{Maximize } TWSD = \sum_{g=1}^{K} w_g * SPSD_g \tag{30}$$

s.t.

$$SPSD_g \geq FPSD_g \qquad \forall_g \tag{31}$$

$$SPSD_1 = (\sum_{i=1}^{m} \sum_{j=1}^{n} \left(x_{ij} * NTS_{ij}\right) - z_1^{worst})/(z_1^{best} - z_1^{worst}) \tag{32}$$

$$SPSD_2 = (z_2^{worst} - \sum_{i=1}^{m} \sum_{j=1}^{n} \left(x_{ij} * Cost_j\right))/(z_2^{worst} - z_2^{best}) \tag{33}$$

$$SPSD_3 = (\sum_{i=1}^{m} \sum_{j=1}^{n} \left(x_{ij} * JC_j\right) - z_3^{worst})/(z_3^{best} - z_3^{worst}) \tag{34}$$

$$SPSD_4 = (\sum_{i=1}^{m} \sum_{j=1}^{n} \left(x_{ij} * NES_j\right) - z_4^{worst})/(z_4^{best} - z_4^{worst}) \tag{35}$$

The general satisfaction degree of the first phase was not conserved in the second phase. As a result of the values obtained after running the model for the second phase, a considerable improvement was provided in the satisfaction degrees. The weighted satisfaction degree of the second phase (*TWSD*) was obtained as 0.60237105. The second phase satisfaction degrees $SPSD_1$, $SPSD_2$, $SPSD_3$, and $SPSD_4$ of the goals were calculated as 0.91361004, 0.49862467, 0.49862455, 0.49862494, respectively. From here, it can be concluded that the satisfaction degree of the first objective was improved significantly and the satisfaction degree of the fourth objective was improved slightly in the second phase, whereas the satisfaction degrees of the second and the third objectives were conserved. This means that the first objective function associated with the technical score was relatively more important since its coefficient in the equation was increased in the second stage. On the other hand, the reason why there was no change in the results obtained in the second phase is that the membership values of the objective functions obtained in the first phase were very close to each other. Results were summarized in Table 7.2.

In literature, there are many studies related to scoring of model parameters such as Deveci and Güler (2020) uses defuzzified score for renewable energy resources, and more specifically Chalvatzis et al. (2019) develop a multi-objective model based on assessment scores to optimize the environmental, technical, and social utility of the energy production diversity. Studies reveal that technical aspect has been an important part for problems in the renewable energy field especially in the process of mathematical model development.

Table 7.2 Summary of results

PHASE-I			
X(i,j)	**REGION**	**RESOURCE TYPE**	**AMOUNT (MWh)**
X(2,3)	VANGÖLÜ	GEOTHERMAL	935557.42
X(3,4)	ARAS	BIOMASS	8414053.00
X(4,1)	ÇORUH	SOLAR	13223783.00
X(4,4)	ÇORUH	BIOMASS	16308903.00
X(7,4)	TOROSLAR	BIOMASS	20767460.00
X(12,3)	ULUDAĞ	GEOTHERMAL	2482824.8.0
X(12,4)	ULUDAĞ	BIOMASS	1316027.70
X(13,1)	TRAKYA	SOLAR	17131234.00
X(14,1)	ANATOLIAN S.	SOLAR	19050720.00
X(19,3)	MENDERES	GEOTHERMAL	248840.97
X(21,1)	YEŞİLIRMAK	SOLAR	120596.27
PHASE-II			
X(i,j)	**REGION**	**RESOURCE TYPE**	**AMOUNT (MWh)**
X(1,1)	DİCLE	SOLAR	22622714.00
X(2,4)	VANGÖLÜ	BIOMASS	1641636.40
X(4,4)	ÇORUH	BIOMASS	24108757.00
X(9,4)	BAŞKENT	BIOMASS	2827157.90
X(10,1)	AKDENİZ	SOLAR	5811632.60
X(11,3)	GEDİZ	GEOTHERMAL	2734705.90
X(15,4)	SAKARYA	BIOMASS	1544788.40
X(19,3)	MENDERES	GEOTHERMAL	932571.35
X(20,1)	GÖKSU	SOLAR	21091974.00
X(21,4)	YEŞİLIRMAK	BIOMASS	16684063.00

According to results obtained in the first phase, the model was suggested to select three locations including Vangölü, Uludağ, and Menderes for geothermal energy production, four locations covering Çoruh, Trakya, Anatolian Side, Yeşilırmak for solar energy production, and four locations involving Aras, Çoruh, Toroslar, Uludağ for biomass energy production in order to meet the required energy demand.

On the other hand, the results obtained in the second phase were provided a better solution for the decision-making problem. As seen in Table 7.2, the number of regions offered by the proposed model for biomass energy production were increased to five as a result of Phase II, namely Vangölü, Çoruh, Başkent, Sakarya, Yeşilırmak. However, the total number of regions suggested for solar power production was decreased to three including Göksu, Dicle, and Akdeniz. These regions have the highest technical scores respectively in terms of solar energy. Furthermore, one of the differences observed from results arose from Yeşilırmak region. Regarding renewable energy planning in this region, it was recommended to produce solar energy in the first phase, but based on the results revealed in the second phase, producing bioenergy was presented as a more feasible option.

Likewise, the number of regions selected in this phase for geothermal energy production was decreased to two regions that are Gediz and Menderes. It is observed that the regions selected for solar energy production were completely different with respect to Phase I and Phase II. Moreover, Menderes region was included in both phases for geothermal energy production. Instead of Vangölü and Uludağ regions selected in the first phase, the results yielded in the second phase were recommended to choose Gediz region for geothermal energy production. Since the effect of the technical score on the selection of the regions increases in the second phase and the Gediz region has the highest technical score in terms of geothermal energy, it is more reasonable to choose this region for geothermal energy production.

In brief, it has been observed that in both phases, half of the total energy demand can be met by solar energy, while 47% of the total from biomass energy, and 4% of the total from geothermal energy. From a regional perspective, Çoruh, Toroslar, Anatolian Side, Trakya, and Aras regions were listed as the top five regions in terms of contribution to the total energy production in the first phase, producing 30%, 21%, 19%, 17%, and 8% of the total energy demand, respectively. In the second phase, this ranking has changed almost completely, except Çoruh region. The top five regions with a large share in meeting energy demand were ranked as Çoruh, Dicle, Göksu, Yeşilırmak, Akdeniz having the total share of 24%, 23%, 21%, 17%, and 6%, respectively.

In summary, this study has proposed a model regarding the multi-objective decision-making problem that assesses the amount of energy to be produced from renewable energy sources on a multiregional basis. In the context of the stated objectives and defined constraints, the results obtained from the proposed model have been evaluated in detail. Accordingly, it is observed that each region and renewable energy type selected by the model for energy production has been determined based on the feasibility of that location concerning relevant renewable energy resources.

8. CONCLUSION

The real-world problems towards planning activities are required to consider multiple conflicting objectives simultaneously in particular cases. In recent years, renewable energy planning has become a very important issue due to the impact of economic, social, and environmental concerns. Since the planning process involves taking many important decisions considering several conflicting goals, it is found as an appropriate solution method to develop a comprehensive evaluation model that will examine multiple objectives together.

In this study, a multi-objective decision-making problem is investigated and a mathematical model is developed as an effective solution method for renewable energy planning. The renewable energy field has been examined from technical, economic, social, and environmental aspects in the evaluation and goal determination process of the study. Although there are various different methods in the literature to solve multiple objective decision-making problems, a two-phase fuzzy goal programming methodology is preferred in this study as a solution method for the model application. The developed model is solved by using LINGO software.

According to results obtained by running the model, renewable energy sources including solar, biomass, and geothermal energy have a significant role in energy production. It is provided that solar energy will be accounted for almost half of the total renewable energy production, followed by biomass, and geothermal energy. From a multiregional perspective, the results obtained in the second phase of the two-phase method reveals that regions selected for solar energy production, namely, Göksu, Dicle, and Akdeniz have the highest technical scores in terms of solar energy, respectively. Similarly, the regions selected for geothermal energy production, such as Gediz and Menderes, are ranked first and second regions having the highest technical scores in terms of geothermal energy, respectively.

