RENEWABLE ENERGY PLANNING IN TURKEY
WITH A FOCUS ON HYDROPOWER

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WITH A FOCUS ON HYDROPOWER

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ABSTRACT

RENEWABLE ENERGY PLANNING IN TURKEY WITH A FOCUS ON HYDROPOWER

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As a country highly dependent on foreign fossil fuel sources, Turkey experiences many problems due to its increasing energy consumption in parallel with increasing population and rapid economic growth. Foreign fossil fuel dependency adversely affects sustainable development of the country by hindering its economic development. Because of this, renewable energy sources of the country should be evaluated and developed as soon as possible. Prioritization of the development of renewable energy sources to increase their contribution to electricity generation is a multi-criteria decision making problem. Both energy and environmental goals need to be considered in selecting the most suitable renewable energy source. In this study, which one of the renewable energy sources, solar, biomass, geothermal, wind, or hydropower, should be given priority to increase its contribution to Turkey's electricity generation is examined by employing Analytic Hierarchy Process. These renewable energy sources are compared with respect to selected criteria and sub-criteria determined as a result of a comprehensive literature review by a group of experts who are mostly academicians and professionals working in public and private sector. As a result of this study, it is found that satisfaction of energy goals are given higher priority compared to satisfaction of environmental goals and hydropower is selected as the most preferred renewable energy source to increase its contribution to Turkey's electricity generation. However, experts identified maintaining environmental sustainability and maintaining social acceptability as the most important problems associated with hydropower. Solar and wind energies are identified as the second and third choices to be considered for development in terms of electricity generation.

Keywords: Renewable Energy Sources, Electricity Generation, Analytic Hierarchy Process, Sensitivity Analysis.

ÖZ

TÜRKİYE'DE HİDROLİK ENERJİ ODAKLI YENİLENEBİLİR ENERJİ PLANLAMASI

Gök, Emre

Yüksek Lisans, İnşaat Mühendisliği Bölümü

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Büyük oranda yabancı fosil kaynaklarına bağımlı olan Türkiye, artan nüfus ve hızla gelişen ekonomiye paralel olarak artan enerji tüketimi nedeniyle pek çok sorun yaşamaktadır. Yabancı fosil kaynaklarına olan bağımlılık ekonomik gelişmeyi engelleyerek ülkenin sürdürülebilir kalkınmasını olumsuz etkilemektedir. Bu nedenle, ülkenin yenilenebilir enerji kaynakları bir an önce değerlendirilmeli ve geliştirilmelidir. Elektrik üretimindeki katkılarının arttırılması için geliştirilecek olan yenilenebilir enerji kaynaklarının önceliklendirilmesi ise çok kriterli bir karar verme problemidir. En uygun yenilenebilir enerji kaynağının seçimi için enerji ve çevresel hedefler göz önünde bulundurulmalıdır. Bu çalışmada, elektrik üretimindeki katkısını arttırmak için Türkiye'nin sahip olduğu güneş, biyokütle, jeotermal, rüzgâr ve hidrolik kaynaklarından hangisine öncelik verilmesi gerektiği Analitik Hiyerarşi Süreci (AHS) yöntemi kullanılarak incelenmiştir. Bu yenilenebilir enerji kaynakları, çoğu kamu ve özel sektörde çalışan akademisyenlerden ve profesyonellerden oluşan bir grup uzman tarafından, kapsamlı bir literatür taraması sonucu belirlenen kriterlere ve alt kriterlere göre değerlendirilmiştir. Bu çalışmanın sonucunda, enerji hedeflerini gerçekleştirmenin çevresel hedefleri gerçekleştirmeye göre daha önemli olduğu ve hidrolik enerjinin Türkiye'nin elektrik üretimindeki katkısını arttırmak için en çok tercih edilen yenilenebilir enerji kaynağı olduğu ortaya çıkmıştır. Bununla birlikte, çevresel sürdürülebilirliğin sağlanması ve sosyal kabul edilebilirliğin sağlanması konusundaki sorunlar, uzmanlar tarafından hidrolik enerjinin en büyük sorunları olarak belirlenmiştir. Güneş ve rüzgâr enerjisi ise elektrik üretimindeki katkısını arttırmak için geliştirilebilecek ikinci ve üçüncü seçenekler olarak seçilmişlerdir.

Anahtar Kelimeler: Yenilenebilir Enerji Kaynakları, Elektrik Üretimi, Analitik Hiyerarşi Süreci, Duyarlılık Analizi.

To My Family and My Supporters

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LIST OF SYMBOLS AND ABBREVIATIONS

AHP: Analytic Hierarchy Process

ASES: American Solar Energy Society

CH_4: Methane

CI: Consistency Index

CR: Consistency Ratio

CO_2: Carbon Dioxide

CREZ: Competitive Renewable Energy Zone

DEK-TMK: World Energy Council, Turkish National Committee

DSİ: General Directorate of State Hydraulic Works

EIA: Energy Information Administration

EPA: Environmental Protection Agency

EPDK: Energy Market Regulatory Authority

ETKB: Ministry of Energy and Natural Resources

EWEA: European Wind Energy Association

GAP: Southeastern Anatolian Project

GDP: Gross Domestic Product

GHGs: Greenhouse gases

GWh: Gigawatt hour

HEPPs: Hydroelectric Power Plants

IEC: International Electrotechnical Commission

IPCC: Intergovernmental Panel on Climate Change

IRENA: International Renewable Energy Agency

İMO: Chamber of Civil Engineers

kWh: Kilowatt hour

MCDM: Multi-criteria Decision Making

MSW: Municipal Solid Waste

MTA: General Directorate of Mineral Research and Exploration

Mtoe: Million tones of oil equivalent

MW: Megawatt

N: Normalized Vector

N_2O: Nitrous Oxide

NO_X: Generic term for mono-nitrogen oxides

NRDC: Natural Resources Defense Council

NREL: National Renewable Energy Laboratory

OECD: Organisation for Economic Co-operation and Development

PCM: Pairwise Comparison Matrix

PV: Photovoltaic

R&D: Research and Development

RES: Wind Energy Power Plants

RI: Random Index

$SO_{2:}$ Sulfur Dioxide

SO_X: Generic term for sulfur oxides

TEİAŞ: Turkish Electricity Transmission Company

TMMOB: Union of Chambers of Turkish Engineers and Architects

TUREB: Turkish Wind Energy Association

TÜİK: Turkish Statistical Institute

UNEP: United Nations Environment Programme

UNFCCC: United Nations of Framework Convention on Climate Change

w: Priority vector

WNA: World Nuclear Association

YEGM: General Directorate of Renewable Energy

Λmax: Principal Eigenvalue

CHAPTER 1

INTRODUCTION

1.1. Turkey's Energy Facts

With an increasing population, Turkey has one of the fastest growing economies in the world. Its GDP has increased from $230 billion in 2002 to $786 billion in 2012 (TÜİK, 2013). In parallel with the economic growth and increasing population, energy demand in Turkey has been increasing continuously.

Turkish energy system is highly dependent on fossil fuels. As can be seen in Figure 1, fossil fuels are the main sources to meet the primary energy consumption. Turkey imports a large portion of the consumed fossil fuels. Energy consumption based on fossil fuels creates problems such as dependency on foreign sources, high import expenditures, environmental hazards, air pollution, and risks for human health. For these reasons, Turkey has to evaluate and develop domestic, clean, and reliable energy sources for its sustainable development.

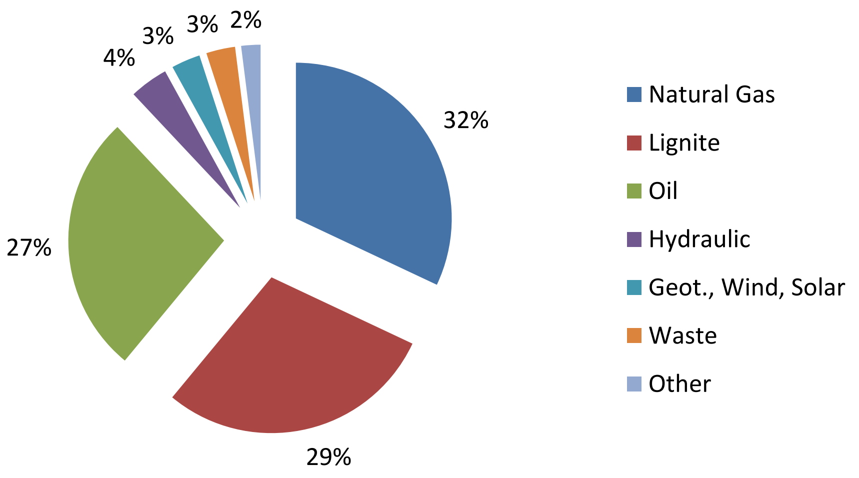

Figure 1. Primary energy consumption by sources in 2011 (DEK-TMK, 2012).

To achieve sustainable development, Ministry of Energy and Natural Resources (ETKB) has set the following mission: "Its our mission to ensure efficient, effective, safe, and environment-sensitive use of energy and natural resources in a way that reduces external dependency of our country, and makes the greatest contribution to our country's welfare" (ETKB, 2013). In supplying the increasing energy demand and maintaining environmental and economic goals, development of renewable energy sources of the country is very important.

The major renewable energy sources of Turkey are solar energy, biomass energy, geothermal energy, wind energy, and hydropower. These sources are utilized in many areas especially for heating purposes and generating electricity. In this study, evaluation of these renewable energy sources in terms of increasing their contribution in electricity generation is considered. Electricity is a major input for residents, industrial facilities, transportation, and water resources systems. Therefore, evaluation and planning of renewable energy sources for electricity generation will provide important guidance for achieving sustainable development. At this point, the following question is arising: which one of these renewable energy sources should be given priority to increase its share in Turkey's electricity generation? In other words, in the near future development of which one of these renewable energy sources should be supported by the government to increase its share in the electricity generation?

The share of renewable energy sources in electricity consumption of Turkey is around 25% (DEK-TMK, 2012). As can be seen in Figure 2, hydropower is the most utilized renewable energy source with 91% (DEK-TMK, 2012). However, around 71% of technical potential of hydropower has not been developed in Turkey yet (DSİ, 2013). Therefore, among these renewable energy sources, hydropower seems to be the most likely choice to be developed first, since Turkey has experience and knowledge in this area. In this study, it is aimed to test this idea using expert opinion by employing Analytic Hierarchy Process (AHP) in a multi-criteria decision making framework.

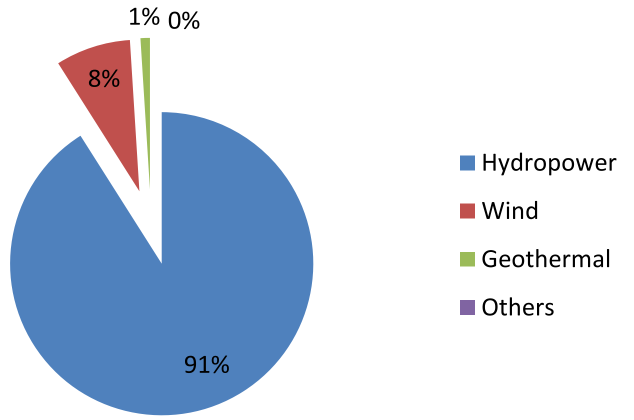

Figure 2. Structure of electricity consumption from renewable energy sources (DEK-TMK, 2012).

Identification of the best renewable energy source to invest money is an important issue since this decision will affect future energy policies of the country. In this study, AHP is used to rank renewable energy sources. Its ease of applicability and ability of integrating experts' experience, knowledge and intuition are the main reasons for the preference of AHP.

In order to evaluate the major renewable energy sources of Turkey, a survey is prepared based on literature review and send out to 120 experts who are academicians and professionals from public and private sector. These experts are selected considering their experiences and previous studies on renewable energy sources, technologies, market conditions, and policies. A total of 37 surveys is collected back and evaluated.

In the survey study, experts are asked to evaluate renewable energy sources with respect to two main criteria, *Energy Goals* and *Environmental Goals*. An extended literature review is conducted and criteria used for *Energy Goals* and *Environmental Goals* are developed based on the literature review. Then expert's responses to the survey are evaluated using AHP. As a result of this evaluation, hydropower is identified as the most preferred renewable energy source followed by solar energy and wind energy. Geothermal energy and biomass energy are far behind these renewable energy sources. In addition, achievement of Turkey's energy goals is identified to be more important than achievement of environmental goals due to the experts.

1.2. Contents of the Study

This study consists of eight chapters. Chapter 1 is the Introduction and it defines the problem and states the objective of this study. Chapter 2 provides information about renewable energy sources and their potentials in Turkey. Chapter 3 includes literature review, especially studies in which AHP is applied for multi-criteria decision making. Chapter 4 explains the methodology of AHP. In Chapter 5, selected criteria and sub-criteria to evaluate five major renewable energy sources of Turkey are explained. Chapter 6 contains the analysis of survey forms and sensitivity analysis which is performed to determine the degree of influence of a criterion on the overall output. In Chapter 7, the results of the analyses are discussed and compared with the results of the Life Cycle Assessment (LCA) studies. Chapter 8 concludes the study and briefly explains the performed efforts and results. Additionally, some recommendations are given in this chapter.

CHAPTER 2

RENEWABLE ENERGY SOURCES OF TURKEY

2.1. What is Renewable Energy?

IEA (2013) defines renewable energy as energy derived from natural processes (*e.g.* sunlight and wind) that are replenished at a faster rate than they are consumed. Similarly, U.S. Department of Energy (NREL, 2001) states that renewable energy uses energy sources that are continually replenished by nature-the sun, the wind, water, the Earth's heat, and plants. Solar, wind, geothermal, hydro, and some forms of biomass are common sources of renewable energy.

2.2. Renewable Energy Sources

Main renewable energy sources; solar, biomass, geothermal, wind, and hydropower are briefly explained here.

2.2.1. Solar Energy

Solar energy refers to conversion of the sun's energy into useful forms such as electricity or heat. The amount of solar radiation received at a specific location depends on a variety of factors including geographic location, time of day, season, local landscape, and local weather. Solar energy can be converted into electricity by two ways (ETKB, 2010):

i) **Photovoltaic (PV) or solar cells:** change sunlight directly into electricity.

ii) **Concentrating Solar Power Plants (CSP):** generate electricity by using the heat from solar thermal collectors to heat the fluid which produces steam. The steam is used to power a turbine and generate electricity.

Having a high potential for solar energy due to its geographical position as seen in Figure 3, Turkey's average annual sunshine duration is estimated as 2640 hours (daily total is 7.2 hours) and average total radiation pressure is 1.311 kWh/m^2/year (ETKB, 2010). Economic solar energy potential of Turkey is estimated as 380 billion kWh/year (ETKB, 2010).

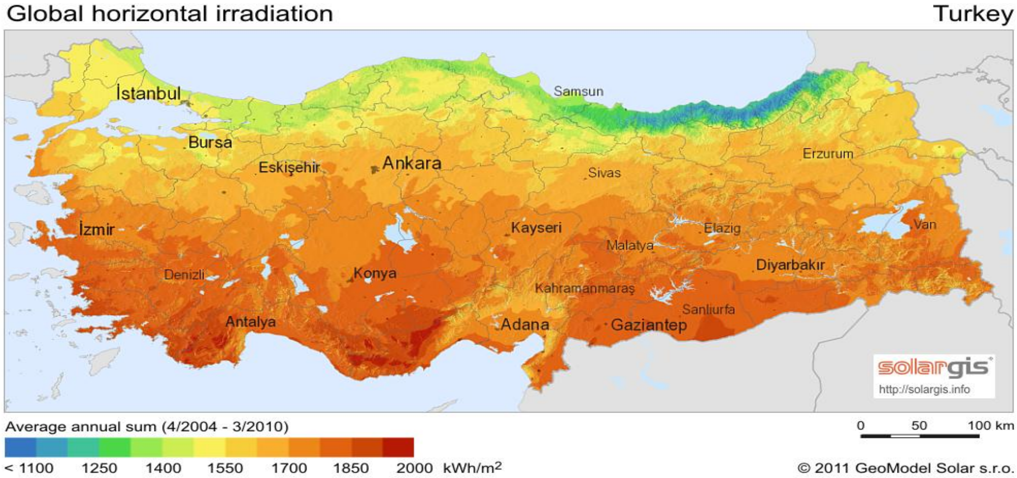

Figure 3. Solar map of Turkey (SolarGIS, 2013).

The main solar energy consumption mechanism in Turkey is the utilization of flat plate collectors for domestic hot water systems. Although Turkey is in the 2nd rank of the top countries using solar thermal power worldwide, electricity generation from solar energy is negligible (DEK-TMK, 2009) and utilization of photovoltaic systems is limited to some governmental organizations in remote service areas such as telecom stations, forest fire observation towers, highway emergency applications, and universities for research studies (İncecik et al., 2011).

2.2.2. Biomass Energy

Biomass is biological material derived from living or recently living organisms. All organic matter is known as biomass and energy released from biomass when it is eaten, burnt or converted into fuels is called biomass energy. However, most of the biomass used commercially today comes from resources that are not sustainable (it is called traditional biomass) (NRDC, 2013). If biomass is produced in a sustainable way, it is named as modern biomass (i.e. biodiesel, biogas, bio-ethanol) (Benefits-of-Recycling , 2013). In recent years, there has been a controversial issue about traditional biomass is a renewable source or not due to the opinions on traditional biomass is not a replaced source (Goldemberg and Coelho, 2004). Common biomass sources (including traditional and modern biomass) are shown in Figure 4.

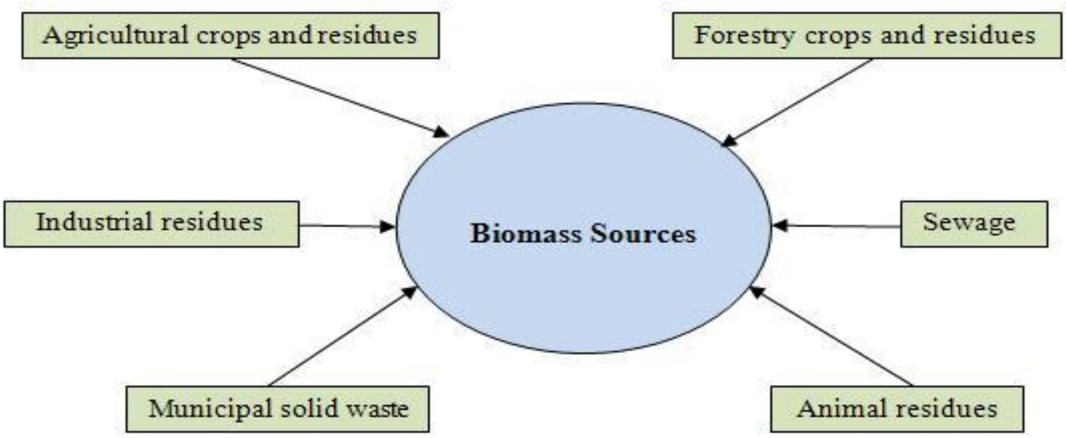

Figure 4. Biomass sources (Ahmed et al., 2012).

The economic modern biomass energy potential of Turkey is estimated as 290 billion kWh/year (Karayılmazlar et al., 2011). Although biomass is abundant and has remarkable potential in Turkey, insufficient attention has been given for the utilization of biomass and the benefits it can offer. In Turkey, there is only one power plant located in Çaycuma that generates electricity from biomass with 6 MW installed capacity (Karayılmazlar et al., 2011).

2.2.3. Geothermal Energy

Geothermal Energy is the heat energy obtained from hot water, steam and dry steam, and hot dry rocks, which is formed when heat accumulated in deep subterranean rocks is carried by fluids and stored in reservoirs. Geothermal resources are mainly found around active fault systems and volcanic and magmatic units (ETKB, 2010).

In Turkey, up to now, 190 geothermal fields have been discovered by General Directorate of Mineral Research and Exploration (MTA) and the economic geothermal potential of Turkey is estimated as 1.4 billion kWh/year (Cebeci, 2005). The number of drilled wells is about 498 and the total depth is about 242,515 m in 2010 (MTA, 2012). According to MTA (2011), Turkey is the 7th in the utilization of geothermal energy for direct use in the world and 1st in Europe (which excludes power generation).

In Turkey, geothermal energy is mainly used in thermal tourism, heating applications, obtaining industrial minerals, and electricity production. There are 17 geothermal fields discovered by MTA, which are suitable for geothermal power production and six of them (see Table 1) are currently used for electricity production (MTA, 2012).

Table 1. Electricity generation from geothermal energy (MTA, 2012).

Geothermal Site	*Installed Capacity (MW)*
Denizli-Kızıldere	15
Denizli-Kızıldere	5
Aydın-Salavatlı	9.5
Aydın-Salavatlı	7.4
Aydın-Germencik	47.4
Çanakkale	7.5
Total	**91.7**

2.2.4. Wind Energy

It is the energy derived from the movement of the wind across the earth. It is generated as a result of the heating of oceans, earth, and atmosphere by the sun. Of the energy that reaches the earth from the sun, 1% to 2% is transformed to wind energy (YEGM, 2012).

Feasibility studies confirmed that Turkey has a great economic potential for wind energy production which is estimated as 50 billion kWh/year (Cebeci, 2005). According to wind map of Turkey (Figure 5), it is estimated that Turkey has a minimum wind energy potential of 5,000 MW in regions with annual wind speed of 8.5 m/s and higher, and 48,000 MW with wind speed higher than 7.0 m/s (ETKB, 2010).

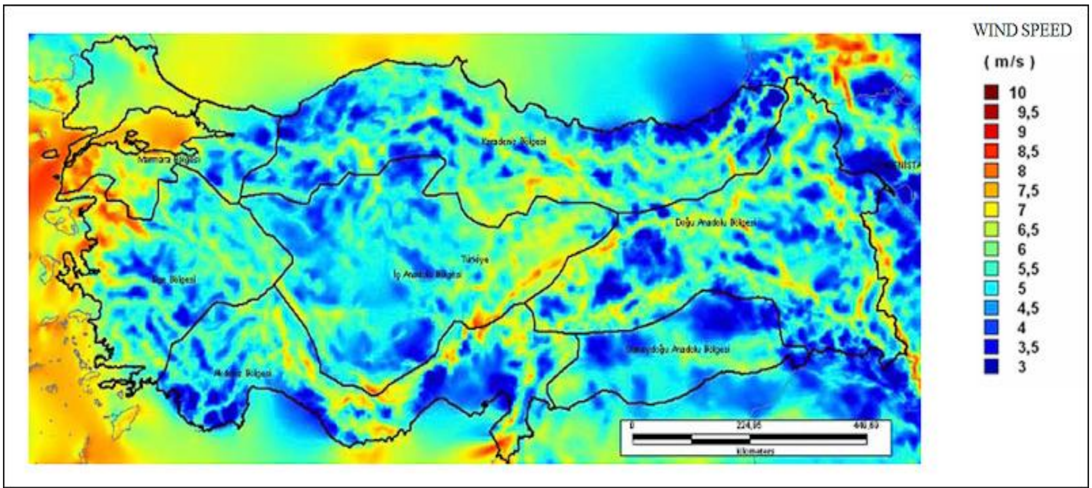

Figure 5. The distribution of average wind speed in 50 m. (Çalışkan, 2011).

In Turkey, approximately 50 wind energy power plants are in operation and total installed capacity of these plants is around 1802 MW (TUREB, 2012). Additionally, 13 wind energy power plants are under construction and their total installed capacity is around 507 MW (TUREB, 2012). Large portion of these projects are located in Western parts of Turkey. Table 2 provides currently operated wind energy power plants with installed capacity bigger than 50 MW.

Table 2. Operated wind energy power plants in Turkey with installed capacity > 50 MW (TUREB, 2012).

Project Name	***Location***	***Installed Capacity (MW)***	***Commencement of Operation***
Şamlı RES	Balıkesir	113.40	2008
Aliağa RES	İzmir	90	2010
Soma RES	Manisa	90	2010
Bandırma RES	Balıkesir	60	2010
ŞahRES	Balıkesir	93	2011
YuntdağRES	İzmir	57.50	2008
Gökçedağ RES	Osmaniye	135	2010
Çatalca RES	İstanbul	60	2008
Soma RES	Manisa	140.10	2012
Ziyaret RES	Hatay	57.50	2011

2.2.5. Hydropower

Recently, there has been a considerable debate about which hydropower projects can be considered as renewable. The type of sources that qualify as renewable is one of the key elements of Renewable Portfolio Standard (RPS) which is a regulatory mandate to increase production of energy from renewable sources (NREL, 2013). For example, since the goal of an RPS is to encourage the development of new renewable energy sources, most states of the U.S. do not let existing hydropower qualify (Hydropower Reform Coalition, 2013). However, each country treats hydropower in its own way. In some countries, hydropower is restricted by size while in others it is restricted by technology (Fagan and Knight, 2011). In this study, there is no restriction or classification on hydropower to be evaluated as a renewable source.

USBR (2005) defines hydropower as a renewable energy source that utilizes flowing water due to winter and spring runoff from mountains, streams and clear lakes. Water falls due to gravity, turns turbines and generators produce electricity.

The most common type of hydroelectric power plant is composed of a dam built on a river reach to store water in an artificial reservoir. Water released from reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity. There are two other types of hydroelectric power plants which are run-of-river type power plants, and pumped storage power plants (not used in Turkey).

Turkey has vast hydropower resources. With 25 river basins and a varied topography, Turkey has 17.6 % of Europe's theoretical hydropower potential and 1.5% of the world total (DSİ, 2013). Turkey's hydropower potential is estimated as 433 billion kWh/year and economic hydropower potential is estimated as 140 billion kWh/year (YEGM, 2012). Information about existing and planned hydropower plants in Turkey is provided in the following section.

2.3. Renewable Energy Potentials of Turkey

The estimated economic potentials of Turkey's renewable energy sources and developed parts of these potentials in terms of electricity generation are given in Table 3. As can be seen from Table 3, although solar and biomass have very high economic potentials, they have not been developed yet. On the other hand hydropower, having a considerable economic potential, is the most developed source. Approximately half of the economic potential of hydropower is developed. As explained in the Introduction chapter, currently the best utilized renewable energy source in Turkey is hydropower.

Table 3. Potentials of Turkey's renewable energy sources.

Renewable Energy Source	***Economic Potential (billion kWh/year)***	***Current Installed Capacity (MW)***	***Share in Total Installed Capacity of Turkey (%)***	***Reference***
Solar Energy	380	-	-	ETKB (2010)
Biomass	290*	150**	0.3	Karayılmazlar et al. (2010), DSİ (2013)
Geothermal	1.4	160	0.3	(Cebeci, 2005) DSİ (2013)
Wind Energy	50	2,200	4	(Cebeci, 2005) DSİ (2013)
Hydropower	140	20,000	35	ETKB (2010), DSİ (2013)

*Converted from 25 Mtoe.
**Includes modern biomass.

In Turkey, electricity generation from hydropower was started with a micro-scale hydroelectric power plant of 60 kW in Tarsus in 1902 (DSİ, 2013). After the establishment of State Hydraulic Works (DSİ) in 1954, development of hydropower has been accelerated. Today, hydropower is the major renewable energy source of Turkey. Technical maturity with a history over a hundred years, low operation cost, and ability to store energy are the main reasons of the accelerated development of hydropower in Turkey. As of 2012, 781 dams and 370 Hydroelectric Power Plants (HEPPs) are in operation and 144 dam and 212 HEPPs are under the construction as can be seen from Table 4. Large portion of these projects are located in Eastern parts of Turkey.

Table 4. Hydropower plants in Turkey (DSİ, 2013).

	In Operation			***Under Construction***		
Type of Facility	DSİ	Other	**Total**	DSİ	Other	**Total**
Dam						
Number of Dams	741	40	**781**	133	11	**144**
HEPPs						
Number of HEPPs	62	308	**370**	5	207	**212**
Installed Capacity (MW)	*11,600*	*9,400*	***20,000***	*2,000*	*6,000*	***8,000***
Annual Generation (GWh)	*41,000*	*29,000*	***70,000***	*7,000*	*22,000*	***29,000***

Total annual economic hydropower potential of Turkey is identified as 140000 GWh and half of this potential is currently developed. Although, in total electricity generation, utilization of natural gas has increased in a regular manner after 1980s up to now (see Figure 6), hydropower has a significant share in Turkey and it was around 20% in 2011 (TEİAŞ, 2011).

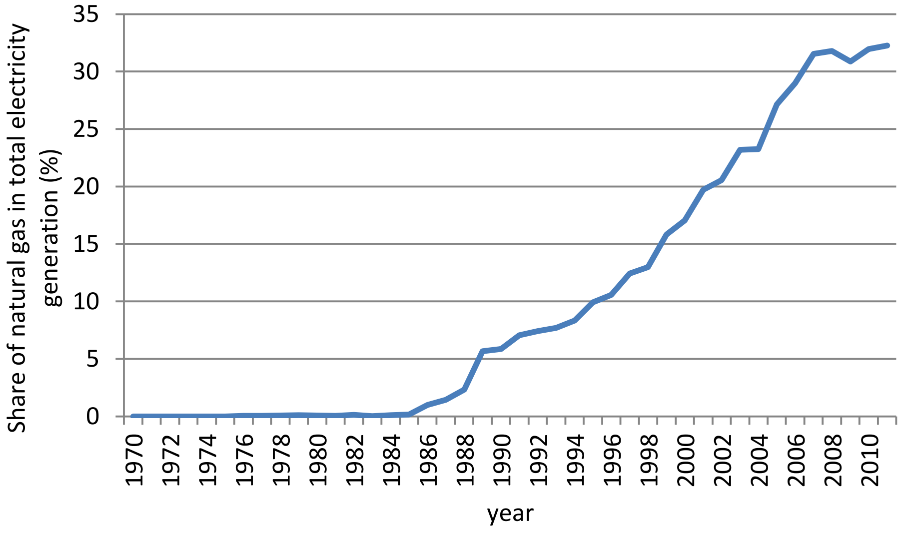

Figure 6. Share of natural gas in total electricity generation (ETKB, 2013).

As can be seen in Figure 7, the share of hydropower in the total electricity generation oscillated between 18% and 60% from 1970s to 2011. This figure shows that development and utilization of hydropower in Turkey is well practiced. Passing of Electricity Market Law No. 4628 in 2001 resulted in planning and construction of a large number of hydropower plants in Turkey (Kentel and Alp, 2013). However, necessary emphasis has not been put on environmental and social consequences of these power plants and this resulted in public opposition and many lawsuits. It can be concluded that in the past decade development of hydropower received considerable attraction in Turkey. However, environmental and social problems associated with hydropower plants, especially run-of-river type plants, resulted in major problems and created negative opinions about this renewable source. Thus, development of unused hydropower potential in the near future became a controversial issue in Turkey. In this study, it is aimed to evaluate of experts about development of renewable energy sources in terms of electricity generation in Turkey. One auxiliary question this study tries to answer is the following: "Is hydropower the best renewable energy source to be developed for electricity generation in Turkey?".

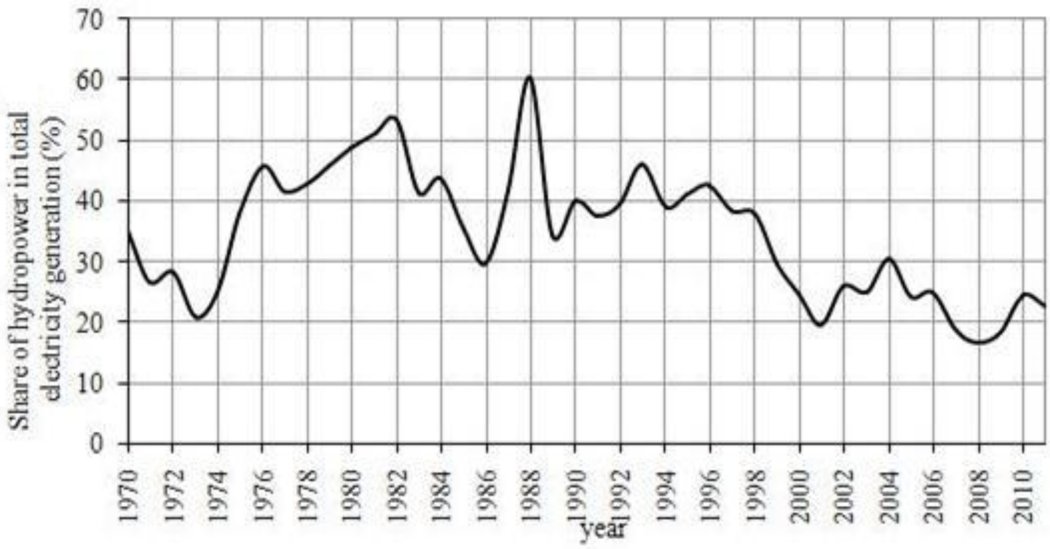

Figure 7. Share of hydropower in total electricity generation from 1970 to 2011 (TEİAŞ, 2011).

CHAPTER 3

LITERATURE REVIEW

3.1. Renewable Energy Studies

As one of the most attractive topics in modern energy policies, renewable energy has been investigated by many researchers, academicians, private, and public sector. Benefits, barriers, and supporting policies associated with different types of renewable energy sources are among main research topics.

There are many studies conducted for identifying the development of which renewable energy sources should be given priorities in the world. Some of these studies are given below by considering technical, economical, and environmental aspects on the evaluation of renewable energy sources.

The Wall Street Journal (2013) put the question "What renewable energy source, if any, has the most promise for becoming a major energy source?" to the experts. Among these experts, Mazen Skaf, who is the managing director of the U.S. based management consulting firm Strategic Decision Group, states that although wind-powered and solar-powered generation are projected to account for about 7% and 2%, respectively of global power supply by 2040, hydropower will continue to attract attention due to the advantages it offers such as lowest levelized cost of electricity (LCOE), grid stability, and potential for energy storage.

Michael Levi, another expert in The Wall Street Journal's article (2013), who is the director at Council of Foreign Relations in U.S., argues that there are three reasons to consider solar over other renewable energy supplies. The first reason is that solar may benefit from improvements in materials, computing, and nanotechnology in ways other technologies cannot do nearly as effectively. The second reason is that solar has a host of initial niches it can grow in, from rooftop generation to off-grid and micro-grid energy in often sunny developing countries that lack good infrastructure. The third reason is that solar is a better match for our energy demand than wind is. Also he states that the biggest barrier for solar is the costs of installing it.

In another study, Sen (2011) developed a model for electricity generation from a mix of renewable sources to satisfy the electrical needs of an off-grid remote village in India with the help of HOMER Software. In this study, small hydropower, wind turbine generator, solar photovoltaic, and biodiesel generator are used as renewable energy sources. As a result of this study, Sen (2011) concluded that a combination of small hydropower, solar photovoltaic, and biodiesel generator is the best combination.