In general, the renewable energy industry is reviewed from different approaches by applying various methods in the literature. Besides these, this study particularly focused on evaluating multiple objectives regarding energy planning from several aspects with developing a mathematical model to provide consistent results. In brief, the model developed in this study contains similarities with other models in literature in some aspects, however, the final version of the model is different from others by way of handling. Accordingly, the objective functions included in the proposed model are distinguished from others with the originality of their usage in the process. Moreover, the case application part has reinforced the originality of the study since it differs from other studies in terms of implementation by taking into account 21 electricity distribution regions of Turkey, five types of renewable energy sources, and using reliable data obtained from various sources. Another special characteristic of the study is the solution methodology used for the decision-making model. As an effective approach, a two-phase fuzzy goal programming methodology is employed in this study to obtain consistent results.

For future study, the proposed model can be improved by assigning different weights to the determined objectives in the model to obtain comparisons of the goals under various conditions and reveal the major differences of the model coefficients. Furthermore, the scope of this study can be extended by evaluating more than five renewable energy alternatives and various regions in detail to provide more comprehensive perspectives into the field. Moreover, the proposed model can be modified by adding more objectives or parameters regarding different aspects to cover more subjects simultaneously in a single model. In other words, the mathematical model can be customized based on specific locations. In addition, the global and national energy needs, total annual demand, and strategic targets can be examined by creating different scenarios related to renewable energy planning in the short and the long term. Afterward crucial information and valuable insights for decision-makers, investors, policymakers, and academicians can be provided by running the model under different scenarios. Also, a powerful solution can be provided by combining different solution methods and techniques that can work in harmony with each other, ensuring the integration of the model with other models presented in genuine studies.

REFERENCES

Afgan, N. H., & Carvalho, M. G. (2002). Multi-criteria assessment of new and renewable energy power plants. *Energy, 27*(8), 739-755.

Akkas, O. P., Erten, M. Y., Cam, E., & Inanc, N. (2017). Optimal site selection for a solar power plant in the Central Anatolian Region of Turkey. *International Journal of Photoenergy*, 1-14.

Akkuş, İ., & Alan, H. (2016). Türkiye'nin jeotermal kaynakları, projeksiyonlar, sorunlar ve öneriler raporu. *TMMOB Jeoloji Mühendisleri Odası, 89s*.

Aksoy, A. (2019). Integrated model for renewable energy planning in Turkey. *International journal of green energy, 16*(1), 34–48.

Alarcon-Rodriguez, A., Ault, G., & Galloway, S. (2010). Multi-objective planning of distributed energy resources: A review of the state-of-the-art. *Renewable and Sustainable Energy Reviews, 14*(5), 1353–1366.

Albadvi, A., Chaharsooghi, S. K., & Esfahanipour, A. (2007). Decision making in stock trading: An application of PROMETHEE. *European Journal of Operational Research, 177*(2), 673–683.

American Gas Association (AGA). *What is natural gas?* Retrieved from https://www.aga.org/natural-gas/energy-education/

Aouni, B., Colapinto, C., La Torre, D., Liuzzi, D., & Marsiglio, S. (2015). On dynamic multiple criteria decision making models: A goal programming approach. In *Multiple criteria decision making in finance, insurance and investment* (s. 31–48). Springer.

API Gravity. (n.d.). Retrieved from http://www.petroleum.co.uk/api

Arıkan, F., & Güngör, Z. (2007). A two-phase approach for multi-objective programming problems with fuzzy coefficients. *Information sciences, 177*(23), 5191–5202.

Asif, M., & Muneer, T. (2007). Energy supply, its demand and security issues for developed and emerging economies. *Renewable and sustainable energy reviews, 11*(7), 1388–1413.

Atici, K. B., Simsek, A. B., Ulucan, A., & Tosun, M. U. (2015). A GIS-based Multiple Criteria Decision Analysis approach for wind power plant site selection. *Utilities Policy, 37*, 86-96.

Atlı, G. (2018). *Energy-financial evaluation of a coal fired power plant and an application for Zonguldak province* (Master's thesis, Istanbul Technical University).

Ayan, T., Pabuçcu, H. (2013). Evaluation of the renewable energy investment project with analytic hierarchy process method. *Suleyman Demirel University The Journal of Faculty of Economics and Administrative Sciences, 18*(3), 89-110.

Aydin, N. Y., Kentel, E., & Duzgun, S. (2010). GIS-based environmental assessment of wind energy systems for spatial planning: A case study from Western Turkey. *Renewable and Sustainable Energy Reviews*, *14*(1), 364-373.

Balasubramaniam, P. (2011). Control, Computation and Information Systems. In *First International Conference on Logic, Information, Control and Computation, ICLICC 2011, Gandhigram, India, February 25-27, 2011, Proceedings* (Vol. 140). Springer Science & Business Media.

Barlev, D., Vidu, R., & Stroeve, P. (2011). Innovation in concentrated solar power. *Solar Energy Materials and Solar Cells, 95*(10), 2703–2725.

Baskar, C., Baskar, S., & Dhillon, R. S. (2012). *Biomass conversion: The interface of biotechnology, chemistry and materials science.* Springer Science & Business Media.

Baysal, M. E., & Çetin, N. C. (2018). Priority ranking for energy resources in Turkey and investment planning for renewable energy resources. *Complex & Intelligent Systems, 4*(4), 261–269.

Beccali, M., Cellura, M., & Mistretta, M. (2003). Decision-making in energy planning. Application of the Electre method at regional level for the diffusion of renewable energy technology. *Renewable Energy, 28*(13), 2063–2087.

Benli, H. (2013). Potential of renewable energy in electrical energy production and sustainable energy development of Turkey: Performance and policies. *Renewable Energy, 50*, 33–46.

Brans, J. P., & Vincke, P. (1985). Note—A Preference Ranking Organisation Method: (The PROMETHEE Method for Multiple Criteria Decision-Making). *Management Science, 31*(6), 647–656.

British Petroleum Company (BP). (2019). *BP statistical review of world energy.* London: British Petroleum Co.

British Petroleum Company (BP). (2020). *BP statistical review of world energy.* London: British Petroleum Co.

Bruckner, T., Bashmakov, I. A., Mulugetta, Y., Chum, H., de la Vega Navarro, A., Edmonds, J. … Zhang, X. (2014). Energy Systems. In: *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*

Büyüközkan, G., Karabulut, Y., & Mukul, E. (2018). A novel renewable energy selection model for United Nations' sustainable development goals. *Energy, 165*, 290–302.

Cai, Y. P., Huang, G. H., Tan, Q., & Yang, Z. F. (2009). Planning of community-scale renewable energy management systems in a mixed stochastic and fuzzy environment. *Renewable Energy, 34*(7), 1833-1847.

Cavdur, F., Sebatli, A., Kose-Kucuk, M., & Rodoplu, C. (2019). A two-phase binary-goal programming-based approach for optimal project-team formation. *Journal of the Operational Research Society, 70*(4), 689–706.

Cebeci, S. (2017). Türkiye'de güneş enerjisinden elektrik üretim potansiyelinin değerlendirilmesi. *Uzmanlık Tezi, İktisadi Sektörler ve Koordinasyon Genel Müdürlüğü, Kalkınma Bakanlığı, Yayın, 2977*.

Chalvatzis, K. J., Malekpoor, H., Mishra, N., Lettice, F., & Choudhary, S. (2019). Sustainable resource allocation for power generation: The role of big data in enabling interindustry architectural innovation. *Technological Forecasting and Social Change, 144*, 381–393.

Chang, C. T. (2015). Multi-choice goal programming model for the optimal location of renewable energy facilities. *Renewable and Sustainable Energy Reviews, 41*, 379–389.