In Turkey, due to high potentials of renewable energy sources, the policy of the government to increase utilization of domestic and clean sources, and negative impacts of high dependency on the external sources in terms of national security and energy prices, the desire for energy generation from renewable energy sources increases day by day. There are many studies about renewable energy sources in Turkey.

Ertuğrul and Kurt (2009) studied solar energy and concluded that solar energy can be used for electricity generation in a small scale project and also it can be used together with the other renewable energy sources for electricity generation. In addition to this, they stated that wind energy and geothermal energy are the other renewable energy sources that deserve investment due to their low operation costs.

Similarly, Ertürk (2011) analyzed wind and solar energy potentials of Turkey to find out whether these sources could be utilized economically based on current regulated prices and current wind and solar power plant costs collected from the literature. In this study, Ertürk (2011) constructed five different models for five technologies which are onshore wind, offshore wind, solar PV, solar trough, and solar tower to conduct economic analysis. As a result of his study, he stated that under the current technological structure and considering costs of wind and solar energy technologies and the feed-in-tariffs for renewable energy sources in Turkey, only onshore wind projects are attractive among five alternatives. Moreover, he concluded that although solar tower power plant projects will also attract investments in the future, Turkey has to wait for construction cost of solar tower power plants to decrease in order to utilize solar potential.

In a recent study, Öğünlü (2012) stated in his research that Turkey is at the edge of deciding its pathway to reach its goal concerning utilization of renewable energy sources, especially wind power. He investigated the project called Competitive Renewable Energy Zone (CREZ) in Texas which utilizes new transmission projects to transfer the wind power into electricity in an efficient manner. As a result of studying the design and implementation of CREZ project, for Turkey he suggested ways to handle renewable applications in combination with existing transmission constraints. Some of those suggestions are as follows:

- **i)** reduction of dependency on foreign countries,
- **ii)** development of an optimum management strategy and wind farm allocation to reach the Country's goal on renewable energy by 2023,
- **iii)** designation of CREZ like regions by Energy Market Regulatory Authority (EPDK).

In addition to these, Yılmaz and Kösem (2011) studied the estimation of energy and electricity consumption of Turkey in 2015. According to this study, energy and electricity consumption of Turkey are estimated as 114.779 Mtoe and 259.407 GWh, respectively. Then, they compared these data with the annual wind energy potential of Turkey (400 GWh) and concluded that the energy demand of Turkey in 2015 can be supplied entirely by the wind energy potential of Turkey.

As stated previously, one of the main reasons to evaluate renewable energy sources contribution in the energy generation is that these sources are clean, in other words environmentally friendly. Because of the fact that they have no or relatively less harm on the environment, increasing utilization of renewable energy sources is necessary for sustainable development of Turkey. There are many studies about environmental and social aspects of renewable energy sources. Some of them are given below.

Ocak et al. (2004) studied energy utilization and its environmental impacts in the view of sustainable development in Turkey. They investigated energy utilization, renewable energy, energy efficiency, environment, and sustainable development aspects in terms of both current and future perspectives. According to this study, environmental pollution is becoming a serious problem due to increasing energy consumption. Regarding this situation, they stated that renewable energy sources are one of the most efficient and effective solutions for sustainable energy development and environmental pollution prevention in Turkey. As a result, they stated that especially solar, biomass, hydropower, geothermal, and wind energy should be evaluated and supported by government and private sectors.

Similarly, Onat and Bayar (2010) studied investment amounts and greenhouse gas emission details until 2020 by considering current electricity sector and increasing capacity. They stated that Turkey is at a critical point with regard to installed power required to meet the energy demand. Within the next 10 years, about 45-50 GW power must be added to the existing system. By anticipating the rate of fossil fuel plants in the additional installed power as 65% until 2020, a significant increase was expected especially in SO_x emission. This problem may be overcome by the utilization of renewable energy sources.

Another reason to evaluate and invest money for renewable energy sources is their positive effects on economic development. In order to create new jobs, create new industries, and promote the development of certain regions, policy makers in many countries are now implementing renewable energy policies (IRENA, 2011). The relation between renewable energy and its economic benefits are investigated in many studies. Some of these studies are given below.

According to American Solar Energy Society (ASES), the renewable energy and energy efficiency industries created a total of 8.5 million jobs in 2006. By 2030, 1 out of 4 workers in the U.S. will be working in renewable energy sector and energy efficiency industries. The 40 million jobs including engineering-related, manufacturing, construction, accounting, and management will be created (Werner, 2008).

Similar to the estimations in U.S., Bölük (2013) studied impacts of renewable energy policy both on energy sector and whole national economy of Turkey. In this study, two possible scenarios which are Policy Scenario -1 for 2013-2015 period and Policy Scenario -2 for 2023 term were investigated. According to this study, for 2013-2023 period, most employment will be created by wind energy sector. The possible number of jobs created by wind energy sector is estimated as 288,000. Wind energy sector is followed by hydropower (200,000 jobs), solar PV (41,640 jobs), geothermal (11,520 jobs), and biomass (5,735 jobs) energy sectors for 2013-2023 periods.

In another study, Inglesi-Lotz (2013) studied estimation of the impact of renewable energy consumption to economic welfare by employing panel data techniques. In this study, annual data for 31 OECD countries from 1990 to 2010 were evaluated within a multivariate framework. According to this study, it is revealed that there is long run equilibrium relationship between real GDP and real GDP per capita, total renewable energy consumption or share of total renewable energy consumption, real gross fixed capital formation and the employment of the countries. It is indicated that a 1% increase in renewable energy consumption will increase GDP by 0.022% and GDP per capita by 0.033% while a 1% increase of the share of the renewable energy to the energy mix of the countries will increase GPD by 0.019% and GDP per capita by 0.027%.

It is apparent that development of renewable energy sources is inevitable for sustainable development of Turkey if it aims to have secure and stable energy supply and low energy prices as explained in the Strategic Plan of ETKB (2010). In addition to these, Turkey needs clean and environmentally friendly energy sources to mitigate its increasing rate of pollution and carbon emission. The goal of this study is to seek an answer to the question of which renewable energy source should be selected to increase its contribution to Turkey's electricity generation. Based on the literature review, this evaluation is done considering two main criteria, *Energy Goals* and *Environmental Goals*. *Energy Goals* are evaluated in terms of (i) maintaining security for electricity supply, (ii) supplying electricity with low prices, (iii) maintaining stability for electricity generation, and (iv) maintaining economic development. On the other hand, *Environmental Goals* are evaluated with respect to (i) maintaining low carbon, SO_x, and NO_x emission, (ii) maintaining environmental sustainability, (iii) minimum impact on public health, and (iv) maintaining social acceptability.

3.2. Studies Performed with AHP

AHP is one of the most widely used approaches for multi-criteria decision making problems, developed by Thomas Saaty (1980). AHP allows decision makers to model a complex problem in a hierarchical structure, considering relationships between objectives, criteria, and alternatives. AHP has many application areas such as evaluation and prioritization, resource allocation, quality management, group decision making, environmental application, etc. (Forman and Gass, 1999).

Modeling the problem with AHP, allows decision makers to easily reveal the priorities of the alternatives and rank them to reach the stated goal. There are many studies performed with AHP to prioritize the alternatives. Some of the studies conducted using AHP are summarized below.

Forman and Gass (1999) illustrated areas in which AHP has been applied. Some of them are given as follows. The Xerox Corporation uses AHP for R&D decisions on portfolio management, technology implementation, and engineering design selection. Car designers at the General Motor's Advanced Engineering Staff use AHP to evaluate design alternatives, perform risk management, and arrive at the best and most cost-effective automobile designs. In addition to these, NASA/DOE used AHP to evaluate alternatives, ranging from photovoltaic cell farms to nuclear reactor, with respect to selected criteria to recommend a power source for the first lunar outpost.

Sarucan et al. (2010) established a hierarchical structure and applied AHP to select the best wind turbine among candidate turbine brands. In this study, they considered four criteria which are technical specifications, economical specifications, environmental impacts, and customer services to evaluate six wind turbine brands (i.e. Enercon, Fuhrlander, GE-Energy, Nordex, Vensys, and Vestas). As a result of this study, they concluded that technical specifications are the most important criterion in selecting the best wind turbine brand followed by economical specifications and Vestas is identified as the most appropriate one among six wind turbine brands.

In another study, Palaz and Kovancı (2008) used AHP to determine submarine types which are the most preferred in Submarine Fleet. Their objective for performing this study was to develop a flexible and practical R&D project selection methodology that can be used by Turkish Naval Force managers. In this study, they considered five criteria including secrecy, robustness, speed, sensors and devices, and weapon systems to evaluate four types of submarine. They concluded that secrecy is the most important criterion and AIP type of submarine is the most preferred type of submarine.

In a different study, Güngör et al. (2010) applied AHP to determine the priorities of districts which are eligible to become provinces in Turkey. In this study, they selected nine different criteria to evaluate eight districts located in different regions of Turkey. According to this study, they concluded that Alanya is the most eligible district to become a province and income per capita is the most important criterion to select the most eligible province.

Identification of the most suitable renewable source to invest money in is an important and complex problem because this decision will impact future energy policies of the country. AHP is widely used by researchers and policy makers to examine renewable energy sources in order to create energy policies in the world. Some of the studies in which renewable energy sources are evaluated are summarized below.

Shen et al. (2011) examined how different policy goals lead to utilization of various renewable energy sources in Taiwan. In their study, it is stated that renewable energy is considered by many policy makers to contribute to achieving at least three major policy goals: the energy goal, the environmental goal, and the economic goal (3E Goals). Parallel with this idea, Taiwan announced the Sustainable Energy Policy Principles in 2008. According to these principles, Taiwan's renewable energy policy should accomplish the 3E goals. In order to weight the goals, AHP is used. According to this study, environmental goal is the most important criteria followed by economic goal. As a result of this study, non-pumped storage hydropower is identified as the most important alternative according to energy and environmental goals, however, solar energy come forward when economical aspects are considered. They concluded that non-pumped storage hydropower, solar energy, and wind energy are the three sources that could meet 3E Goals at the same time.

Similarly, Gerogiannis et al. (2010) used AHP to prioritize hydropower, geothermal, biomass, wind power, and photovoltaic with respect to cost (of different power plant types related to investment costs), CO_2 emissions, man years (creation of job during a year), and efficiency. In this study, the research data were obtained by a survey given to four different population groups in Greece which are economists, engineers, environmentalists, and citizens. Another set of data was gathered from World Energy Council reports and other researches. As a result of this study, wind power is identified to be the most suitable option among the major renewable energy source alternatives for all groups except engineers who ranked hydropower first.

In another study, Phdungsilp and Wuttipornpun (2011) used AHP to develop an assessment framework regarding risks to health and environment and the society's benefits of the electric power plant generation from renewable energy sources in Bangkok. In their study, solar power plant, PV plant, biomass, biogas, and municipal solid waste plant (MSW) were evaluated as renewable energy sources. According to this study, solar power plant has the lowest risk to human health and the environment followed by PV plant. In the society's benefit case, biomass has the highest potential followed by biogas.

In a different study, Daniel et al. (2010) evaluated significant renewable energy sources in India using AHP. Parameters like cost, efficiency, environmental impact, installed capacity, estimated potential, reliability, and social acceptance are considered in this model to identify and rank the renewable energy sources such as solar, wind, and biomass. The following ranking is obtained as a result of this study with respect to Indian policies and conditions to meet the future energy demand: wind energy, biomass energy, and solar energy. Cost and efficiency are identified as the most important parameters. The relative importances of the other parameters were far behind the cost and efficiency.

A similar study is conducted by Kabir and Shihan (2003) for Bangladesh. They evaluated solar energy, wind energy, and biogas as renewable energy sources with respect to selected criteria such as unit cost, technical characteristics (equipment design and complexity, plant design, equipment and parts availability, plant safety, maintainability, training required), location (plant size, flexibility), environment (impact on ecosystem, noise) and social impacts (people’s acceptability and quality of life). As a result of this study, it is concluded that solar energy is the most preferred option followed by biogas and then wind energy.

CHAPTER 4

METHODOLOGY

4.1. Multi-criteria Decision Making (MCDM)

Multi-criteria Decision Making (MCDM) deals with complex problems that are characterized by a mixture of quantitative and qualitative objectives. It establishes preferences between alternatives subject to an explicit set of objectives and measureable criteria. It is one of the most preferred tools within operations research field for problems that involve multiple and conflicting objectives (Ishizaka and Labib, 2011). It is well known that existence of many conflicting objectives makes the problem more complex and it becomes harder to make a decision. In addition to selecting the best alternative, MCDM approaches can as well be used to generate an overall ordering of options, from the most preferred to the least preferred. Thus, MCDM approaches provide a systematic procedure to help decision makers choose the most desirable and satisfactory alternative under uncertain situations (Cheng, 2000).

Although there are many MCDM methods, AHP proposed by Saaty (1980) is one of the best known and widely used approaches to deal with problems that involve multiple and conflicting objectives. In this study, AHP is used to develop a renewable energy source assessment model for selecting a renewable energy source to increase its contribution to Turkey’s electricity generation. Additionally, in this study, a sensitivity analysis is conducted by changing priorities of each criterion to represent possible scenarios and their impacts on the final decision. Using these scenarios as guidelines, impact of each criterion on the ranking of renewable energy sources can be evaluated by policy-makers. A brief introduction to AHP is provided in the following section.

4.2. Analytic Hierarchy Process

AHP, introduced by Thomas L. Saaty (1980), helps the decision maker to set priorities and make the best decision. Saaty (1980) provided the theoretical foundation for the AHP such that the decision making approach can take into account both tangible and intangible aspects. Therefore, it supports decision makers to make decisions according to their experience, knowledge, and intuition (Berrittella et al., 2007).

In AHP, the decision problem is decomposed into its elements according to their common characteristics and levels of importance. Although there are several hierarchical models, a basic hierarchy model consists of three major levels which are goal, criteria, and alternatives.

> **Goal:** Upper level of hierarchy. (For example, a newly married couple wants to take a vacation for their honeymoon. Their goal is to select the best place for their honeymoon.)

Criteria: Mid level of hierarchy. They are a group of factors which relate alternatives to the goal. (For example, there may be three important criteria for the newly married couple: ease of transportation, nightlife, and natural beauties.)

Alternatives: Lower level of hierarchy. They are a group of options for reaching the goal. (For example, there may be three alternative locations for their honeymoon which are Maldives, Phuket Island, and Antalya.)

Schematic representation of this basic hierarchical model is given in Figure 8. Each level is referred to as $L_i, i = 1, 2, \ldots, t$ where i is the index showing the level number and t is the total number of levels. It shows a goal to be reached, four alternative ways of reaching the goal, and three criteria against which the alternatives need to be evaluated. The hierarchical structure of the basic AHP allows dependencies among elements to be only between consecutive levels of the hierarchy, and the only possible direction of impacts is from the top to the bottom. The elements of a given level are assumed to be mutually independent (Adamcsek, 2008).

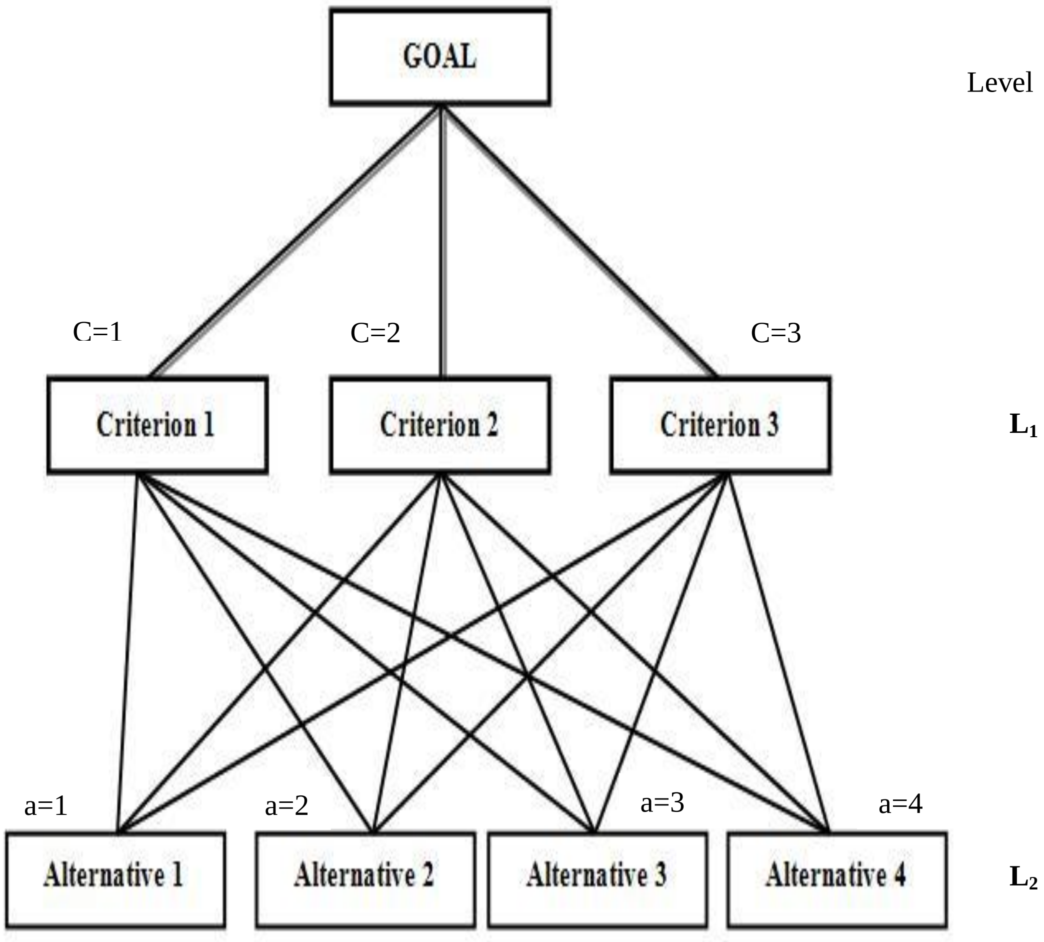

Figure 8. A simple AHP Hierarchy Model.

4.3. The Steps of AHP

After decision making problem is identified by clearly defining the criteria that affect the alternatives, there are five main steps to be followed in making a decision. These five steps are (Ishizaka and Labib, 2011; Saaty, 2008):

- **1-** Developing a hierarchy structure using the goal, criteria, and alternatives.
- **2-** Comparing the elements of hierarchy by making pairwise comparisons.
- **3-** Derivation of priority vectors.
- **4-** Measuring the consistency of the preferences.
- **5-** Obtaining the overall priorities of the alternatives.

In AHP, priorities represent the relative importance of elements in a hierarchy level with respect to each other. Thus, overall priorities of the alternatives can be used to rank the alternatives in achieving the selected objective.

4.3.1. Structuring the Hierarchy

Structuring the problem as a hierarchy depends on the number of hierarchical levels, complexity of the problem, and required detail for solving the problem. According to Dyer and Forman (1991), there are several hierarchical models which can be used to represent the problems in AHP. Some of them are as follows:

- Goal, Criteria, Alternatives.
- Goal, Criteria, Sub-criteria, Alternatives.
- Goal, Criteria, Sub-criteria, Scenarios, Alternatives.
- Goal, Actors, Criteria, Alternatives.
- Goal, Actors, Criteria, Sub-criteria, Alternatives.

Due to the fact that human brain can compare approximately 7 ± 2 subjects at a time, it is advised to restrict the subjects of the pairwise comparisons and thereby elements of each of the hierarchical level to less than 7 (Schomoldt, 1995).

4.3.2. Pairwise Comparisons

After structuring the hierarchy model for the problem, the next step is to compare the elements of each hierarchy level by making pairwise comparisons. Firstly, the level of relative importance of each criterion is identified with respect to the selected goal by pairwise comparison. Secondly, the pairwise comparisons of the alternatives are evaluated with respect to each criterion. Pairwise comparisons are represented in a matrix format and this matrix is named as the pairwise comparison matrix (PCM).

When forming PCMs in AHP, there are several important factors to be taken into account. These are as follows (Saaty, 1990):

- The matrix used in AHP must be formed from the same level of elements.
- The PCM must include all possible pairwise combinations.
- The pairwise comparisons are performed for each hierarchy level for the alternatives given in the lowest level of the hierarchy with respect to all the criteria given in the hierarchy level above.
- The PCM must be square (nxn).

In this study, PCMs are named using the following convention:

i. Each PCM matrix is named as $PCM_{(.)}$.

ii. The first level has a number of elements called criteria. If the PCM belongs to the first level it will have only one PCM and this PCM will have a single index which will be 1. Thus the PCM of L_1 is PCM_1.

iii. The elements (i.e. criteria) in L_1 will be connected to a number of elements (i.e. sub-criteria) in L_2. The second level will have one PCM for each criteria of L_1. The PCMs of L_2 will have two indices. The first index will provide information about L_1(i.e. the index of the criteria) and the second index will provide information about L_2 (i.e. the range of sub-criteria connected to the criteria of concern).

iv. Similar to the second level, PCMs of L_3 will have 3 indices.

An example is provided here to clear the naming scheme for PCMs. Consider the structure given in Figure 9.

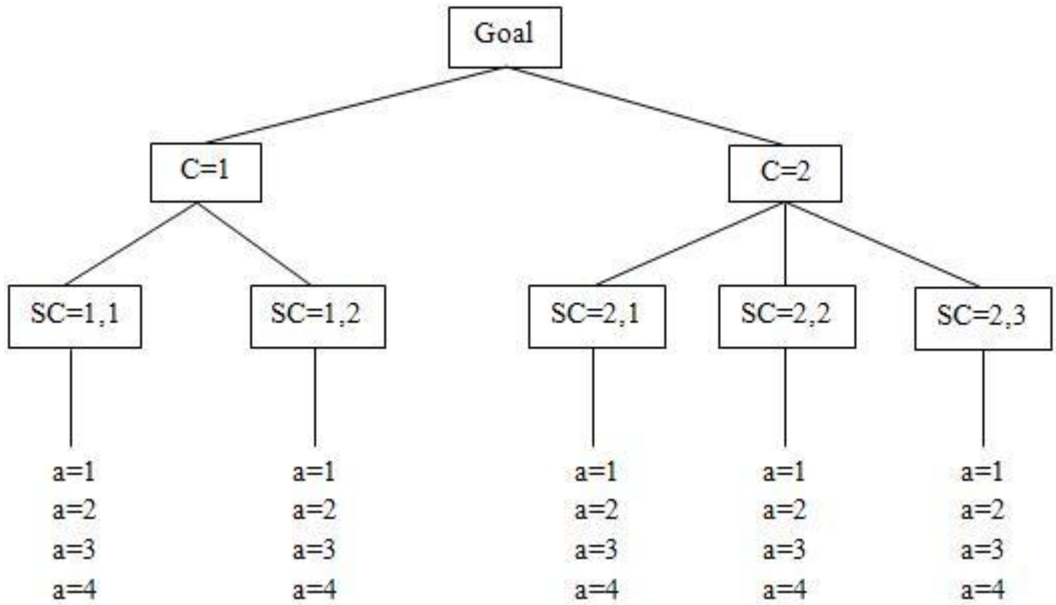

Figure 9. An example hierarchy structure.

For the first level, L_1, there is only one PCM:

$PCM_1 =$ (1)

	$C = 1$	$C = 2$
$C = 1$		
$C = 2$		

For the second level, L_2 there are two PCMs, one for each criteria (i.e. $C = 1$ and $C = 2$). The PCM for $C = 1$:

$PCM_{1,1-2} =$ (2)

	$SC = 1,1$	$SC = 1,2$
$SC = 1,1$		
$SC = 1,2$		

The PCM for $C = 2$:

$PCM_{2,1-3} =$ (3)

	$SC = 2,1$	$SC = 2,2$	$SC = 2,3$
$SC = 2,1$			
$SC = 2,2$			
$SC = 2,3$			

For the third level, L_3, there are five PCMs, one for each sub-criteria (i.e. $SC = (1,1), (1,2), \ldots, (2,3)$).

The PCM for $SC = 1{,}1$:

$PCM_{1,1,1-4} =$ (4)

	$a = 1$	$a = 2$	$a = 3$	$a = 4$
$a = 1$				
$a = 2$				
$a = 3$				
$a = 4$				

Other four PCMs are named as $PCM_{1,2,1-4}$, $PCM_{2,1,1-4}$, $PCM_{2,2,1-4}$, and $PCM_{2,3,1-4}$. They look like the same as Equation (4) but each one of the pairwise comparisons should be done with respect to the relevant sub-criteria (i.e. the second index in the name of the PCM).

When making pairwise comparison, the levels of relative importance of an element to the other elements are measured. In order to do this, a scale that combines qualitative and quantitative assessments is needed. As a result of many studies, applications, and the theoretical comparisons with other scales, Saaty (1990) developed a fundamental scale (Table 5) which is considered as the best scale for applications of AHP. This scale can be used in both quantitative and qualitative assessments such as social, psychological, and political fields. This scale is used for filling out the PCMs.

Table 5. AHP Fundamental Scale (Saaty, 1990).

Level of relative importance	**Definition**
1	Equally important.
3	Moderately more important
5	Strongly more important.
7	Very strongly more important.
9	Extremely more important.
2, 4, 6, 8	Intermediate values to reflect compromise.

The PCM for the first level, PCM_1, associated with the newly married couples decision problem is given in Equation (5). PCM_1 is used for comparison of three criteria that are identified by the couple in selecting their honeymoon place. Three other PCMs needs to be prepared for the next hierarchy level (i.e. alternatives).

$PCM_1 =$ (5)

	Ease of Transportation	Night Life	Natural Beauties
Ease of Transportation			
Night Life			
Natural Beauties			

After PCMs are formed, they are send out to survey participants and filled out by them using the AHP fundamental scale given in Table 5. While filling out PCMs, the numbers 1, 3, 5, 7, 9 or reciprocal of these numbers (i.e. 1/3, 1/5, 1/7, 1/9) are used. When compromise is needed in pairwise comparisons, intermediate values 2, 4, 6, 8, 1/2, 1/4, 1/6, 1/8 can also be used. However, it should be noted that even numbers and reciprocals of the even numbers are generally not needed.

Each element of PCM_1matrix, a_{ij} represents the relative importance of (i) with respect to (j) as can be seen in Equation (6). The diagonal elements of PCM_1 are all one, since each criteria or alternative must be equally important to itself (i.e. $a_{11} = a_{22} = a_{33} =$…..= $nn = 1$). Moreover, level of relative importance of (j) to (i) is represented by $1/a_{ij}$. For example, if the level of relative importance of “ease of transportation” to “night life” is 3 (i.e. $a_{12} = 3$) then the level of relative importance of “night life” to “ease of transportation” will be $1/3$ (i.e. a_{21} =$1/3$) in PCM_1 as shown in Equation (6).

$PCM_1 =$ (6)

	Ease of Transportation	Night Life	Natural Beauties
Ease of Transportation	a_{11}	a_{21}	a_{31}
Night Life	a_{12}	a_{22}	a_{32}
Natural Beauties	a_{13}	a_{23}	a_{33}

4.3.3. Determining Priorities

After PCMs are formed, send out to survey participants and filled out by them using the AHP fundamental scale, priorities of the elements in each PCM are calculated. As explained before, priorities of each element represent the relative importance of the elements with respect to the item they are connected to in the upper level of the hierarchy. Priority vector of the PCM is calculated. The elements of the priority vector are the priorities or the preferences of the elements of the PCM. Saaty (1977) suggested using eigenvector method to derive priorities in AHP applications. However, later, Ishizaka and Labib (2011) suggested two other methods, namely Mean of the Row Method and Geometric Mean Method and stated that Geometric Mean Method is a credible method and can be preferred to the eigenvector method. These two methods are explained below.

1- ***Mean of the Row Method:*** Firstly, the elements of each column are divided by the sum of corresponding column, so all elements are normalized. Then, arithmetic mean of each row is calculated to form the priority vector.

2- ***Geometric Mean Method:*** Firstly, geometric mean value of each row is calculated and a vector showing the geometric mean value of each row is obtained. Then, this vector is normalized using the sum of the geometric mean values to obtain the priority vector.

Newly married couple example is used here to illustrate these two methods. Equation (7) shows PCM_1 for L_1 filled out by the groom.

$PCM_1 =$

	Ease of Transportation	Night Life	Natural Beauties
Ease of Transportation	1	1/3	1/5
Night Life	3	1	1/2
Natural Beauties	5	2	1

(7)

In the mean of the row method, elements of each column are normalized using the sum of the consequent column:

$$N = \begin{bmatrix} 0.111 & 0.100 & 0.118 \\ 0.333 & 0.300 & 0.294 \\ 0.556 & 0.600 & 0.588 \end{bmatrix} \tag{8}$$

Then, arithmetic mean of each row is calculated to obtain the priority vector.

$$\mathrm{W}_{PCM_1}^{N} = \begin{bmatrix} 0.110 \\ 0.309 \\ 0.581 \end{bmatrix} \tag{9}$$

This priority vector represents the priorities of each criterion. The priority vector indicates that natural beauties are relatively more important than ease of transportation and night life for the groom in selecting the best place for their honeymoon.

In the geometric mean method, geometric means of each row are calculated:

$$\mathrm{G} = \begin{bmatrix} 0.405 \\ 1.145 \\ 2.154 \end{bmatrix} \tag{10}$$

Then this vector is normalized using the sum of the geometric mean values (i.e. $0.405 + 1.145 + 2.154 = 3.704$):

$$\mathrm{W}_{PCM_1}^{G} = \begin{bmatrix} 0.109 \\ 0.309 \\ 0.582 \end{bmatrix} \tag{11}$$

Generally, Mean of the Row Method gives similar results with those of the Geometric Mean Method. In this study, Geometric Mean Method is used to calculate the priority vectors. The priority vectors are named using the following convention:

i. For L_1: The priority vector of PCM_1 is named as W_{PCM_1}. For Equation (1), the elements of the priority vector are named as follows:

$$W_{PCM_1} = \begin{bmatrix} w_1 \\ w_2 \end{bmatrix}$$

ii. For L_2: The priority vector of $PCM_{1,1-2}$ is named as $W_{PCM_{1,1-2}}$. For Equation (2), the elements of the priority vector are named as follows:

$$W_{PCM_{1,1-2}} = \begin{bmatrix} w_{1,1} \\ w_{1,2} \end{bmatrix}$$

and for Equation (3), the elements of the priority vector are named as follows:

$$W_{PCM_{2,1-3}} = \begin{bmatrix} w_{2,1} \\ w_{2,2} \\ w_{2,3} \end{bmatrix}$$

iii. For L_3: The priority vector$PCM_{1,1,1-4}$ is named as $W_{PCM_{1,1,1-4}}$. For Equation (4), the element of the priority vector are named as follows:

$$W_{PCM_{1,1,1-4}} = \begin{bmatrix} w_{1,1,1} \\ w_{1,1,2} \\ w_{1,1,3} \\ w_{1,1,4} \end{bmatrix}$$

For the remaining priority vectors the elements are named similarly. The elements of $W_{PCM_{1,2,1-4}}$ are named as follows:

$$W_{PCM_{1,2,1-4}} = \begin{bmatrix} w_{1,2,1} \\ w_{1,2,2} \\ w_{1,2,3} \\ w_{1,2,4} \end{bmatrix}$$

The elements of $W_{PCM_{2,1,1-4}}$are named as follows:

$$W_{PCM_{2,1,1-4}} = \begin{bmatrix} w_{2,1,1} \\ w_{2,1,2} \\ w_{2,1,3} \\ w_{2,1,4} \end{bmatrix}$$

The elements of $W_{PCM_{2,2,1-4}}$ are named as follows:

$$W_{PCM_{2,2,1-4}} = \begin{bmatrix} w_{2,2,1} \\ w_{2,2,2} \\ w_{2,2,3} \\ w_{2,2,4} \end{bmatrix}$$

The elements of $W_{PCM_{2,3,1-4}}$ are named as follows:

$$W_{PCM_{2,3,1-4}} = \begin{bmatrix} w_{2,3,1} \\ w_{2,3,2} \\ w_{2,3,3} \\ w_{2,3,4} \end{bmatrix}$$

4.3.4. Consistency of Preferences

After obtaining the priority of each element in a PCM (i.e. priority vectors), consistency of survey participants' preferences for each PCM is evaluated. AHP has a certain tolerance for inconsistency. Surveys which have at least one PCM that does not satisfy the tolerance are not included in the evaluation; they will be left out of the analysis. To measure the consistency of the preferences, Saaty (1980) developed a Consistency Ratio, CR. If the consistency ratio is lower than 0.1, the participants' answers are accepted and considered to be consistent and his/her survey can be processed. If the consistency ratio is bigger than 0.1, there is unacceptable inconsistency and participants should fill out the survey again or his/her survey will be left out of the analysis. Consistency Ratio, CR can be calculated using the following equation:

$$CR = \frac{CI}{RI} \tag{12}$$

Where CI is the consistency index and RI is the random index.

In order to evaluate the consistency of the preferences, first the principal eigenvalue λmax of the PCM is calculated from (Saaty, 1990):

$$PCM(\mathrm{W}_{PCM}) = \lambda max(\mathrm{W}_{PCM}) \tag{13}$$

where W_{PCM} is the priority vector of the elements and λmax is the principal eigenvalue of PCM matrix. If the PCM is fully consistent, then $\lambda max = n$ (size of matrix) (Saaty, 1990).

After obtaining the principal eigenvalue of matrix, PCM, then the CI is calculated as follows (Coyle, 2004):

$$CI = \frac{\lambda max - n}{n - 1} \tag{14}$$

Random index values, RI for various sizes of a PCM, n are given in Table 6 (Saaty, 1977).

Table 6. Random Index values, RI for various sizes of a PCM, n

$\boldsymbol{n}$	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
$\boldsymbol{RI}$	*0.00*	*0.00*	*0.58*	*0.90*	*1.12*	*1.24*	*1.32*	*1.41*	*1.45*	*1.49*

4.3.5. Overall Priorities of Alternatives

The last step of AHP is calculation of overall priorities of each alternative with respect to the stated objective. In order to find the overall priority of an alternative, priorities of this alternative with respect to its corresponding upper level elements are used. For an AHP structure with a goal, n criteria, and m sub-criteria, the overall priority of an alternative is calculated as follows (modified from Ishizaka and Labib, 2011):

$$w_{alternative\ i} = \sum_{c=1}^{n} w_c \sum_{k=1}^{m} w_{c,k,i} \times w_{c,k} \qquad i = 1,2,\ldots,p \qquad (15)$$

where $w_{alternative\ i}$ is the overall priority of alternative i and p is the total number of alternatives, $w_{(.)}$ is the priority of element represented by $(.)$.

4.4. Group Decision Making in AHP

AHP is often used to aggregate decisions of a group of people. There are a number of methods to combine the preferences of individuals to obtain a single preference for the group (Ishizaka and Labib, 2011). One commonly used aggregation method is the Geometric Mean on Preferences method. In this method, the preferences of all participants are combined by taking the geometric mean of individual's preferences. For example; if person A enters a preference 5 and person B enters 1/5, then the overall preference becomes $\sqrt{5 \times \left(\frac{1}{5}\right)} = 1$.