Chatzimouratidis, A. I., & Pilavachi, P. A. (2009). Technological, economic and sustainability evaluation of power plants using the Analytic Hierarchy Process. *Energy Policy, 37*(3), 778-787.

Chen, K., Ren, Z., Mu, S., Sun, T. Q., & Mu, R. (2020). Integrating the Delphi survey into scenario planning for China's renewable energy development strategy towards 2030. *Technological Forecasting and Social Change, 158*, 120157.

Cheng, V. K., & Hammond, G. P. (2017). Life-cycle energy densities and land-take requirements of various power generators: A UK perspective. *Journal of the Energy Institute, 90*(2), 201–213.

Chou, S.-Y., Chang, Y.-H., & Shen, C.-Y. (2008). A fuzzy simple additive weighting system under group decision-making for facility location selection with objective/subjective attributes. *European Journal of Operational Research, 189*(1), 132–145.

Choudhary, D., & Shankar, R. (2012). An STEEP-fuzzy AHP-TOPSIS framework for evaluation and selection of thermal power plant location: A case study from India. *Energy, 42*(1), 510-521

Cong, R.-G. (2013). An optimization model for renewable energy generation and its application in China: a perspective of maximum utilization. *Renewable and Sustainable Energy Reviews, 17*, 94–103.

Connolly, D., Lund, H., & Mathiesen, B. V. (2016). Smart Energy Europe: The technical and economic impact of one potential 100% renewable energy scenario for the European Union. *Renewable and Sustainable Energy Reviews, 60*, 1634–1653.

Cucchiella, F., & Koh, L. (2015). *Sustainable future energy technology and supply chains: A Multi-perspective analysis.* Springer.

Cui, Y., Geng, Z., Zhu, Q., & Han, Y. (2017). Multi-objective optimization methods and application in energy saving. *Energy, 125*, 681–704.

Dai, K., Bergot, A., Liang, C., Xiang, W.-N., & Huang, Z. (2015). Environmental issues associated with wind energy–A review. *Renewable Energy, 75*, 911–921.

Deloitte. (2014). *Golden age of biomass.* Retrieved from https://www2.deloitte.com/tr/en/pages/energy-and-resources/articles/golden-age-of-biomass-article.html

de Simón-Martín, M., de la Puente-Gil, Á., Borge-Diez, D., Ciria-Garcés, T., & González-Martínez, A. (2019). Wind energy planning for a sustainable transition to a decarbonized generation scenario based on the opportunity cost of the wind energy: Spanish Iberian Peninsula as case study. *Energy Procedia, 157*, 1144–1163.

Deveci, K., & Güler, Ö. (2020). A CMOPSO based multi-objective optimization of renewable energy planning: Case of Turkey. *Renewable Energy, 155*, 578–590.

Deveci, K., Cin, R., & Kağızman, A. (2020). A modified interval valued intuitionistic fuzzy CODAS method and its application to multi-criteria selection among renewable energy alternatives in Turkey. *Applied Soft Computing, 96*, 106660.

Dey, B., Bairagi, B., Sarkar, B., & Sanyal, S. K. (2017). Group heterogeneity in multi member decision making model with an application to warehouse location selection in a supply chain. *Computers & Industrial Engineering, 105*, 101–122.

Dickson, M. H., & Fanelli, M. (2004). *Geothermal energy.* Wiley.

Dinçer, H., & Yüksel, S. (2019). Multidimensional evaluation of global investments on the renewable energy with the integrated fuzzy decision-making model under the hesitancy. *International Journal of Energy Research, 43*(5), 1775–1784.

Dinçer, İ., Alma, M. H., Arcaklıoğlu, E., Bayazıtoğlu, Y., Hepbaşlı, A., Kakaç, S., . . . others. (2018). Tüba-Güneş Enerjisi Teknolojileri Raporu. *Tüba-Güneş Enerjisi Teknolojileri Raporu*. Ankara.

Dinçer, İ., Alma, M. H., Arcaklıoğlu, E., Bayazıtoğlu, Y., Hepbaşlı, A., Kakaç, S., Kaygusuz, K., Midilli, A., Sarı, A., Sarıçiftçi, N., S., Şahin, B., Turan, R. (2019). *Tüba-Rüzgar Enerjisi Teknolojileri Raporu*. Ankara.

Dowling, A. W., Zheng, T., & Zavala, V. M. (2017). Economic assessment of concentrated solar power technologies: A review. *Renewable and Sustainable Energy Reviews, 72*, 1019–1032.

Dufo-López, R., Bernal-Agustín, J. L., Yusta-Loyo, J. M., Domínguez-Navarro, J. A., Ramírez-Rosado, I. J., Lujano, J., & Aso, I. (2011). Multi-objective optimization minimizing cost and life cycle emissions of stand-alone PV–wind–diesel systems with batteries storage. *Applied Energy, 88*(11), 4033-4041.

Dursun, M., Karsak, E. E., & Sener, Z. (2013). A Fuzzy Multiple Objective Decision Making Methodology for Electricity Generation Planning. In *Proceedings of the International Conference on Information and Knowledge Engineering (IKE),* 1. The Steering Committee of The World Congress in Computer Science, Computer Engineering and Applied Computing (WorldComp).

Electricity Generation Company (EÜAŞ). (2016). *Elektrik üretim sektör raporu.* Retrieved from https://www.euas.gov.tr/tr-TR/sektor-raporu.

Electricity Generation Company (EÜAŞ). (2019a). *Elektrik üretimi ve ticareti sektör raporu.* Retrieved from https://www.euas.gov.tr/tr-TR/sektor-raporu.

Electricity Generation Company (EÜAŞ). (2019b). *Annual report 2019.* Retrieved from https://www.euas.gov.tr/tr-TR/yillik-raporlar

Emeç, Ş., & Akkaya, G. (2018). Stochastic AHP and fuzzy VIKOR approach for warehouse location selection problem. *Journal of Enterprise Information Management, 31*(6), 950-962.

Energy Efficiency and Renewable Energy (EERE). (n.d.) *Types of hydropower plants.* Retrieved October 15, 2020, from https://www.energy.gov/eere/water/types-hydropower-plants

Enerji Atlası. (2019). *Hidroelectricity power plants.* Retrieved from https://www.enerjiatlasi.com/hidroelektrik/

Enerji Portalı. (n.d.). *What is oil? What is crude oil?*. Retrieved from https://www.enerjiportali.com/petrol-nedir-ham-petrol-nedir/

Erdin, C., & Ozkaya, G. (2019). Turkey's 2023 energy strategies and investment opportunities for renewable energy sources: site selection based on electre. *Sustainability, 11*(7), 2136.

Erol, S., & Özcan, E. C. (2013). Türkiye'de elektrik üretim planlaması için çok amaçlı bir karışık tam sayılı doğrusal programlama modeli. *Selcuk University Journal of Engineering, Science and Technology, 1*(1), 41-54.

Ertuğrul, İ., & Karakaşoğlu, N. (2008). Comparison of fuzzy AHP and fuzzy TOPSIS methods for facility location selection. *The International Journal of Advanced Manufacturing Technology, 39*(7-8), 783–795.

Ervural, B. C. (2018). *An integrated multi-objective decision model for renewable energy planning*. (Doctoral dissertation). Istanbul Technical University.

Ervural, B. C., Ervural, B., & Evren, R. (2016). Optimization Models in Energy: A Literature Review. *Ege Academic Review, 16,* 51-70.

Ervural, B. C., Evren, R., & Delen, D. (2018a). A multi-objective decision-making approach for sustainable energy investment planning. *Renewable Energy, 126,* 387–402.

Ervural, B. C., Zaim, S., Demirel, O. F., Aydin, Z., & Delen, D. (2018b). An ANP and fuzzy TOPSIS-based SWOT analysis for Turkey's energy planning. *Renewable and Sustainable Energy Reviews, 82*, 1538-1550.