In this study, aggregation of individuals' preferences to obtain a single preference for the group is performed using the Geometric Mean on Preferences method.

4.5. Sensitivity Analysis

Sensitivity analysis comprises of the manipulation of preferences of criteria to determine the degree of influence that each criterion has on the overall output. Sensitivity analysis allows generation of different rankings resulting from manipulated preferences of the criteria. If the ranking does not change, the results are said to be robust, otherwise they are said to be sensitive (Ishizaka and Labib, 2011). Through sensitivity analysis, different scenarios can be generated and these scenarios may provide additional information for decision makers about how different circumstances affect the decision without forcing them to change their original considerations (Shen et al., 2011).

CHAPTER 5

ELEMENTS OF SURVEY

5.1. Objective of the Survey Study

The objective of this survey study is to select a renewable energy source to increase its contribution to Turkey's electricity generation. Although renewable energy sources have been used for various purposes, in this study, they have been evaluated only in terms of increasing their contribution to electricity generation. In order to select an appropriate renewable energy source for this aim, a survey has been conducted with experts who have experience and studies on renewable energy technologies, market conditions, and energy policies.

In order to reach the stated objective, two criteria and four sub-criteria related to each of these criteria have been selected as a result of a comprehensive literature review and opinions of academicians and professionals. By considering these criteria and sub-criteria, five renewable energy sources which are ***solar***, ***biomass***, ***geothermal***, ***wind,*** and ***hydropower*** have been evaluated. The structure of the model is given in Figure 10. The criteria and sub-criteria mentioned above are explained below.

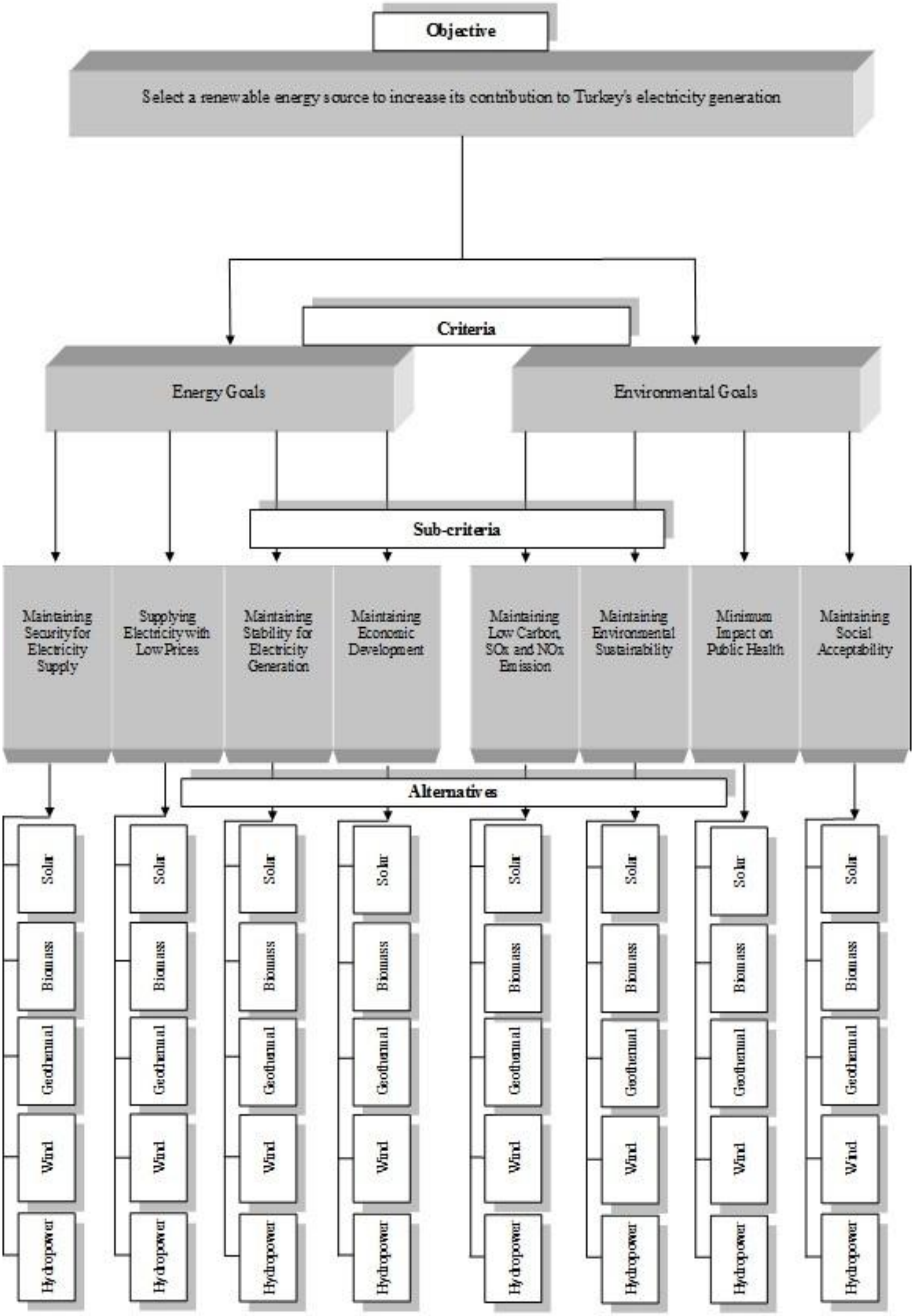

Figure 10. Structure of the Model.

5.2. Energy Goals

Based on the literature review, *Energy Goals* are evaluated in terms of four main sub-criteria for Turkey as given in Figure 10. The list may be extended, however, pairwise comparisons required by AHP becomes difficult as the number of sub-criteria increases. Thus, both *Energy Goals* and *Environmental Goals* are limited to four sub-criteria. Each sub-criterion of *Energy Goals* is explained below.

5.2.1. Maintaining Security for Electricity Supply

Turkey has high dependency on external sources for energy and electricity supply. In parallel to the increase in energy demand, Turkey's dependency on foreign sources increased from 52% in 1990 to 72% in 2011 (TMMOB, 2012). Moreover, the energy intensity (units of energy per unit of GDP) is higher than OECD standards which show that energy efficiency is low in Turkey (Bilginoğlu and Dumrul, 2012).

In addition to these, rapid population growth, internal immigration and irregular urbanization, monopolization of the world's energy markets, high import rate in primary energy demand, and increase in dependency on natural gas increases the dependency of Turkey on foreign sources (Bilginoğlu and Dumrul, 2012). Due to high dependency on natural gas, lignite, and imported coal for electricity generation, Turkey is highly exposed to international and political changes and decisions. Therefore, energy security is low in Turkey. In order to maintain security for electricity supply, the share of renewable energy sources in electricity generation should be increased in Turkey. Thus, in this study, "Maintaining Security for Electricity Supply" is chosen as a sub-criterion of *Energy Goals*.

5.2.2. Supplying Electricity with Low Prices

Turkey obtains 45% and 10% of its electricity from natural gas and imported coal as external energy sources (DEK-TMK, 2012). As a country located between the Middle East and Balkans, having an unstable geopolitics, Turkey has been affected in an inevitable manner from the conflictions in this region. Therefore, the electricity sector is vulnerable to the price fluctuations in these energy sources.

Electricity is one of the main economic inputs for residents, industry, agriculture, transportation, and other sectors (Shen et al., 2011). In order to maintain resident's living standards and national competitiveness, electricity prices should be low. However, renewable energy density is so low that energy prices are usually higher than fossil fuels in worldwide as can be seen in Table 7. In order to supply electricity with low prices in parallel with sustainable development, development of renewable energy sources should consider electricity prices as a sub-criterion.

Table 7. Investment costs and energy costs of sources (EPA, 2012; IRENA, 2012; IEA, 2013).

Source	*Investment Cost ($/kW)*	*Cost of Energy ($/MWh)*
Coal	1,000-1,500	25-50
Natural Gas	400-800	37-55
Biomass	1,880-6,800	60
Hydropower	1,500-2,500	10-50
Solar	6,300-10,500	170-360
Geothermal	3,500-4,600	59-94
Wind	1,800-2,200	60-140

5.2.3. Maintaining Stability for Electricity Generation

A common drawback of renewable energy sources is the unpredictable and intermittent output of electrical power (Shen et al., 2011). Although the output of any actual power plant is variable and unpredictable to a certain output, wind energy and solar energy have these characteristics in a high degree (Perez-Arriaga and Batlle, 2012). Wind energy and solar energy both experience intermittency which is a combination of *non-controllable variability*, *unpredictability*, and dependency on sources that are *location dependent* (IEC, 2012). Each of these three aspects creates distinct challenges for manufacturers and grid operators in integrating wind and solar generation.

- **Non-controllable variability:** Due to the fact that wind and sun are variable sources, their availability as an energy source fluctuates due to their patterns, clouds, and cycles of day and night (Komor, 2009). Therefore, additional energy is needed to balance supply and demand on the grid because of this fluctuation in power output (IEC, 2012).

- **Unpredictability:** The availability of wind and sunlight is partially unpredictable. A wind turbine may only produce electricity when the wind is blowing, and solar PV systems work when the sunlight exists (IEC, 2012). It is very difficult to predict the accuracy of output of wind and solar even if forecasting techniques are improving (Perez-Arriaga and Batlle, 2012). Therefore, wind and solar power plants should be established in locations in which regular and constant wind and sunlight are available (Acar and Doğan, 2008).

- **Location dependence:** The best wind and solar sources must be located where they are sufficient and cannot be transported to generation site, unlike fossil fuels (Komor, 2009). Generation must be located with the source itself, and often these locations are far from the places where the power will ultimately be used (IEC, 2012).

In order to achieve *Energy Goals*, especially wind and solar energy technologies should be improved or - modified or these sources should be utilized together with other renewable or conventional sources. In order to take into account intermittency and unpredictability problems, “Maintaining Stability for Electricity Generation” is considered as a sub-criterion in this study.

5.2.4. Maintaining Economic Development

Although many studies have stated that there is a proportional relation between energy consumption and the level of economic development, increasing demand for energy together with population growth brings about a problem of energy supply security (Bilginoğlu and Dumrul, 2012). In countries with high import dependency like Turkey, domestic and renewable energy sources may be not only an important alternative solution to the energy supply security but also a source of employment for the young population (Erdal, 2012).

Renewable energy technologies have many contributions to economic development especially through creating new job opportunities and supporting development of local economies. According to UNEP (2013), more than 3.5 million people worldwide were estimated to be working on renewable energy sector in 2010, either directly or indirectly. Technologies dependent on renewable energy sources such as solar, geothermal, wind, hydropower, and biomass involve the greatest number of jobs in the installation, manufacturing, and administration phases (IRENA, 2011). In addition to these, some benefits of renewable energy technologies related with economic development are given below.

- Solar PV technology requires engineers and technicians to process raw materials and assemble system components. Qualified personnel is needed in project development to conduct resource assessments, as well as system designers, energy officers, business managers, financial analysts, and wholesalers (IRENA, 2011). Solar energy plants create considerable job opportunities especially in the construction phase of the plants (UNEP, 2012).

- Biomass energy creates job opportunities especially in rural areas because obtaining energy from biomass needs heavy agricultural labor. This may also contribute the prevention of immigration from rural to urban areas (YEGM, 2012). Additionally, creating new markets for traditional crops and mitigating land clearing costs are other main economical benefits of utilization of biomass energy (EPA, 2009).

- Due to the fact that geothermal is a location dependent energy source, it contributes to local economic development in various ways. Tourism, agriculture, industrial facilities, and heating places are the main job opportunities created by geothermal energy (Erkul, 2012). According to the Ministry of Development, the annual contribution of geothermal facilities to Turkish economy is around $5 billion and they create around 40,000 job opportunities in Turkey (Kalkınma Bakanlığı, 2013).

- Wind energy provides benefits to economy mainly in two ways (Noble Environmental Power, 2013):

  i) Wind energy contributes to stability of wholesale electricity cost, which is good for both consumers and for businesses.

  ii) Usage of wind energy creates demands for turbines and turbine components, which stimulates the manufacturing sector.

  Wind energy facilities bring economic development to the rural communities. Landowners can utilize their areas for farming and at the same time they can lease their land to companies to establish wind farms (NREL, 1997). Thus, local economy of the region develops and considerable job opportunities are created.

- With an average lifetime of 50 to 100 years, hydropower facilities are long term investments that may be benefited by various generations. Hydropower facilities bring electricity, highways, industry, and commerce to communities (USGS, 2013). In Turkey, Southeastern Anatolian Project (GAP) is a good example of an attempt to develop regional economy. With the help of this project, it is aimed to create around 3.8 million jobs in parallel with construction of electricity generation, irrigational, and agricultural facilities (GAP, 2011).

Thus in this study "Maintaining Economic Development" is selected as a sub-criterion of *Energy Goals*. Evaluation of the renewable energy sources should be done considering job creation possibilities, local economic development potentials, and commercialization potentials of these energy sources.

5.3. Environmental Goals

In Turkey, recently, environmental problems started drawing more attention from public due to increasing awareness and education. Harvesting, processing, distribution, and use of fuels have major environmental impacts (Holdren and Simith, 2000). As pollution and climate change have become a global threat, renewable energy sources became more and more desirable. In this study, maintaining low carbon, SO_X, and NO_X emission, maintaining environmental sustainability, minimum impact on public health, and social acceptability are identified as sub-criteria to evaluate renewable energy sources in terms of *Environmental Goals*. Each of these sub-criteria is explained below.

5.3.1. Maintaining Low Carbon, SO_x, and NO_x Emission

Intergovernmental Panel on Climate Change (IPCC) defines direct green house gases (GHGs) mainly as CO_2, CH_4, and N_2O and indirect GHGs mainly as NO_x, CO, and SO_2 (IPCC, 2013). Pollutants resulting from production and consumption of energy, gasses with green house effects, and global warming are the main environmental problems. Moreover, United Nations Framework Convention on Climate Change (UNFCCC) pointed out that climate change is the most important problem world has faced with (UNFCCC, 2007).

As a fossil fuel dependent country, Turkey is faced with environmental problems associated with increasing rate of GHG emissions. The inventory results revealed that overall GHG emissions as CO_2 equivalent for the year 2011 were 422.4 million tons in Turkey (TÜİK, 2013). In overall 2011 emissions, the energy sector had the largest share with 71%.

According to the World Nuclear Association Report, CO_2 emission resulted from electricity generation constitutes 37% of world CO_2 emission (WNA , 2011). WNA also reported that lignite, coal, oil, and natural gas have the highest CO_2 emissions and emissions from renewable energy sources are so far behind those of the conventional sources.

Experiencing the same problem with the rest of the world, Turkey has to take necessary actions in the energy sector to limit GHGs emissions. Thus, in this study, “Maintaining Low Carbon, SO_x, and NO_x Emission” is used as a sub-criterion of *Environmental Goals*.

5.3.2. Maintaining Environmental Sustainability

Sustainability is defined as meeting the needs of the current generation without compromising the ability of future generations to meet their needs (Morelli, 2011). More specifically, environmental sustainability is defined as a condition of balance, resilience, and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing biological diversity (Morelli, 2011).

Although renewable energy is considered to contribute environmental sustainability through substitution of fossil fuels, environmental impacts caused by the exploitation of renewable energy sources should be evaluated. Some of the impacts of renewable energy sources on environmental sustainability are as follows.

- **Solar Energy:** Solar power plants may affect the habitats, plants, and animal species (U.S. Department of Energy, 2012). Moreover, solar power plants require large areas. This causes the reduction of cultivable areas (Turney and Fthenakis, 2011). During the construction phase, solar power plants release toxic and flammable materials. In addition to these, solar power plants may cause water pollution due to thermal or chemical discharges (Tsoutsos et al., 2005).

- **Biomass Energy:** The traditional biomass may lead to forest degradation, decline in biodiversity, and soil degradation (IPCC, 2011). Additionally, fauna and flora may be affected and local climate change may occur due to utilization of the land for biomass power plants (IEA, 2002).

- **Geothermal Energy:** Although the impacts of geothermal power plants on environment are very small, negative effects on vegetation and wild life due to land use and subsidence caused by fluid withdrawal are the associated issues resulting from utilization of geothermal power (Wanqing, 2001). In addition to these, land features may be altered by geothermal power plants and some distorted formations may occur on the land (Kagel et al., 2007).

- **Wind energy:** Wind power plants may have negative effects on natural habitat if the site contains threatened species or be located on the migration route of the birds (Karydis, 2013).

- **Hydropower:** Large dams may have negative impact on local climate. Change in local climate may lead to changes in precipitation and temperature in the catchment area (IPCC, 2011). Moreover, according to NRDC (2013), hydropower facilities have negative impacts on habitats especially on fauna and flora. Additionally, hydropower facilities with large dams have impact on the land use. Utilization of large scale hydropower facilities may increase acidification and eutrophication (IEA, 2002).

Evaluation of renewable energy sources should consider these aspects of sustainability. Thus, one sub-criterion of the *Environmental Goals* is selected as “Maintaining Environmental Sustainability”.

5.3.3. Minimum Impact on Public Health

Renewable energy sources are substantially intended to restrict the negative effects of non-renewable energy sources. However, in addition to the impacts of renewable energy sources on nature and habitat, they may have some negative effects on public health. Major impacts of renewable energy sources on public health are noise, visual effects, and diseases related to them. Some of the negative effects of renewable energy sources on public health may be summarized as follows:

- **Solar Energy:** The accidental leakage of coolant systems may cause fire and gas releases from vaporized coolant and it affects public health and safety (Tsoutsos et al., 2005). Also, the released hazardous materials such as toxic wastes and corrosive liquids from solar power plants may risk the public health (IPCC, 2011). In addition to these, steel intensive infrastructure of solar power plants may cause negative impacts on public health due to their mineral and fossil source consumption (Meier and Steinfeld, 2010).

- **Biomass Energy:** The activity of the micro-organisms in the biomass storage volume may cause allergic reactions especially for workers (IPCC, 2011). In addition to these, biomass power plant ash gives off dust and it may risk the public health (IEA, 2002).

- **Geothermal Energy:** Geothermal power plants have negative impacts on mainly local land and water use (IPCC, 2011). Local hazards such as micro earthquakes may occur due to operation of a geothermal field (Kagel et al., 2007). The geothermal power plants may also have several negative effects on public health due to the released toxic gases which may affect health of both public and workers. In addition to these, noise is another problem arising from geothermal power plants especially in the construction phase (Gupta and Roy, 2007).

- **Wind Energy:** Due to the operation of the turbines, noise is the major concern for wind power plants (EWEA, 2013). Visual impacts of wind turbines are other concerns for public (IPCC, 2011). In addition to these, the wind turbines may produce a "shadow flicker" as sunlight passes through the rotating blades. This effect may risk the epilepsy sufferers (IEA, 2002).

- **Hydropower:** Hydropower facilities may cause change in water quality, and may increase water-borne diseases. Due to the stagnation of water by constructing dams, growth of harmful micro-organisms may accelerate (IPCC, 2011). Moreover, hydropower facilities may have a significant effect on the visual amenity of the region. Natural beauties of the region may disappear. In addition to these, noise is another concern of hydropower facilities especially during their construction phase (IEA, 2002).

Impacts of the energy generation facilities on public health are very controversial issues in today's world. In this study, evaluation of renewable energy sources should be performed by considering these negative effects associated with utilization of renewable energy sources.

5.3.4. Maintaining Social Acceptability

Renewable energy sources are inevitable to maintain sustainable development. They provide many benefits in many aspects such as energy, environment, and economy as stated before. However, social acceptance is recognized as an important issue shaping the widespread implementation of renewable energy technologies and the achievement of energy policy targets (Devine-Wright, 2007). Several indicators show that social acceptance for renewable energy technologies and policies are high in many countries (Horbaty, 2008) whereas in others there is public resistance for some renewable energy power plants such as small hydropower plants.

In Turkey, there are several controversial issues about development of renewable energy plants especially for hydropower facilities. Public reactions to development of hydropower facilities mainly cover the excessive usage of water and have been increased after the passing of Electricity Market Law No. 4628 (TMMOB, 2011). At first, public opposition was seen in the eastern part of Black Sea region due to the construction of large amount of run-of-river hydropower plants. Recently, public opposition to hydropower facilities has spread to power facilities in south and southeastern parts of country (TMMOB, 2010). Similar public reactions may be seen for other renewable energy sources due to excessive land use, limitation on agricultural facilities, and negative effects on public health. Thus, "Maintaining Social Acceptability" is considered as a sub-criterion of *Environmental Goals*.

5.4. Survey Form

As explained before, AHP is chosen as the multi-criteria decision making method in this study. As required by AHP, a survey form is prepared to collect expert opinion. The survey form is composed of pairwise comparison matrices associated with two criteria (i.e. *Energy Goals* and *Environmental Goals*) and four sub-criteria associated with each of these criteria. The survey form is given in Appendix A.

CHAPTER 6

ANALYSIS OF STUDY

6.1. Assessments of Survey Forms

As stated before, a total of 120 survey forms are send out to experts who are experienced and studying on renewable energy technologies, market conditions, and energy policies. Among 120 experts, 37 of them filled out and returned the surveys. However, eight of the returned survey forms had consistency ratios bigger than 0.1 and left out of the analysis. Thus, a total of 29 survey forms are evaluated in this study. The distribution of employers for 29 experts is given in Table 8. In this survey study, experts performed pairwise comparisons for all PCMs given in Appendix A using the AHP fundamental scale given in Table 5.

Table 8. Distribution of experts' employers.

Number of Experts	Employer
10	University
4	General Directorate of Renewable Energy (YEGM)
4	World Energy Council - Turkish National Committee (DEK-TMK)
2	Ministry of Energy and Natural Resources (ETKB)
1	Energy Market Regulatory Authority (EPDK)
1	Turkish Electricity Transmission Company (TEİAŞ)
1	General Directorate of Mineral Research and Exploration (MTA)
1	General Directorate of State Hydraulic Works (DSİ)
1	Ministry of Development
3	Private Sector
1	Editor of an Energy Journal

6.2. Analysis of Survey Forms

The methodology of AHP explained in Chapter 4 is followed to analyze the survey forms. A sample analysis conducted for one of the expert's survey forms is provided here. The survey form filled out by one of the experts (will be referred to as Expert 1 from here on) is given in Appendix B. For the sake of completeness, necessary PCMs are repeated here.

AHP procedure followed for Expert 1's survey data is explained below.

Pairwise comparisons of criteria with respect to the objective provided by Expert 1, PCM_1 is given in Equation (16).

PCM_1 = (16)

	Energy Goals	Environmental Goals
Energy Goals	1	1
Environmental Goals	1	1

Priority vector of PCM_1 is obtained by using geometric mean method and given in Equation (17).

$$W_{PCM_1} = \begin{bmatrix} 0.5 \\ 0.5 \end{bmatrix} \tag{17}$$

Since W_{PCM_1} consists of two elements, the consistency ratio of it is equal to 0.

Pairwise comparisons of sub-criteria with respect to *Energy Goals*, $PCM_{1,1-4}$, is given in Equation (18).

$PCM_{1,1-4} =$ (18)

	Maintaining Security for Electricity Supply	Supplying Electricity with Low Prices	Maintaining Stability for Electricity Generation	Maintaining Economic Development
Maintaining Security for Electricity Supply	1	1/2	1	3
Supplying Electricity with Low Prices	2	1	3	5
Maintaining Stability for Electricity Generation	1	1/3	1	6
Maintaining Economic Development	1/3	1/5	1/6	1

The priority vector of $PCM_{1,1-4}$ is obtained by using the geometric mean method and given in Equation (19).

$$W_{PCM_{1,1-4}} = \begin{bmatrix} 0.223 \\ 0.472 \\ 0.240 \\ 0.065 \end{bmatrix} \tag{19}$$

To calculate the CR of $PCM_{1,1-4}$, firstly, λmax is obtained using Equation (13) as 4.147.

Then, CI is calculated using Equation (14):

$$CI = \frac{4.147 - 4}{4 - 1} = 0.049 \tag{20}$$

After these, RI is taken from Table 6 and CR is calculated using Equation (12):

$$CR = \frac{0.049}{0.090} = 0.055 \tag{21}$$

Due to the fact that CR is smaller than 0.1, the preferences of Expert 1 with respect to *Energy Goals* criteria are found to be consistent. The rest of $PCMs$ of Expert 1 (see Appendix B) and $PCMs$ of other experts are evaluated in the same manner.

The next step is aggregation of the individuals' pairwise comparison matrices into a single pairwise comparison matrix for the group. The group $PCMs$ are compiled by Geometric Mean on Preferences method and overall priorities of the alternatives are obtained. The group $PCMs$, priority vectors, and consistency ratios of these $PCMs$ are provided below.

PCM_1 for the group is calculated and given in Equation (22).

$PCM_1 =$ (22)

	Energy Goals	Environmental Goals
Energy Goals	1	1.950
Environmental Goals	0.513	1

CR = 0

Priority vector of PCM_1 is given in Equation (23).

$$W_{PCM_1} = \begin{bmatrix} 0.661 \\ 0.339 \end{bmatrix} \quad (23)$$

$PCM_{1,1-4}$ (i.e. pairwise comparisons of sub-criteria with respect to *Energy Goals*) for the group is calculated and given in Equation (24).

$PCM_{1,1-4} =$ (24)

	Maintaining Security for Electricity Supply	Supplying Electricity with Low Prices	Maintaining Stability for Electricity Generation	Maintaining Economic Development
Maintaining Security for Electricity Supply	1	2.000	1.211	2.118
Supplying Electricity with Low Prices	0.5	1	0.677	1.023
Maintaining Stability for Electricity Generation	0.826	1.477	1	1.732
Maintaining Economic Development	0.472	0.978	0.577	1

CR = 0.001

Priority vector of $PCM_{1,1-4}$ is given in Equation (25).

$$W_{PCM_{1,1-4}} = \begin{bmatrix} 0.359 \\ 0.183 \\ 0.287 \\ 0.171 \end{bmatrix} \quad (25)$$

$PCM_{1,1,1-5}$ (pairwise comparisons of alternatives with respect to "Maintaining Security for Electricity Supply") for the group is calculated and given in Equation (26).

$PCM_{1,1,1-5}$ = (26)

	Solar	Biomass	Geothermal	Wind	Hydropower
Solar	1	1.813	1.628	0.912	0.406
Biomass	0.552	1	1.068	0.641	0.370
Geothermal	0.614	0.936	1	0.621	0.300
Wind	1.096	1.560	1.610	1	0.391
Hydropower	2.463	2.703	3.333	2.558	1

CR = 0.006

Priority vector of $PCM_{1,1,1-5}$ is given in Equation (27).

$$W_{PCM_{1,1,1-5}} = \begin{bmatrix} 0.182 \\ 0.121 \\ 0.114 \\ 0.182 \\ 0.401 \end{bmatrix} \quad (27)$$

$PCM_{1,2,1-5}$ (pairwise comparisons of alternatives with respect to "Supplying Electricity with Low Prices") for the group is calculated and given in Equation (28).

$PCM_{1,2,1-5}$ = (28)

	Solar	Biomass	Geothermal	Wind	Hydropower
Solar	1	0.699	0.661	0.506	0.256
Biomass	1.431	1	1.019	0.777	0.342
Geothermal	1.513	0.981	1	0.662	0.322
Wind	1.976	1.287	1.511	1	0.384
Hydropower	3.906	2.924	3.106	2.604	1

CR = 0.002

Priority vector of $PCM_{1,2,1-5}$ is given in Equation (29).

$$W_{PCM_{1,2,1-5}} = \begin{bmatrix} 0.099 \\ 0.144 \\ 0.138 \\ 0.188 \\ 0.430 \end{bmatrix} \quad (29)$$

$PCM_{1,3,1-5}$ (pairwise comparisons of alternatives with respect to "Maintaining Stability for Electricity Generation") for the group is calculated and given in Equation (30).

$PCM_{1,3,1-5}$ = (30)

	Solar	Biomass	Geothermal	Wind	Hydropower
Solar	1	0.618	0.552	0.882	0.200
Biomass	1.618	1	1.310	1.509	0.442
Geothermal	1.812	0.763	1	1.720	0.525
Wind	1.134	0.663	0.581	1	0.339
Hydropower	5.000	2.262	1.905	2.950	1

CR = 0.008

Priority vector of $PCM_{1,3,1-5}$ is given in Equation (31).

$$W_{PCM_{1,3,1-5}} = \begin{bmatrix} 0.101 \\ 0.189 \\ 0.185 \\ 0.121 \\ 0.405 \end{bmatrix} \quad (31)$$

$PCM_{1,4,1-5}$ (pairwise comparisons of alternatives with respect to "Maintaining Economic Development") for the group is calculated and given in Equation (32).

$PCM_{1,4,1-5}$ = (32)

	Solar	Biomass	Geothermal	Wind	Hydropower
Solar	1	1.147	1.348	0.946	0.577
Biomass	0.872	1	1.107	0.836	0.468
Geothermal	0.742	0.903	1	0.788	0.414
Wind	1.057	1.196	1.269	1	0.578
Hydropower	1.733	2.137	2.415	1.730	1

CR = 0

Priority vector of $PCM_{1,4,1-5}$ is given in Equation (33).

$$W_{PCM_{1,4,1-5}} = \begin{bmatrix} 0.184 \\ 0.157 \\ 0.141 \\ 0.188 \\ 0.330 \end{bmatrix} \quad (33)$$

$PCM_{2,1-4}$ (pairwise comparisons of sub-criteria with respect to *Environmental Goals*) for the group is calculated and given in Equation (34).

$PCM_{2,1-4}$ = (34)

	Maintaining Low Carbon SO_x, and NO_x Emission	Maintaining Environmental Sustainability	Minimum Impact on Public Health	Maintaining Social Acceptability
Maintaining Low Carbon SO_x, and NO_x Emission	1	1.054	0.842	1.152
Maintaining Environmental Sustainability	0.949	1	0.940	1.187
Minimum Impact on Public Health	1.188	1.064	1	1.481
Maintaining Social Acceptability	0.868	0.842	0.675	1

CR = 0.002

Priority vector of $PCM_{2,1-4}$ is given in Equation (35).

$$W_{PCM_{2,1-4}} = \begin{bmatrix} 0.250 \\ 0.252 \\ 0.290 \\ 0.208 \end{bmatrix} \quad (35)$$

$PCM_{2,1,1-5}$ (pairwise comparisons of alternatives with repsect to "Maintaining Low Carbon, SO_X, and NO_X Emission") for the group is calculated and given in Equation (36).

$PCM_{2,1,1-5}$ = (36)

	Solar	Biomass	Geothermal	Wind	Hydropower
Solar	1	3.485	2.374	1.054	1.356
Biomass	0.287	1	0.623	0.315	0.357
Geothermal	0.421	1.605	1	0.443	0.512
Wind	0.949	3.175	2.257	1	1.219
Hydropower	0.737	2.801	1.953	0.820	1

CR = 0.001

Priority vector of $PCM_{2,1,1-5}$ is given in Equation (37).

$$W_{PCM_{2,1,1-5}} = \begin{bmatrix} 0.294 \\ 0.082 \\ 0.123 \\ 0.274 \\ 0.228 \end{bmatrix} \quad (37)$$

$PCM_{2,2,1-5}$ (pairwise comparisons of alternatives with repsect to "Maintaining Environmental Sustainability") for the group is calculated and given in Equation (38).

$PCM_{2,2,1-5}$ = (38)

	Solar	Biomass	Geothermal	Wind	Hydropower
Solar	1	1.303	1.466	1.083	1.730
Biomass	0.767	1	1.073	0.690	1.050
Geothermal	0.682	0.932	1	0.706	1.084
Wind	0.923	1.449	1.416	1	1.687
Hydropower	0.578	0.952	0.923	0.593	1

$CR = 0.001$

Priority vector of $PCM_{2,2,1-5}$ is given in Equation (39).

$$W_{PCM_{2,2,1-5}} = \begin{bmatrix} 0.253 \\ 0.177 \\ 0.170 \\ 0.247 \\ 0.154 \end{bmatrix} \quad (39)$$

$PCM_{2,3,1-5}$ (pairwise comparisons of alternatives with repsect to "Minimum Impact on Public Health") for the group is calculated and given in Equation (40).

$PCM_{2,3,1-5}$ = (40)

	Solar	Biomass	Geothermal	Wind	Hydropower
Solar	1	3.118	2.785	1.362	1.604
Biomass	0.321	1	0.819	0.412	0.561
Geothermal	0.359	1.221	1	0.528	0.654
Wind	0.734	2.427	1.894	1	1.432
Hydropower	0.623	1.783	1.529	0.698	1

$CR = 0.001$

Priority vector of $PCM_{2,3,1-5}$ is given in Equation (41).

$$W_{PCM_{2,3,1-5}} = \begin{bmatrix} 0.330 \\ 0.105 \\ 0.125 \\ 0.251 \\ 0.189 \end{bmatrix} \quad (41)$$

$PCM_{2,4,1-5}$ (pairwise comparisons of alternatives with repsect to "Maintaining Social Acceptability") for the group is calculated and given in Equation (42).

$PCM_{2,4,1-5}$ = (42)

	Solar	Biomass	Geothermal	Wind	Hydropower
Solar	1	2.567	1.552	1.492	3.216
Biomass	0.390	1	0.641	0.644	1.509
Geothermal	0.644	1.560	1	0.944	2.183
Wind	0.670	1.553	1.059	1	1.954
Hydropower	0.311	0.663	0.458	0.512	1

$CR = 0.001$

Priority vector of $PCM_{2,4,1-5}$ is given in Equation (43).

$$W_{PCM_{2,4,1-5}} = \begin{bmatrix} 0.333 \\ 0.139 \\ 0.213 \\ 0.215 \\ 0.101 \end{bmatrix} \quad (43)$$

Overall priorities of Solar, Biomass, Geothermal, Wind Energies, and Hydropower with respect to the stated objective are given in Equations (44), (45), (46), (47), and (48) respectively and summarized in Table 9. Graphical representation of the overall priorities of renewable energy sources is given in Figure 11.

$$0.661 * (0.182 * 0.359 + 0.099 * 0.183 + 0.101 * 0.287 + 0.184 * 0.171) + 0.339 * (0.294 * 0.250 + 0.253 * 0.252 + 0.330 * 0.290 + 0.333 * 0.208) = \mathbf{0.197} \quad (44)$$

$$0.661 * (0.121 * 0.359 + 0.144 * 0.183 + 0.189 * 0.287 + 0.157 * 0.171) + 0.339 * (0.082 * 0.250 + 0.177 * 0.252 + 0.105 * 0.290 + 0.139 * 0.208) = \mathbf{0.142} \quad (45)$$

$$0.661 * (0.114 * 0.359 + 0.138 * 0.183 + 0.185 * 0.287 + 0.141 * 0.171) + 0.339 * (0.123 * 0.250 + 0.170 * 0.252 + 0.125 * 0.290 + 0.213 * 0.208) = \mathbf{0.147} \quad (46)$$

$$0.661 * (0.182 * 0.359 + 0.188 * 0.183 + 0.121 * 0.287 + 0.188 * 0.171) + 0.339 * (0.274 * 0.250 + 0.247 * 0.252 + 0.251 * 0.290 + 0.215 * 0.208) = \mathbf{0.194} \quad (47)$$

$$0.661 * (0.401 * 0.359 + 0.430 * 0.183 + 0.405 * 0.287 + 0.330 * 0.171) + 0.339 * (0.228 * 0.250 + 0.154 * 0.252 + 0.189 * 0.290 + 0.101 * 0.208) = \mathbf{0.320} \quad (48)$$

Table 9. Overall priorities.