European Association for Coal and Lignite (EURACOAL). (2019). *Annual report*. Retrieved from https://euracoal.eu/library/annual-reports/

European Commission. (2020). *2030 climate & energy framework.* Retrieved from *https://ec.europa.eu/clima/policies/strategies/2030_en*

Evans, A., Strezov, V., & Evans, T. (2010). *Comparing the sustainability parameters of renewable, nuclear and fossil fuel electricity generation technologies*. WEC 2010, Montreal, Quebec, Canada.

Farahani, R. Z., SteadieSeifi, M., & Asgari, N. (2010). Multiple criteria facility location problems: A survey. *Applied mathematical modelling, 34*(7), 1689–1709.

Fazlollahi, S., Mandel, P., Becker, G., & Maréchal, F. (2012). Methods for multi-objective investment and operating optimization of complex energy systems. *Energy, 45*(1), 12–22.

Ferreira, J. H., & Camacho, J. R. (2017). Prospects of small hydropower technology. *Renewable Hydropower Technologies*. IntechOpen.

Fleten, S. E., Maribu, K. M., & Wangensteen, I. (2007). Optimal investment strategies in decentralized renewable power generation under uncertainty. *Energy*, *32*(5), 803-815.

Franco, C., Bojesen, M., Hougaard, J. L., & Nielsen, K. (2015). A fuzzy approach to a multiple criteria and Geographical Information System for decision support on suitable locations for biogas plants. *Applied Energy, 140*, 304–315.

Garg, H., & others. (2019). Algorithms for possibility linguistic single-valued neutrosophic decision-making based on COPRAS and aggregation operators with new information measures. *Measurement, 138*, 278–290.

Garg, R., Kumar, R., & Garg, S. (2018). MADM-based parametric selection and ranking of E-learning websites using fuzzy COPRAS. *IEEE Transactions on Education*, *62*(1), 11–18.

General Directorate of Mineral Research and Exploration (MTA). (n.d.). *Distribution map of geothermal resources in Turkey*. Retrieved from https://www.mta.gov.tr/v3.0/hizmetler/jeotermal-harita

General Directorate of State Hydraulic Works (DSİ). (2019). *Annual Report*. Retrieved from https://www.dsi.gov.tr/Sayfa/Detay/759

Ghosh, T. K., & Prelas, M. A. (2011). *Energy resources and systems: volume 2: renewable resources*. Springer Science & Business Media.

Global Solar Atlas (GSA). (2020) Retrieved from https://globalsolaratlas.info

Global Wind Atlas (GWA). (2020) Retrieved from https://globalwindatlas.info/

Gonzalez, A., Riba, J. R., Esteban, B., & Rius, A. (2018). Environmental and cost optimal design of a biomass–Wind–PV electricity generation system. *Renewable Energy, 126*, 420-430.

Grady, S. A., Hussaini, M. Y., & Abdullah, M. M. (2005). Placement of wind turbines using genetic algorithms. *Renewable Energy, 30*(2), 259-270.

Guu, S. M., Wu, Y. K., & Lee, E. S. (2011). Multi-objective optimization with a max-t-norm fuzzy relational equation constraint. *Computers & Mathematics with Applications, 61*(6), 1559–1566.

Guua, S. M., & Wu, Y. K. (1999). Two-phase approach for solving the fuzzy linear programming problems. *Fuzzy Sets and Systems, 107*(2), 191–195.

Güney, T. (2019). Renewable energy, non-renewable energy and sustainable development. *International Journal of Sustainable Development & World Ecology, 26*(5), 389–397.

Hanine, M., Boutkhoum, O., El Maknissi, A., Tikniouine, A., & Agouti, T. (2016). Decision making under uncertainty using PEES–fuzzy AHP–fuzzy TOPSIS methodology for landfill location selection. *Environment Systems and Decisions, 36*(4), 351–367.

Haralambopoulos, D. A., & Polatidis, H. (2003). Renewable energy projects: structuring a multi-criteria group decision-making framework. *Renewable Energy, 28*(6), 961-973.

He, P., Chen, Z., & Xu, X. (2011). On flexibility investment in manufacturing system: A multi-objective decision making method. *Expert Systems with Applications, 38*(9), 11813–11819.

Ho, Y. F., Chang, C. C., Wei, C. C., & Wang, H. L. (2014). Multi-objective programming model for energy conservation and renewable energy structure of a low carbon campus. *Energy and Buildings, 80*, 461–468.

Hocine, A., Guellil, M. S., Dogan, E., Ghouali, S., & Kouaissah, N. (2020). A fuzzy goal programming with interval target model and its application to the decision problem of renewable energy planning. *Environmental and Ecological Statistics, 27*(3), 527–547.

Hocine, A., Kouaissah, N., Bettahar, S., & Benbouziane, M. (2018). Optimizing renewable energy portfolios under uncertainty: A multi-segment fuzzy goal programming approach. *Renewable energy, 129*, 540–552.

Holma, A., Leskinen, P., Myllyviita, T., Manninen, K., Sokka, L., Sinkko, T., & Pasanen, K. (2018). Environmental impacts and risks of the national renewable energy targets–A review and a qualitative case study from Finland. *Renewable and Sustainable Energy Reviews, 82*, 1433–1441.

Huttrer, G. W. (2020). Geothermal power generation in the world 2015-2020 update report. In *Proceedings World Geothermal Congress*, *2020*, p. 17.

International Energy Agency (IEA). (2019a). *World energy outlook 2019.* IEA, Paris. https://www.iea.org/reports/world-energy-outlook-2019

International Energy Agency (IEA). (2019b). *Solar PV.* IEA, Paris. https://www.iea.org/reports/solar-pv

International Energy Agency (IEA). (2020a). *Key World Energy Statistics 2020.* IEA, Paris. https://www.iea.org/reports/key-world-energy-statistics-2020

International Energy Agency (IEA). (2020b). *Renewables 2020.* IEA, Paris. https://www.iea.org/reports/renewables-2020

International Energy Agency (IEA). (2020c). *World Energy Balances: Overview.* IEA, Paris. https://www.iea.org/reports/world-energy-balances-overview

International Energy Agency (IEA). (2020d). *Renewables Information Overview.* IEA, Paris.

International Energy Agency (IEA). (2020e). *Renewable energy market update.* IEA, Paris. https://www.iea.org/reports/renewable-energy-market-update

International Energy Agency (IEA). (2020f). *Unit converter and glossary.* IEA, Paris. https://www.iea.org/reports/unit-converter-and-glossary

International Energy Agency (IEA). (2020g). *Electricity information: overview.* IEA, Paris. https://www.iea.org/reports/electricity-information-overview

International Hydropower Association (IHA). (2017). *Country profile: Norway.* Retrieved from https://www.hydropower.org/country-profiles/norway

International Renewable Energy Agency (IRENA). (2012). *Renewable Energy Cost Analysis - Solar Photovoltaics.* https://irena.org/publications/2012/Jun/Renewable-Energy-Cost-Analysis---Solar-Photovoltaics

International Renewable Energy Agency (IRENA). (2017). *Energy and land use.* Global Land Outlook.

International Renewable Energy Agency (IRENA). (2018). *Renewable Power Generation Costs in 2018.* https://irena.org/publications/2019/May/Renewable-power-generation-costs-in-2018

International Renewable Energy Agency (IRENA). (2019a).*Geothermal energy.* Retrieved December 12, 2020, from https://www.irena.org/en/geothermal.

International Renewable Energy Agency (IRENA). (2019b). *Renewable power generation costs in 2019.* Retrieved from https://www.irena.org/publications /2020/Jun/Renewable-Power-Costs-in-2019

International Renewable Energy Agency (IRENA). (2019c). *Renewable capacity statistics 2019.* Retrieved from https://www.irena.org/publications/2019/Mar/Renewable-Capacity-Statistics-2019

International Renewable Energy Agency (IRENA). (2019d). *Renewable energy and jobs: annnual review 2019.* Retrieved from https://www.irena.org/publications/2019/Jun/Renewable-Energy-and-Jobs-Annual-Review-2019

International Renewable Energy Agency (IRENA). (2020a).*Recycle: bioenergy*. Circular Carbon Economy Report.