Elements of Hierarchy	***Priorities of criteria and sub-criteria***	***Solar Energy***	***Biomass Energy***	***Geothermal Energy***	***Wind Energy***	***Hydropower***
Energy Goals	**0.661**					
Maintaining Security for Electricity Supply	0.359	0.182	0.121	0.114	0.182	0.401
Supplying Electricity with Low Prices	0.183	0.099	0.144	0.138	0.188	0.430
Maintaining Stability for Electricity Generation	0.287	0.101	0.189	0.185	0.121	0.405
Maintaining Economic Development	0.171	0.184	0.157	0.141	0.188	0.330
Environmental Goals	**0.339**					
Maintaining Low Carbon, SOx, and NOx Emission	0.250	0.294	0.082	0.123	0.274	0.228
Maintaining Environmental Sustainability	0.252	0.253	0.177	0.170	0.247	0.154
Minimum Impact on Public Health	0.290	0.330	0.105	0.125	0.251	0.189
Maintaining Social Acceptability	0.208	0.333	0.139	0.213	0.215	0.101
Final Scores		**0.197**	**0.142**	**0.147**	**0.194**	**0.320**
Rank		**2**	**5**	**4**	**3**	**1**

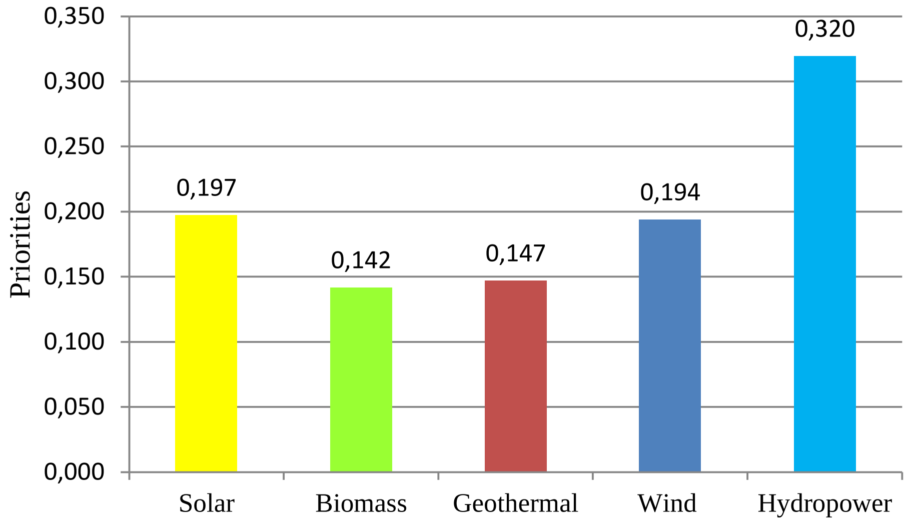

Figure 11. Overall priorities of renewable energy sources.

6.3. Sensitivity Analysis

A number of scenarios are designed and AHP is applied to calculate overall priorities of renewable energy sources for these scenarios. A total three scenarios are evaluated.

i) Scenario 1

In this scenario, the importance of each criterion (i.e. *Energy Goals* and *Environmental Goals*) is considered equal and their priorities are adjusted to 0.5 without changing the rest of the survey results. The whole AHP procedure is applied using these priorities and results are obtained and given in Figure 12.

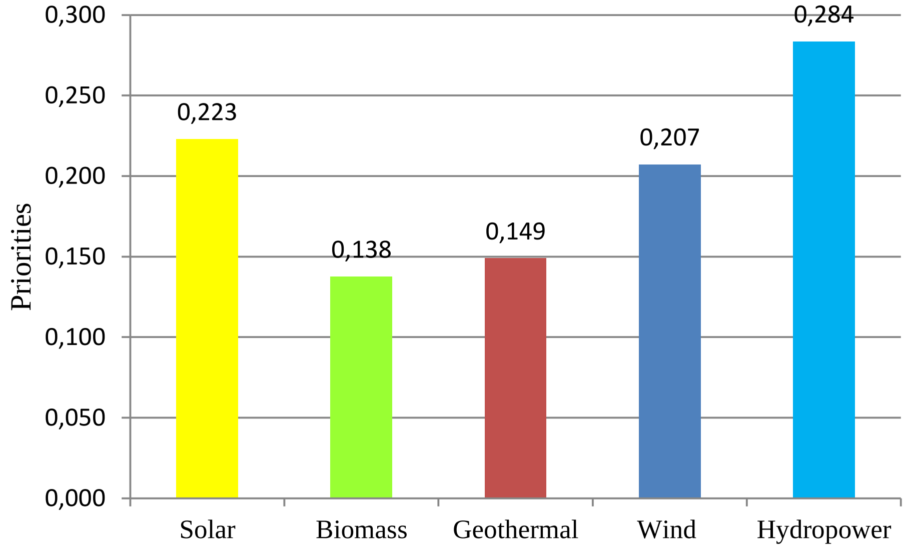

Figure 12. Overall priorities wrt. Scenario 1.

ii) Scenario 2

In this scenario, the priority of *Energy Goals* criterion is considered extremely more important than *Environmental Goals* criterion and its priority is adjusted to 0.900 without changing the rest of the survey results. Figure 13 shows the priorities of alternatives for this scenario.

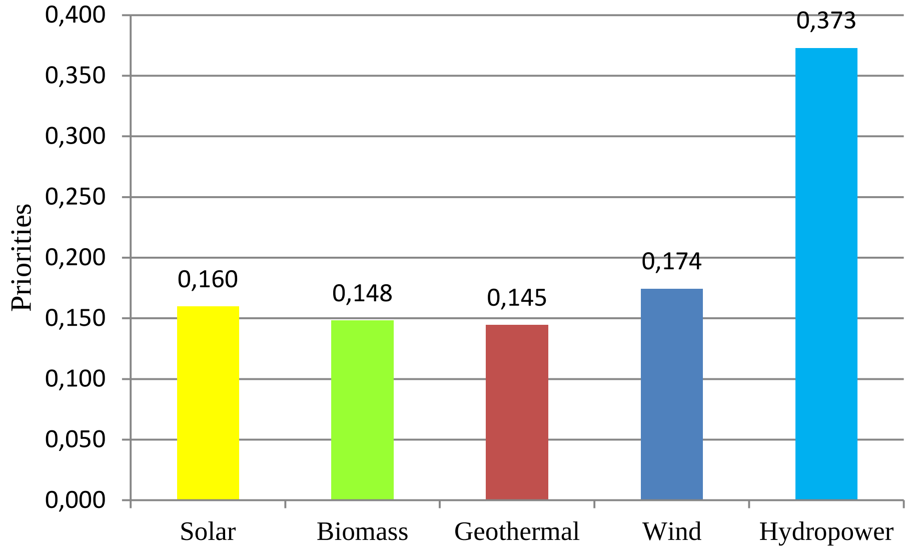

Figure 13. Overall priorities wrt. Scenario 2.

iii) Scenario 3

In this scenario *Environmental Goals* are considered to be more important than *Energy Goals* and the priority of *Environmental Goals* criterion is set to 0.900 without changing the rest of the survey results. Overall priorities of alternatives obtained for Scenario 3 are given in Figure 14.

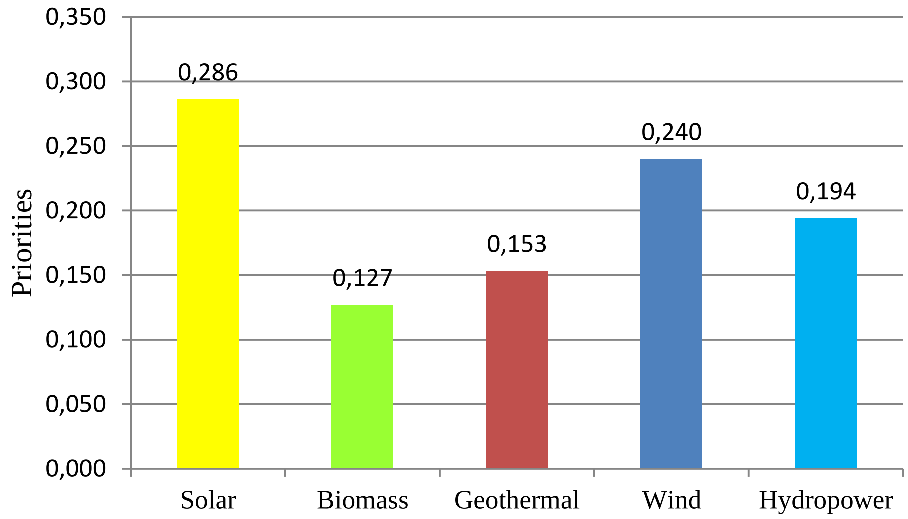

Figure 14. Overall priorities wrt. Scenario 3.

CHAPTER 7

DISCUSSION AND RESULTS

7.1. Results of AHP

This survey study is performed with experts who are believed to have experience and knowledge on renewable energy issues. They mostly belong to government offices and universities. Because of this reason, there exists some bias and the results of this study has to be evaluated considering the fact that opinions of environmentalist groups, local people, and public in general are not represented in this study.

Energy is necessary for better quality life, human progress, and economic growth. Dependency on foreign energy sources jeopardizes these factors. Turkey is an energy importing country and decreasing dependency on imported sources is necessary for increasing life standards in Turkey by keeping the money inside the country and implementing policies that suits public needs the best. In parallel with these facts, experts assigned higher priority to *Energy Goals* compared to *Environmental Goals* (see Table 9). This means that renewable energy sources that support achieving *Energy Goals* are given higher priority.

Within the *Energy Goals* criterion, “Maintaining Security for Electricity Supply” sub-criterion is identified as the most important factor in evaluating renewable energy sources (i.e. this sub-criterion received a priority of 0.359 and from here on just the numerical value of the priority will be given in the parenthesis next to the criterion or sub-criterion). Energy security is one of the most controversial issues in Turkey. As stated before, Turkey has high dependency on imported fossil fuels. In parallel with economic growth, energy demand in Turkey has been increasing rapidly and most of this energy demand is met by imported sources. This high dependence on imported sources shows that Turkey is highly exposed to international economic and political changes in terms of price fluctuations. In addition to this, the volatility in fossil fuels prices, along with the difficulty of forecasting fossil fuel prices, causes risks for both energy costumers and providers. Because of these reasons, maintaining security for electricity supply play a critical role in achieving *Energy Goals*.

“Maintaining Stability for Electricity Generation” (0.287) is considered as the second important sub-criterion of *Energy Goals*. Due to the high demand for electricity especially in residents and industrial facilities, supplying electricity is at risk in Turkey. The main reason of this situation is that, Turkey imports most of its energy sources and electricity supply is uncontrollable due to the lack of alternative energy sources which may be put in operation at critical times. Thus, diversifying the energy sources of the country with domestic and renewable energy sources is crucial. However, it should be remembered that there are several important problems associated with the stability of electricity generation from renewable energy sources. A common drawback exists in renewable energy due to its unpredictable and intermittent output. Necessary precautions such as hybrid systems (i.e. implementation of two renewable energy systems simultaneously) or electricity generation facilities such as pumped-hydro (i.e. to provide flexibility in terms of timing of electricity generation), need to be taken together with development of renewable energy sources to achieve stability in electricity generation.

Contrary to the expectation, the importance of “Supplying Electricity with Low Prices” sub-criterion (0.183) is evaluated far behind the first two sub-criteria. The main reason of this is that having access to stable electricity is considered to be more crucial compared to supplying electricity with low prices. Secure and stable electricity supply is a basic requirement of a civilized life; without electricity at health care facilities, food industry, agriculture, educational facilities, it is not possible to maintain the social welfare. Thus, “Supplying Electricity with Low Prices” is ranked after “Maintaining Security for Electricity Supply” and “Maintaining Stability for Electricity Generation”.

The last sub-criterion “Maintaining Economic Development” has the lowest priority (0.171) within the *Energy Goals* criterion. Although renewable energy facilities may develop local economy, some of them need very large areas to capture energy. This may cause economic losses, which are proportional to specific value of site because this land may be used in more lucrative activities for people who live in this region. Therefore, this sub-criterion is not considered critical to achieve energy goals of Turkey.

As a result of the evaluation of these sub-criteria related to *Energy Goals* criterion, it can be said that low security in electricity supply resulted from high dependency on fossil fuels and risks on the stability for electricity generation due to high rate of unpredictable and intermittent output of electrical power in Turkey are the major concerns related with *Energy Goals* criterion. Maintaining low electricity prices and economic development are the latter subjects to be evaluated in achieving the *Energy Goals* criteria.

Within the *Environmental Goals* criterion, "Minimum Impact on Public Health" is the most critical sub-criterion (0.290) among the others. The biggest health impacts are due to harvesting and burning of fossil fuels. One of the main reasons of the utilization of renewable energy sources instead of fossil fuels is to reduce the impact of electricity generation facilities on public health particularly among poor populations. Although renewable energy sources have health impacts, these impacts are much smaller than those for fossil fuels and some of these effects can be managed and minimized. Renewable energy sources with lower impact on public health are preferred by the experts and development of these energy sources are promoted.

"Maintaining Environmental Sustainability" (0.252) and "Maintaining Low Carbon, SO_X, and NO_X Emission" (0.250) are evaluated second and third important factor within *Environmental Goals* criterion. Diminishing biological diversity, chemical wastes, and negative effects on natural habitat and wild life are the main obstacles to maintain environmental sustainability. Because of this reason, allowing human society to satisfy its needs without compromising the ability of future generations is considered as critical factor to achieve environmental goals. In last two or three decades, air pollution and climate change related to increasing rate of GHGs emissions has been one of the most important environmental problems. Having relatively poor and high population, in Turkey, increasing rate of utilization of fossil fuels such as coal and oil in residential and industrial facilities create discussions among people especially environmentalists. Because of these reasons, these two criteria are considered as critical factors in achieving environmental goals.

The fourth ranked sub-criterion is "Maintaining Social Acceptability" (0.208). Although public reaction toward hydropower caused major problems for electricity generation projects in last decade, experts ranked maintaining social acceptability as the least important criteria among the others. One reason of this output may be that maintaining the first three sub-criteria may increase social acceptability.

As a result of the evaluation of *Environmental Goals* related sub-criteria, it can be said that minimizing the negative effects of energy sources on public health, maintaining environmental sustainability, and low carbon, SO_X, and NO_X emission are critical factors to achieve *Environmental Goals* criterion. With the success in these concerns, it is believed that environmental troubles in sustainable development of Turkey will be minimized. In addition to these, it may be concluded that as a result of maintaining these three sub-criteria, public may approach positively to energy generation projects.

To summarize, as a result of the evaluation of 29 Experts' preferences, the following outputs are obtained for each renewable energy source.

- **Hydropower** is selected as the most preferred renewable energy source (0.320) followed by solar energy (0.197) and wind energy (0.194) to increase their contribution to electricity generation in Turkey. Geothermal energy (0.147) and biomass energy (0.142) are not preferred due to their relatively low priorities. As being a mature and mostly utilized renewable energy source in Turkey, hydropower serves best for the stated objective. Especially, in terms of energy goals, hydropower performs the best with respect to the other sources due to its untapped potential, providing the electricity with low prices, and its nature of storing water and potential for generating electricity in a stable manner.

  However, in environmental aspects, performance of hydropower is not excellent. Forcing population displacement and impoverishment and loss of cultural heritage assets are the obstacles on maintaining social acceptance of hydropower (Cernea, 2004). In addition to these, large land use for hydropower plants with large reservoirs and operation of hydropower plants have negative impacts on nature and habitat.

- **Solar energy** performed the best in terms of *Environmental Goals*. Social acceptability and opinions that solar energy has low impact on public health are the main reasons of this performance. In addition to these, having negligible negative effects on air pollution is another reason of considering solar energy as the best with respect to environmental goals.

  Solar energy received very close priority to that of the wind energy which followed hydropower. Thus, solar energy is ranked the third in terms of *Energy Goals*. The main problem identified by the experts is the high cost associated with solar energy. Thus, it can be concluded that development of solar energy will become beneficial and preferred once low-cost electricity generation technologies become available.

- In terms of both energy and environmental concerns, the overall performance of **wind energy** is very good. The priority of wind energy is very close to that of solar energy. Although solar energy performs the best in environmental aspects, supplying electricity with low prices and maintaining economic development causes wind energy to be preferred over solar energy. As expected, stability for electricity generation is a critical problem both for solar energy and wind energy.