International Renewable Energy Agency (IRENA). (2020b). *Renewable capacity statistics 2020.* https://www.irena.org/publications/2020/Mar/Renewable-Capacity-Statistics-2020

Ishizaka, A., Nemery, P., & Lidouh, K. (2013). Location selection for the construction of a casino in the Greater London region: a triple multi-criteria approach. *Tourism Management*, *34*, 211–220.

Ismail, B. I. (2017). Introductory Chapter-Aspects of Renewable Hydroelectric Power Generation. *Renewable Hydropower Technologies.* IntechOpen.

Jayaraman, R., Liuzzi, D., Colapinto, C., & Malik, T. (2017). A fuzzy goal programming model to analyze energy, environmental and sustainability goals of the United Arab Emirates. *Annals of Operations Research*, *251*(1-2), 255–270.

Johansson, T. B., Patwardhan, A. P., Nakićenović, N., Gomez-Echeverri, L. (2012). *Global energy assessment: toward a sustainable future*. Cambridge University Press.

Kahraman, C., Kaya, İ., & Cebi, S. (2009). A comparative analysis for multiattribute selection among renewable energy alternatives using fuzzy axiomatic design and fuzzy analytic hierarchy process. *Energy*, *34*(10), 1603-1616.

Kaplan, Y. A. (2015). Overview of wind energy in the world and assessment of current wind energy policies in Turkey. *Renewable and Sustainable Energy Reviews*, *43*, 562–568.

Karaca, C., & Ulutaş, A. (2018). The selection of appropriate renewable energy source for Turkey by using Entropy and Waspas methods. *Ege Academic Review*, *18*(3), 483–494.

Karaca, C., Ulutaş, A., & Eşgünoğlu, M. (2017). Türkiye'de optimal yenilenebilir enerji kaynağının COPRAS yöntemiyle tespiti ve yenilenebilir enerji yatırımlarının istihdam artırıcı etkisi. *Maliye Dergisi*, *172*, 111–132.

Karagöl, E. T., & Tür, M. R. (2017). *Türkiye'de elektrik enerjisi*. Foundation for Political, Economic and Social Research (SETA).

Karakostas, S., & Economou, D. (2014). Enhanced multi-objective optimization algorithm for renewable energy sources: optimal spatial development of wind farms. *International Journal of Geographical Information Science, 28*(1), 83–103.

Kaya, İ., Çolak, M., & Terzi, F. (2018). Use of MCDM techniques for energy policy and decision-making problems: A review. *International Journal of Energy Research*, *42*(7), 2344–2372.

Kaya, T., & Kahraman, C. (2010). Multicriteria renewable energy planning using an integrated fuzzy VIKOR & AHP methodology: The case of Istanbul. *Energy, 35*(6), 2517-2527.

Kaya, T., & Kahraman, C. (2011). Multicriteria decision making in energy planning using a modified fuzzy TOPSIS methodology. *Expert Systems with Applications, 38*(6), 6577-6585.

Kilic, H. S., & Yalcin, A. S. (2020). Modified two-phase fuzzy goal programming integrated with IF-TOPSIS for green supplier selection. *Applied Soft Computing, 93*, 106371.

Kim, Y., & Chung, E.-S. (2013). Assessing climate change vulnerability with group multi-criteria decision making approaches. *Climatic change, 121*(2), 301–315.

Knopf, B., Nahmmacher, P., & Schmid, E. (2015). The European renewable energy target for 2030–An impact assessment of the electricity sector. *Energy Policy, 85*, 50–60.

Kok, B., & Benli, H. (2017). Energy diversity and nuclear energy for sustainable development in Turkey. *Renewable Energy, 111*, 870–877.

Korkmaz Başel, E. D. (2010). *An investigation of geothermal energy potential of Turkey*. (Doctoral dissertation). Istanbul Technical University.

Korkmaz, E. D., Serpen, U., & Satman, A. (2014). Geothermal boom in Turkey: growth in identified capacities and potentials. *Renewable Energy, 68*, 314-325.

KPMG. (2020). *Energy: Sectoral Overview 2020*. Retrieved from https://home.kpmg/tr/tr/home/gorusler/2020/03/sektorel-bakis-2020-enerji.html

Kumar, K., & Kumanan, S. (2012). Decision Making in Location Selection: An Integrated Approach with Clustering and TOPSIS. *IUP Journal of Operations Management*, *11*(1), 7-20.

Lee, H. C., & Chang, C. T. (2018). Comparative analysis of MCDM methods for ranking renewable energy sources in Taiwan. *Renewable and Sustainable Energy Reviews, 92*, 883–896.

Liang, T.-F. (2009). Fuzzy multi-objective project management decisions using two-phase fuzzy goal programming approach. *Computers & Industrial Engineering, 57*(4), 1407–1416.

Liu, Y., He, L., & Shen, J. (2017). Optimization-based provincial hybrid renewable and non-renewable energy planning–A case study of Shanxi, China. *Energy, 128*, 839–856.

Løken, E., Botterud, A., & Holen, A. T. (2009). Use of the equivalent attribute technique in multi-criteria planning of local energy systems. *European Journal of Operational Research*, *197*(3), 1075-1083.

Macharis, C., Springael, J., De Brucker, K., & Verbeke, A. (2004). PROMETHEE and AHP: The design of operational synergies in multicriteria analysis.: Strengthening PROMETHEE with ideas of AHP. *European journal of operational research, 153*(2), 307–317.

Mahdavi, I., Javadi, B., Sahebjamnia, N., & Mahdavi-Amiri, N. (2009). A two-phase linear programming methodology for fuzzy multi-objective mixed-model assembly line problem. *The International Journal of Advanced Manufacturing Technology, 44*(9), 1010–1023.

Malhotra, R. (Ed.). (2013). *Fossil Energy*. Springer New York.

Marinković, S., Nikolić, I., & Rakićević, J. (2018). Selecting location for a new business unit in ICT industry. *Zbornik radova Ekonomskog fakulteta u Rijeci: časopis za ekonomsku teoriju i praksu, 36*(2), 801–825.

Mathew, S. (2006). *Wind energy: fundamentals, resource analysis and economics.* Springer.

Maxim, A. (2014). Sustainability assessment of electricity generation technologies using weighted multi-criteria decision analysis. *Energy Policy, 65*, 284–297.

McEvoy, A., Markvart, T., Castañer, L. (Eds.). (2012). *Practical handbook of photovoltaics: fundamentals and applications*. Elsevier.

Melikoglu, M. (2017). Vision 2023: Status quo and future of biomass and coal for sustainable energy generation in Turkey. *Renewable and Sustainable Energy Reviews, 74*, 800–808.

Mellit, A. (2007). Sizing of photovoltaic systems: a review. *Revue des Energies Renouvelables*, *10*(4), 463-472.

Michaelides, E. E. (2012). *Alternative energy sources.* Springer Science & Business Media.

Middle Black Sea Development Agency (OKA). *TR83 Region Renewable Energy Report.* Retrieved from https://www.oka.org.tr/yayinlar-ve-belgeler/yayinlar-ve-raporlar/tr83-bolgesi-yenilenebilir-enerji-raporu

Montoya, F. G., Manzano-Agugliaro, F., López-Márquez, S., Hernández-Escobedo, Q., & Gil, C. (2014). Wind turbine selection for wind farm layout using multi-objective evolutionary algorithms. *Expert Systems with Applications, 41*(15), 6585–6595.

Mourmouris, J. C., & Potolias, C. (2013). A multi-criteria methodology for energy planning and developing renewable energy sources at a regional level: A case study Thassos, Greece. *Energy Policy, 52*, 522–530.

Mousa, O. B., Taylor, R. A., & Shirazi, A. (2019). Multi-objective optimization of solar photovoltaic and solar thermal collectors for industrial rooftop applications. *Energy Conversion and Management, 195*, 392–408.

Mousavi, S. M., Tavakkoli-Moghaddam, R., Heydar, M., & Ebrahimnejad, S. (2013). Multi-criteria decision making for plant location selection: an integrated Delphi–AHP–PROMETHEE methodology. *Arabian Journal for Science and Engineering, 38*(5), 1255–1268.

Mousavi-Nasab, S. H., & Sotoudeh-Anvari, A. (2017). A comprehensive MCDM-based approach using TOPSIS, COPRAS and DEA as an auxiliary tool for material selection problems. *Materials & Design, 121*, 237–253.

NREL. (2020). Best Research-Cell Efficiency Chart. Retrieved January 02, 2021, from https://www.nrel.gov/pv/cell-efficiency.html

Official Gazette. (2005). *The Law on utilization of renewable energy sources for the purpose of generating electrical energy*. Law No. 5346.

Organization of the Petroleum Exporting Countries (OPEC). (2018). *OPEC Share of World Crude Oil Reserves.* Retrieved from https://www.opec.org/opec_web/en/data_graphs/330.htm

Ozdemir, S., & Sahin, G. (2018). Multi-criteria decision-making in the location selection for a solar PV power plant using AHP. *Measurement, 129*, 218–226.

Ozturk, M., & Yuksel, Y. E. (2016). Energy structure of Turkey for sustainable development. *Renewable and Sustainable Energy Reviews, 53*, 1259–1272.

Özcan, E. C., & Erol, S. (2013). A multi-objective mixed integer linear programming model for electricity generation planning in Turkey. *Selcuk University Journal of Engineering, Science and Technology, 1*(1), 41-54.

Özcan, E., & Erol, S. (2014). A multi-objective mixed integer linear programming model for energy resource allocation problem: The case of Turkey. *Gazi University Journal of Science, 27*(4), 1157–1168.

Özcan, E. C., Ünlüsoy, S., & Tamer, E. R. (2017). Evaluation of the renewable energy investments in Turkey using ANP and TOPSIS methods. *Selcuk University Journal of Engineering, Science and Technology, 5*(2), 204-219.

Özcan, T., Çelebi, N., & Esnaf, Ş. (2011). Comparative analysis of multi-criteria decision making methodologies and implementation of a warehouse location selection problem. *Expert Systems with Applications, 38*(8), 9773–9779.

Pamučar, D. S., Božanić, D., & Ranđelović, A. (2017). Multi-criteria decision making: An example of sensitivity analysis. *Serbian Journal of Management*, *12*(1), 1–27.

Pedraza, J. M. (2015). *Electrical energy generation in Europe: The current situation and perspectives in the use of renewable energy sources and nuclear power for regional electricity generation.* Springer International Publishing.

Petroleum and Natural Gas Platform Association. (n.d.). *What is oil?* Retrieved from https://www.petform.org.tr/en/arama-uretim-sektoru/petrol-nedir/

Pratama, Y. W., Purwanto, W. W., Tezuka, T., McLellan, B. C., Hartono, D., Hidayatno, A., & Daud, Y. (2017). Multi-objective optimization of a multiregional electricity system in an archipelagic state: The role of renewable energy in energy system sustainability. *Renewable and Sustainable Energy Reviews, 77*, 423–439.

Prebeg, P., Gasparovic, G., Krajacic, G., & Duic, N. (2016). Long-term energy planning of Croatian power system using multi-objective optimization with focus on renewable energy and integration of electric vehicles. *Applied Energy, 184,* 1493–1507.

Presidency of the Republic of Turkey. (2019). *The Eleventh Development Plan 2019-2023*. Retrieved from https://www.sbb.gov.tr/logo/eleventh-development-plan-2019-2023/

Presidency of the the Republic of Turkey Investment Office. (2018). Turkey's renewable energy market and investment opportunities. Retrieved from https://erranet.org/download/turkeys-renewable-energy-market-and-investment-opportunities/

PricewaterhouseCoopers. (2015). T*he World in 2050: Will the shift in global economic power continue?*. Retrieved from https://www.pwc.com.tr/en/yayinlar/arastirmalar/2050-dunya.html

PricewaterhouseCoopers. (2020). *Overview of the Turkish Electricity Market.* Retrieved from https://www.pwc.com.tr/overview-of-the-turkish-electricity-market

Protocol, K. (1997). United Nations framework convention on climate change. *Kyoto Protocol, Kyoto, 19*, 497.

Queiruga, D., Walther, G., Gonzalez-Benito, J., & Spengler, T. (2008). Evaluation of sites for the location of WEEE recycling plants in Spain. *Waste Management, 28*(1), 181–190.

Razavi Hajiagha, S. H., Hashemi, S. S., & Zavadskas, E. K. (2013). A complex proportional assessment method for group decision making in an interval-valued intuitionistic fuzzy environment. *Technological and Economic Development of Economy, 19*(1), 22–37.

Renewable Energy Policy Network for the 21st Century (REN21). (2019). *Renewables 2019 Global Status Report.* https://www.ren21.net/gsr-2019/

Renewable Energy Policy Network for the 21st Century (REN21). (2020). *Renewables 2020 Global Status Report.* https://www.ren21.net/gsr-2020/

Republic of Turkey Energy Market Regulatory Authority (EMRA). (2013). *Board Decision.* Retrieved from www.epdk.gov.tr

Republic of Turkey Energy Market Regulatory Authority (EMRA). (2018). Electricity Market Development Report. Retrieved from http://epdk.gov.tr/Detay/Icerik/3-0-0-102/yillik-rapor-elektrik-piyasasi-gelisim-raporlari

Republic of Turkey Energy Market Regulatory Authority (EMRA). (2019a). Turkish Petroleum Market Report. Retrieved from https://www.epdk.gov.tr/Detay/Icerik/1-2316/petroleumreports

Republic of Turkey Energy Market Regulatory Authority (EMRA). (2019b). Turkish Natural Gas Market Report. Retrieved from https://www.epdk.gov.tr/Detay/Icerik/1-1275/natural-gasreports

Republic of Turkey Energy Market Regulatory Authority (EMRA). (2019c). Electricity Market Development Report. Retrieved from https://www.epdk.gov.tr/Detay/Icerik/1-1271/electricityreports

Republic of Turkey Energy Market Regulatory Authority (EMRA). (2020a). *The final renewable energy source (YEK) list for 2020*. Retrieved from https://www.tskb.com.tr

Republic of Turkey Energy Market Regulatory Authority (EMRA). (2020b). Turkish Electricity Market Sector Report. Retrieved from https://www.epdk.gov.tr/Detay/Icerik/1-1271/electricityreports

Republic of Turkey Ministry of Energy and Natural Resources (MENR). (2006). *Turkey's Solar Energy Potential Atlas (GEPA)*. Retrieved from https://gepa.enerji.gov.tr/MyCalculator/

Republic of Turkey Ministry of Energy and Natural Resources (MENR). (2016). *Enerji ve Tabi Kaynaklar Bakanlığı ile Bağlı, İlgili ve İlişkili Kuruluşların Amaç ve Faaliyetleri Raporu.* Retrieved from https://www.tskb.com.tr

Republic of Turkey Ministry of Energy and Natural Resources (MENR). (2017). Dünya ve Türkiye enerji ve tabii kaynaklar görünümü. *Sayı, 15*, 8.

Republic of Turkey Ministry of Energy and Natural Resources (MENR). (2019). *2019-2023 Stratejik Planı.* Retrieved from https://sp.enerji.gov.tr/

Republic of Turkey Ministry of Energy and Natural Resources (MENR). (2020). *Biomass Energy Potential Atlas (BEPA)*. Retrieved from https://bepa.enerji.gov.tr

Republic of Turkey Ministry of Energy and Natural Resources (MENR). (n.d.-a). *Coal.* Retrieved from https://enerji.gov.tr/bilgi-merkezi-tabii-kaynaklar-komur

Republic of Turkey Ministry of Energy and Natural Resources (MENR). (n.d.-b). Retrieved from https://nukleer.enerji.gov.tr/en-US/Frequently-Asked-Questions/Is-it-necessary-to-be-established-Nuclear-Power-Plant-in-our-country

Republic of Turkey Ministry of Energy and Natural Resources (MENR). (n.d.-c). *Solar.* Retrieved from https://enerji.gov.tr/bilgi-merkezi-enerji-gunes

Republic of Turkey Ministry of Energy and Natural Resources (MENR). (n.d.-d). *Turkish Wind Energy Potential Atlas (REPA).* Retrieved from https://repa.enerji.gov.tr/REPA/

Rutz, D., & Janssen, R. (2014). *Socio-economic impacts of bioenergy production.* Springer.

Saaty, T. L. (1988). *The Analytic Hierarchy Process: Decision making in complex environments.* In *Avenhaus R., Huber, R.K. (eds) Quantitative Assessment in Arms Control*. Springer, Boston, MA.

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International journal of services sciences, 1*(1), 83–98.

Samy, M. M., Elkhouly, H. I., & Barakat, S. (2020). Multi-objective optimization of hybrid renewable energy system based on biomass and fuel cells. *International Journal of Energy Research*, 1-17.

San Cristóbal, J. R. (2011). Multi-criteria decision-making in the selection of a renewable energy project in spain: The Vikor method. *Renewable Energy, 36*, 498–502.

San Cristóbal, J. R. (2012). A goal programming model for the optimal mix and location of renewable energy plants in the north of Spain. *Renewable and Sustainable Energy Reviews, 16*(7), 4461–4464.

Sánchez-Lozano, J. M., Teruel-Solano, J., Soto-Elvira, P. L., & García-Cascales, M. S. (2013). Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) methods for the evaluation of solar farms locations: Case study in south-eastern Spain. *Renewable and Sustainable Energy Reviews*, *24*, 544-556.

Sari, A. C., Saygin, D., & Lucas, H. (2019). *On the way to efficiently supplying more than half of Turkey's electricity from renewables: Opportunities to strengthen the YEKA auction model for enhancing the regulatory framework of Turkeys power system transformation.* SHURA Energy Transition Center, Istanbul.

Sauhats, A., Petrichenko, R., Baltputnis, K., Broka, Z., & Varfolomejeva, R. (2016). A multi-objective stochastic approach to hydroelectric power generation scheduling. In *2016 Power Systems Computation Conference (PSCC)*, 1–7. IEEE.

Schlömer, S., Bruckner, T., Fulton, L., Hertwich, E., McKinnon, A., Perczyk, D. … Wiser, R. (2014). Annex III: Technology-specific cost and performance parameters. In: *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*

Schulte, D. O., Arnold, D., Geiger, S., Demyanov, V., & Sass, I. (2020). Multi-objective optimization under uncertainty of geothermal reservoirs using experimental design-based proxy models. *Geothermics, 86*, 101792.

Shao, M., Han, Z., Sun, J., Xiao, C., Zhang, S., & Zhao, Y. (2020). A review of multi-criteria decision making applications for renewable energy site selection. *Renewable Energy, 157,* 377-403.

Sheffield, J. (1999). World population and energy demand growth: the potential role of fusion energy in an efficient world. *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences, 357*(1752), 377–395.

Simab, M., Javadi, M. S., & Nezhad, A. E. (2018). Multi-objective programming of pumped-hydro-thermal scheduling problem using normal boundary intersection and VIKOR. *Energy, 143,* 854–866.

Statista. (2019a). *Leading countries in new installed wind power capacity in 2019.* Retrieved from https://www.statista.com/statistics/185514/leading-countries-in-new-installed-windpower-capacity

Statista. (2019b). *Number of employees in the renewable energy sector in Turkey in 2019, by technology*. Retrieved from https://www.statista.com/statistics/893602/renewable-energy-employment-numbers-turkey/

Stein, E. W. (2013). A comprehensive multi-criteria model to rank electric energy production technologies. *Renewable and Sustainable Energy Reviews, 22*, 640–654.

Stiebler, M. (2008). *Wind energy systems for electric power generation.* Springer Science & Business Media.

Suri, M., Cebecauer, T., Suriova, N., Schnierer, B., Betak, J., Cief, B., Madlenakova, V., Skoczek, A., Caltik, M. *Solar resource and photovoltaic potential of Nepal (English)*. Energy Sector Management Assistance Program Washington, D.C. : World Bank Group. Retrieved from http://documents.worldbank.org/curated/en/585921519658176633/Solar-resource-and-photovoltaic-potential-of-Nepal

Şengül, Ü., Eren, M., Shiraz, S. E., Gezder, V., & Şengül, A. B. (2015). Fuzzy TOPSIS method for ranking renewable energy supply systems in Turkey. *Renewable Energy, 75*, 617–625.

Şişbot, S., Turgut, Ö., Tunç, M., & Çamdalı, Ü. (2010). Optimal positioning of wind turbines on Gökçeada using multi-objective genetic algorithm. *Wind Energy: An International Journal for Progress and Applications in Wind Power Conversion Technology, 13*(4), 297–306.

Tasri, A., & Susilawati, A. (2014). Selection among renewable energy alternatives based on a fuzzy analytic hierarchy process in Indonesia. *Sustainable energy technologies and assessments, 7*, 34–44.

Team, G. E., & others. (2012). Global energy assessment. *Cambridge Books*.

Toklu, E. (2017). Biomass energy potential and utilization in Turkey. *Renewable Energy*, *107*, 235-244.

Trainor, A. M., McDonald, R. I., & Fargione, J. (2016). Energy sprawl is the largest driver of land use change in United States. *PloS one, 11*(9), e0162269.

Turkish Coal Operations Authority (TKİ). (2019a). *Coal Sector Report*. Retrieved from http://www.tki.gov.tr/bilgi/yayinlar/sektor-raporu/290

Turkish Coal Operations Authority (TKİ). (2019b). *Annual Report 2019*. Retrieved from http://www.tki.gov.tr/bilgi/yayinlar/faaliyet-raporlari/228

Turkish Coal Operations Authority (TKİ). (2020). *Energy and coal*. Retrieved from http://www.tki.gov.tr/bilgi/komur/enerji-ve-komur/

Turkish Electricity Distribution Corporation (TEDAŞ). (2018). *Annual report.* Retrieved from https://www.tedas.gov.tr/#!tedas_faaliyet_raporlari

Turkish Electricity Transmission Corporation (TEİAŞ). (2019a). *2019 Yılı Türkiye Elektrik İletimi Sektör Raporu.* Retrieved from https://www.teias.gov.tr/tr-TR/sektor-raporlari.

Turkish Electricity Transmission Corporation (TEİAŞ). (2019b). *Annual development of Turkey's Installed Capacity by Primary Energy Sources.* Retrieved from https://www.teias.gov.tr

Turkish Electricity Transmission Corporation (TEİAŞ). (2019c). *Annual development of Turkey's Gross Electricity Generation-Imports-Exports and Demand.* Retrieved from https://www.teias.gov.tr

Turkish Electricity Transmission Corporation (TEİAŞ). (2019d). *Turkey's Gross Electricity Generation and Development of Gross Demand.* Retrieved from https://www.teias.gov.tr

Turkish Electricity Transmission Corporation (TEİAŞ). (2019e). *Türkiye Elektrik Enerjisi 5 Yıllık Üretim Kapasite Raporu.* Retrieved from https://www.teias.gov.tr

Turkish Electricity Transmission Corporation (TEİAŞ). (2019f). *Annual Development of Electricity Generation - Consumption and Losses in Turkey*. Retrieved from https://www.teias.gov.tr

Turkish Petroleum (TPAO). (2019). *Crude oil and natural gas sector report*. Retrieved from https://www.tpao.gov.tr/raporlar-1.

Turkish State Meteorological Service (MGM). (2020). *2019 yılı yağış değerlendirmesi.* Retrieved from https://www.mgm.gov.tr

Turkish State Meteorological Service (MGM, 2019) Retrieved from https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?k=A&m=ANKARA

Tuzkaya, G., Kilic, H. S., & Aglan, C. (2016). A multi-objective supplier selection and order allocation model for green supply chains. *Journal of Management and Information Science, 4*(3), 87–96.

Union of Chambers of Turkish Engineers and Architects (UCTEA). (2014). *Turkey's Energy Outlook.* Energy Report. Retrieved from https://www.mmo.org.tr/

Union of Chambers of Turkish Engineers and Architects (UCTEA). (2016). *Turkey's Energy Outlook.* Energy Report. Retrieved from https://www.mmo.org.tr/

Union of Chambers of Turkish Engineers and Architects (UCTEA). (2018). *Turkey's Energy Outlook.* Energy Report. Retrieved from https://www.mmo.org.tr/

Union of Chambers of Turkish Engineers and Architects (UCTEA). (2020). *Turkey's Energy Outlook.* Energy Report. Retrieved from https://www.mmo.org.tr/

Union of Concerned Scientists (UCSUSA). (2015). *How natural gas is formed?* Retrieved from https://www.ucsusa.org/resources/how-natural-gas-formed

United Nations. (2019). World population prospects 2019: highlights. *Department of Economic and Social Affairs, Population Division*. Retrieved from https://www.un.org/development/desa/publications/world-population-prospects-2019-highlights.html

United Nations. (2020). *The sustainable development agenda*. Retrieved November 20, 2020, from https://www.un.org/sustainabledevelopment/development-agenda/

United Nations Framework Convention on Climate Change (UNFCCC). (2015). *Adoption of the Paris Agreement.* In *Report of the Conference of the Parties to the United Nations Framework Convention on Climate Change (21st Session, 2015: Paris).*

U.S. Energy Information Administration (EIA). (2019). *International Energy Outlook 2019: with projections to 2050*. Retrieved from https://www.eia.gov/outlooks/ieo/

U.S. Energy Information Administration (EIA). (2020a). *Geothermal explained*. Retrieved January 10, 2021, from https://www.eia.gov/energyexplained/geothermal/

U.S. Energy Information Administration (EIA). (2020b). *Biomass explained*. Retrieved January 10, 2021, from https://www.eia.gov/energyexplained/biomass/

U.S. Energy Information Administration (EIA). (2020c). *Nuclear explained*. Retrieved January 10, 2021, from https://www.eia.gov/energyexplained/nuclear/

Ustinovichius, L., Zavadkas, E. K., & Podvezko, V. (2007). Application of a quantitative multiple criteria decision making (MCDM-1) approach to the analysis of investments in construction. *Control and cybernetics, 36*(1), 251.

Ürün, E., & Soyu, E. (2016). A review of the renewable energy resources in the energy production of Turkey. *Dumlupınar University Journal of Social Sciences*, *ICEBSS Special Issue*, 31–45.

Wagner, H. J., & Mathur, J. (2011). *Introduction to Hydro Energy Systems. In Green Energy and Technology.* Springer Berlin Heidelberg.

Wang, C. N., Huang, Y. F., Chai, Y. C., Nguyen, V. T., & others. (2018). A multi-criteria decision making (MCDM) for renewable energy plants location selection in Vietnam under a fuzzy environment. *Applied Sciences, 8*(11), 2069.

Wang, M., Wang, J., Zhao, P., & Dai, Y. (2015). Multi-objective optimization of a combined cooling, heating and power system driven by solar energy. *Energy Conversion and Management, 89*, 289–297.

Wang, J. J., Jing, Y. Y., Zhang, C. F., & Zhao, J. H. (2009). Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renewable and Sustainable Energy Reviews, 13*(9), 2263–2278.

Wang, P., Zhu, Z., & Wang, Y. (2016). A novel hybrid MCDM model combining the SAW, TOPSIS and GRA methods based on experimental design. *Information Sciences, 345*, 27–45.

Williams, A., & Porter, S. (2006). Comparison of hydropower options for developing countries with regard to the environmental, social and economic aspects. *Small, 1*(10).

World Bank. (2015). *Renewable energy consumption (% of total final energy consumption)*. Retrieved from https://data.worldbank.org/indicator /EG.FEC.RNEW.ZS

World Bank. (2019). *Global Solar Atlas 2.0 Technical Report*. Washington, DC: World Bank.

Wu, Q., Zhou, J., Liu, S., Yang, X., & Ren, H. (2016b). Multi-objective optimization of integrated renewable energy system considering economics and CO2 emissions. *Energy Procedia, 104*, 15–20.

Wu, Y., Yang, M., Zhang, H., Chen, K., & Wang, Y. (2016a). Optimal site selection of electric vehicle charging stations based on a cloud model and the PROMETHEE method. *Energies, 9*(3), 157.

Xiao, J., Cai, J., & Wang, X. (2017). A hesitant fuzzy linguistic multicriteria decision-making method with interactive criteria and its application to renewable energy projects selection. *Mathematical Problems in Engineering, 2017*.

Yalcin, L. (2016). *Iğdır ve FV Güneş Elektriği.* Serhat Development Agency (SERKA).

Yeo, S. Z., How, B. S., Ngan, S. L., Ng, W. P., Leong, W. D., Lim, C. H., & Lam, H. L. (2020). An integrated approach to prioritise parameters for multi-objective optimisation: A case study of biomass network. *Journal of Cleaner Production, 274*, 123053.

Yuksel, I., & Kaygusuz, K. (2011). Renewable energy sources for clean and sustainable energy policies in Turkey. *Renewable and Sustainable Energy Reviews*, *15*(8), 4132–4144.

Yumurtaci, Z., & Asmaz, E. (2004). Electric energy demand of Turkey for the year 2050. *Energy Sources*, *26*(12), 1157–1164.

Zafar, M. W., Shahbaz, M., Hou, F., & Sinha, A. (2019). From nonrenewable to renewable energy and its impact on economic growth: the role of research & development expenditures in Asia-Pacific Economic Cooperation countries. *Journal of Cleaner Production, 212*, 1166–1178.

Zhang, H. L., Baeyens, J., Degrève, J., & Cacères, G. (2013). Concentrated solar power plants: Review and design methodology. *Renewable and Sustainable Energy Reviews, 22*, 466–481.

Zhang, S., Andrews-Speed, P., & Perera, P. (2015). The evolving policy regime for pumped storage hydroelectricity in China: A key support for low-carbon energy. *Applied Energy*, *150*, 15–24.

Zhao, Z., & Huang, W. (2011). Multi-objective decision-making on wind power projects based on AHP method. In *2011 International Conference on Computer Distributed Control and Intelligent Environmental Monitoring*,242–245. IEEE.

Zografidou, E., Petridis, K., Petridis, N. E., & Arabatzis, G. (2017). A financial approach to renewable energy production in Greece using goal programming. *Renewable Energy, 108*, 37–51.

Suganthi, L., Iniyan, S., & Samuel, A. A. (2015). Applications of fuzzy logic in renewable energy systems–a review. *Renewable and Sustainable Energy Reviews, 48*, 585-607.

Vafaeipour, M., Zolfani, S. H., Varzandeh, M. H. M., Derakhti, A., & Eshkalag, M. K. (2014). Assessment of regions priority for implementation of solar projects in Iran: New application of a hybrid multi-criteria decision making approach. *Energy Conversion and Management*, *86*, 653-663.

CURRICULUM VITAE

<u>Personal Information</u>

Full Name : Muhammed Bilal HORASAN

Place of Birth: İstanbul, Turkey

<u>Education</u>

M.Sc: Marmara University (2017-2021)

Department of Industrial Engineering

B.Sc: İstanbul Şehir University (2010-2015)

Department of Industrial Engineering

<u>Work Experience</u>

Metrobil Technology (2018 – …)

Project Manager

Turkish Airlines Technic (2016 – 2018)

Aircraft Maintenance Planning Engineer

Turkcell Technology (2015 – 2016)

Process & Network Transition Specialist