- **Geothermal energy** is ranked fourth. Main items causing geothermal energy to be at the end of the list in terms of *Energy Goals* is its low score on "Maintaining Security for Electricity Supply". Unexpectedly, geothermal energy is ranked very poorly in terms of *Environmental Goals* as well, especially for "Maintaining Low Carbon, SO_X, and NO_X Emission" (0.123) and "Minimum Impact on Public Health" (0.125). Against experts beliefs, emissions associated with generating electricity from geothermal technologies are negligible (EPA, 2013) and environmental impacts are lower in comparison to other renewables such as solar, biomass, and wind on an equivalent energy-output basis (Idaho National Laboratory, 2006). In terms of public health effects, contamination of water resources during drilling wells and extracting hot water or steam is the major concern. However, this may be prevented by proper monitoring (Wachtel, 2010). There is inconsistency with experts' evaluation of environmental aspects of geothermal energy and literature and previous studies. The reasons of this inconsistency might be a topic for future research. Case specific projects that have been completed in Turkey need to be investigated and evaluated in terms of their environmental impacts.

- **Biomass energy** received very poor priorities from all four sub-criteria of *Environmental Goals*. This is in agreement with the fact that biomass power plants share some similarities with fossil fuel power plants, the most important one being, both of them involve combustion of a carbon based fuel. The negative health effects and environmental impacts of combustion is very well known, thus this results in biomass energy being ranked very poor in terms of *Environmental Goals*.

7.2. Comparison of the AHP Results with Life Cycle Assessment (LCA) Studies

LCA is a technique for assessing environmental loads of a product or a system (Varun et al., 2009) by (EPA, 2012):

- Compiling an inventory of relevant energy and material inputs and environmental releases.

- Evaluating the potential environmental impacts associated with identified inputs and releases.

- Interpreting the results to make a more informed decision.

Over last thirty years, although there is no set standard for carrying out such analyses (Committee on U.S.-China Cooperation on Electricity from Renewable Sources et al., 2010), thousands of LCAs have been published for different electricity generation technologies. These LCAs have shown wide ranging results (NREL, 2013).

LCA covers studies on raw material acquisition, material manufacture, production, maintenance, and waste management (EPA, 2012). Any energy generation projects, including renewable energy sources, impact the natural and social environments (Donnelly et al., 2010). In this part, LCAs of the first two ranked renewable energy sources (i.e. hydropower and solar energy) are compared with respect to environmental problems associated with them. Then, LCA results for hydropower and solar energy are compared with those obtained from AHP analysis. Table 10 gives the LCA results for solar energy and hydropower gathered from different studies (Pehnt, 2006; Committee on U.S.-China Cooperation on Electricity from Renewable Sources et al., 2010; WNA, 2011).

Table 10. LCA results of environmental impacts of solar energy and hydropower gathered from literature.

Product	***Unit***	***Solar energy***	***Hydropower***
GHGs emissions	t CO_2eq/GWh	85	26
Land Use	m^2/MWh/yr	13	120
Water Use	Gallons/MWh	800	4500
Acidification	mg	98-528	42-61
Eutrophication	mg	10-44	5-6

As can be seen in Table 10, life cycle GHGs emissions of solar energy are higher than those of hydropower. Hydropower has one of the lowest life cycle GHGs emissions among renewable energy sources (Fritsche & Rausch, 2009). However, experts assigned higher priority to solar energy compared to hydropower for "Maintaining Low Carbon, SO_x and NO_x Emission" sub-criterion indicating that this sub-criterion is better satisfied by solar energy than hydropower (see Table 9). One reason of this inconsistency may be that although life cycle GHGs emission of solar energy is low in operation phase, it is relatively high in construction and manufacturing phases (NREL, 2012) and this fact may not be apparent to the experts. Life cycle GHGs emission of solar energy and hydropower plants should be considered in two main stages. These two stages are as follows (IPCC, 2011; Weisser, 2007; Meier, 2002):

i) **Construction and Manufacturing:** GHGs are emitted from the production and transportation of materials (e.g. concrete, steel etc.), engineering and administration, installation, and the use of civil work equipment and materials for construction of the facility.

ii) **Operation and Maintenance:** GHGs emissions can be generated by operation and maintenance activities such as building heating/cooling systems, system control and load dispatching, maintenance of structures and improvements, and maintenance of communication equipments.

Type of technology, type of installation, quantity and grade of silicon used for manufacture, location and irradiation conditions, and lifetime are the main factors of life cycle GHGs emission of solar energy (Weisser, 2007). Due to high rate emissions in construction and manufacturing stages of solar energy (Committee on U.S.-China Cooperation on Electricity from Renewable Sources et al., 2010), SO_x and NO_x emissions from solar energy is much higher than hydropower (Pehnt, 2006).

Moreover, acidification and eutrophication life cycle effects of solar energy are higher than those of hydropower. The main indicators of acidification and eutrophication are SO_x and NO_x emissions (Pehnt, 2006). SO_x emissions may aggravate respiratory illness and heart and lung diseases (The Beacon Hill Institute, 2012). NO_x emissions may contribute to health and environmental problems such as climate change, air toxics, and deterioration of water quality (U.S. Department of Energy, 2012). Contrary to these facts, experts evaluated solar energy to have less impact on public health (see Table 9).

As can be seen from AHP results, "Maintaining Low Carbon, SO_x, and NO_x Emission" and "Minimum Impact on Public Health" sub-criteria are best satisfied by the solar energy. However, LCA results indicate that greenhouse gas emissions are higher for solar energy compared to that of hydropower and associated health effects of these emissions are significant. Thus, as can be seen from the comparisons of LCA and AHP, there are inconsistencies between data and experts' beliefs or opinions. The following points need to be highlighted:

- In this study, only experts are asked to fill out the survey in order to collect knowledge based opinions. However, there are still inconsistencies between survey results and LCA results. This may be due to the fact that experts identified in this study may not have extended knowledge and experience on all types of renewable energy sources evaluated in this study but may have expertise on one of these renewable energy sources. It is also possible that experts have detailed knowledge on some of the aspects (i.e. sub-criteria) of a renewable energy source but not all. On the contrary, experts have specific knowledge and experience about renewable energy applications in Turkey. None of the LCA studies used here are conducted for Turkey, thus they provide general information in terms of environmental impacts. However, all the experts are Turkish and work in the country so the AHP study results provide Turkey specific information.

- AHP results, generated as a result of the surveys collected from 29 experts, only represent their understanding and knowledge about these topics. However, LCA results are generated as a result of detailed calculations based on collected data. Enlarging the expert pool might improve AHP results and may generate more consistent results with those obtained from LCA. Although the survey forms are send out to more than 120 experts, only a small portion agreed to participate.

The impacts on land use are considered to be the surface area occupied by the renewable energy installations during their life cycle. Hydropower plants especially ones with large reservoirs have higher land use requirements than solar energy to generate electricity (IEA, 2002). The construction of hydropower plants can alter sizable portions of land when dams are constructed and lakes are created, flooding land that may have once served as wildlife habitat, farmland, and scenic retreats (EPA, 2013). Excessive use of land may cause erosion and lead to disturbing of fauna and flora (KPGM, 2010). It may also cause population displacement (Eurelectric, 2011). Therefore, negative effects on environmental sustainability and public opposition to hydropower are higher than those of solar energy according to LCA studies. This is in agreement with the low performance of hydropower in “Maintaining Environmental Sustainability” and “Maintaining Social Acceptability” sub-criteria in the AHP analysis.

In addition to this, solar energy technologies use less water than hydropower. Evaporation losses from reservoirs are one of the main reasons of high water losses associated with hydropower (Swart et al., 2009). In addition, creation of massive lakes is another reason of water consumption life cycle impact of hydropower plants (Aden et al., 2010). Moreover, due to the water consumption life cycle, groundwater conditions may be affected by hydropower which may in turn affect water quality (Berger and Finkbeiner, 2010). Furthermore, excessive use of water in life cycle of run-of-river type hydroelectric power plants causes public oppositions (TMMOB, 2010). The water use life cycle impact of hydropower is in agreement with the results of the low performance of hydropower in both “Maintaining Environmental Sustainability” and “Maintaining Social Acceptability” sub-criteria.

7.3. Results of Sensitivity Analysis

For Scenario 1 (i.e. externally equal priorities are assigned to *Energy Goals* and the *Environmental Goals*), ranking of the renewable energy sources remained the same; however, the priority of solar energy got closer to that of the hydropower (see Figure 12). If policy makers believe that energy and environmental aspects have equal importance in evaluating renewable energy sources, hydropower is preferred to increase its contribution to energy generation in Turkey. Solar and wind follows hydropower for this scenario.

In Scenario 2, higher priority is given to *Energy Goals* and energy based sub-criteria are considered to be the main factors in determining the ranking of renewable energy sources. In order to achieve energy goals, primarily security for electricity supply and stability for electricity generation should be maintained. Hydropower is evaluated as the best alternative in terms of all the sub-criteria of *Energy Goals* (see Table 9). Due to this fact, hydropower obtained the highest priority among other renewable energy sources for Scenario 2 (see Figure 13). In this scenario, wind, geothermal, solar, and biomass received relatively lower priorities compared to that of hydropower.

For Scenario 3 (i.e. *Environmental Goals* is considered to be extremely more important than *Energy Goals*), solar energy performed the best (see Figure 14). Impacts of other sources on public health are relatively high especially for biomass and geothermal energy; and negative reaction from public to hydropower caused solar energy to be the preferred alternative when environmental aspects are emphasized.

CHAPTER 8

CONCLUSION AND RECOMMENDATIONS

Energy is a major input for residential, industrial, agricultural, and transportation needs of people. Demand for energy has been increasing and it is expected to increase in the future as well. Energy production planning and meeting increasing energy demand are among the most important items of the development plans of the countries. Having a rapidly growing economy and increasing population, Turkey has to take measures to cope with its growing energy demand. Turkey is highly dependent on foreign energy sources. Moreover, energy consumption based on fossil fuels creates economic, environmental, and political problems. Because of these reasons, Turkey has to evaluate and utilize its domestic and clean energy sources to achieve sustainable development.

In this study, the major renewable energy sources of Turkey; solar energy, biomass energy, geothermal energy, wind energy, and hydropower are examined in terms of electricity generation. These renewable energy sources are evaluated to select the most suitable one to increase its contribution to Turkey's electricity generation. In order to evaluate these renewable energy sources, a survey form is prepared. This survey form includes two criteria, (i.e. *Energy Goals* and *Environmental Goals*) and four sub-criteria under each one of these criteria to evaluate five renewable energy sources. This survey form is filled out by experts and analysis of these survey forms are performed by applying AHP. As a result of this study, the following conclusions are reached:

- *Energy Goals* are ranked more important than *Environmental Goals* by the experts. Thus, while selecting the renewable energy source to increase its contribution to Turkey's electricity generation, first, its success in achieving the *Energy Goals* of the Country has to be considered. The main reason of this preference is that secure and stable electricity with low prices are vital for maintaining good living standards and supporting economic development. Of course minimizing the impact of energy sources on public health, nature, and habitat and reduction of air pollution are very important environmental concerns and they need to be satisfied for the economic development to be sustainable.

- Within *Energy Goals* criterion, "Maintaining Security for Electricity Supply" is considered to be the most important sub-criterion due to existing economic and political problems Turkey is faces with. Experts' choice of "Maintaining Security for Electricity Supply" as the most critical item of *Energy Goals* shows that dependency on foreign energy resources is a major problem for Turkey and needs immediate attention. Experts believe that developing energy sources which will provide most benefit in terms of this sub-criterion should be preferred.

- Hydropower is identified as the best renewable energy source which will serve best for "Maintaining Security for Electricity Supply". This result is in agreement with the current situation in Turkey. Hydropower has a considerably large economic potential (Table 3) and close to half of this potential is still waiting to be developed. The developed hydropower potential which is around 62 billion kWh/year is an indication of the fact that Turkey has a lot of experience in constructing and operating hydropower plants which makes hydropower a potential renewable energy source for further development. However, again in line with the current situation in Turkey, hydropower received very low priorities for "Maintaining Social Acceptability" and "Maintaining Environmental Sustainability". Currently, there is a very big public resistance for hydropower plants especially the run-of-river types in Turkey. Many hydropower projects have been taken to the court and have been suspended or cancelled by the courts (İMO, 2010; Evcimen, 2008). Thus, it is clear that Turkey is in need of developing its unused hydropower potential to increase its contribution to electricity generation of the country. However, in the planning, construction, and operation of the hydropower plants, necessary emphasis has to be placed on the evaluation of environmental and social consequences of these power plants. To maximize benefits of hydropower, sustainable water management principles should be implemented and all stakeholders especially, local people, has to be included in the decision making process.

- Within *Environmental Goals* criterion, all four sub-criteria received approximately equal priorities. "Minimum Impact on Public Health" (0.290) is considered to be a little more important than the others. This may be due to the fact that negative health effects and diseases resulted from utilization of fossil fuels receives a lot of attention and publicity in the world. "Maintaining Environmental Sustainability" (0.252) and "Maintaining Low Carbon, SO_X, and NO_X Emission" (0.250) are ranked higher than "Maintaining Social Acceptability" (0.208).

- Following hydropower, solar energy (0.197) and wind energy (0.194) are identified as preferred renewable energy sources in terms of increasing their contribution to electricity generation in Turkey. Both solar energy and wind energy performed very well in terms of *Environmental Goals*. However, since their performances on *Energy Goals* are not as high as that of hydropower they are ranked as second and third. To make solar energy more attractive in terms of achieving *Energy Goals*, subsidy programs, tax initiatives, and rebate incentives should be promoted by the government. In addition to this, the reliability problems associated with solar and wind energies should be solved by creating new technologies such as batteries to store them or designing and implementing hybrid systems.

- Geothermal energy (0.147) and biomass energy (0.142) are not currently considered as suitable choices to increase their contribution in electricity generation in Turkey. Biomass energy is the least preferred choice due to its negative impacts on public health and relatively low success in terms of *Energy Goals*. The major burden for biomass energy is its associated health effects and it is given lower priority in development. This is reasonable since Turkey has other renewable energy sources which are not associated with such high negative health effects and environmental impacts. Similarly, geothermal energy performed poorly both in terms of *Energy Goals* and *Environmental Goals*. Economic potential of geothermal energy is identified as 1.4 billion kWh/year which is very low compared to the overall economic renewable energy potential of the country (Table 3). Thus, it being ranked at the end in terms of increasing its contribution in electricity generation is reasonable.

- In order to make renewable energy sources more attractive, Turkish government put into effect Law No. 5346 (Law on Utilization of Renewable Energy Sources for the Purpose of Generating Electrical Energy). As stated in this law, solar energy gets the highest purchase price when it is given to the distribution system together with biomass based production facilities. In addition to this, if the mechanical and/or electro-mechanical equipment used in the production facilities are manufactured domestically, solar energy production facilities get the highest contribution among renewable energy sources. The purchase prices and contributions associated with solar energy facilities indicate that high cost of solar energy and lack of technologies to store energy are one of the main obstacles in the development of solar energy utilization. This problem is in agreement with the low performance of the solar energy in “Supplying Electricity with Low Prices” and “Maintaining Stability for Electricity Generation” sub-criteria.

- The results of this study may provide initial guideline for the government in shaping its energy policy. However, similar surveys should be designed and conducted to collect opinions of environmentalists, NGOs, and local public and results of all of these surveys should be evaluated together to make decisions about energy policy of Turkey.

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APPENDIX A

SURVEY FORM

This section provides Survey Form distributed to the experts.

1) **Comparison of the levels of relative importance of the following criteria for maintaining the achievement of OBJECTIVE***

	Energy Goals	**Environmental Goals**
Energy Goals		
Environmental Goals		

(A1)

* Select a renewable energy source to increase its contribution to Turkey's electricity generation.

2)

Comparison of the levels of relative importance of the following sub-criteria in achieving Energy Goals criterion				
	Maintaining Security for Electricity Supply*	Supplying Electricity with Low Prices**	Maintaining Stability for Electricity Generation+	Maintaining Economic Development++
Maintaining Security for Electricity Supply*				
Supplying Electricity with Low Prices**				
Maintaining Stability for Electricity Generation+				
Maintaining Economic Development++				

(A2)

* implies "Reduction of dependence on foreign sources".
** implies "Users being able to buy electricity at low prices".
+ implies "Uninterrupted electricity generation".
++ implies "Increasing employment and economic activities".

2.1)

Comparison of the levels of relative importance of the following RES for Maintaining Security for Electricity Supply					
	Solar	Biomass	Geothermal	Wind	Hydropower
Solar					
Biomass					
Geothermal					
Wind					
Hydropower					

(A3)

2.2)

Comparison of the levels of relative importance of the following RES for Supplying Electricity with Low Prices					
	Solar	Biomass	Geothermal	Wind	Hydropower
Solar					
Biomass					
Geothermal					
Wind					
Hydropower					

(A4)

2.3)

Comparison of the levels of relative importance of the following RES for Maintaining Stability for Electricity Generation					
	Solar	Biomass	Geothermal	Wind	Hydropower
Solar					
Biomass					
Geothermal					
Wind					
Hydropower					

(A5)

2.4)

Comparison of the levels of relative importance of the following RES for Maintaining Economic Development					
	Solar	Biomass	Geothermal	Wind	Hydropower
Solar					
Biomass					
Geothermal					
Wind					
Hydropower					

(A6)

3)

Comparison of the levels of relative importance of the following sub-criteria in achieving Environmental Goals criterion				
	Maintaining Low Carbon, SOx, and NOx Emission	Maintaining Environmental Sustainability*	Minimum Impact on Public Health**	Maintaining Social Acceptability
Maintaining Low Carbon, SO_x and NO_x Emission				
Maintaining Environmental Sustainability*				
Minimum Impact on Public Health**				
Maintaining Social Acceptability				

(A7)

* includes "Low impact on nature and wild life" as well.
** includes "Sound and visual impacts" as well.

3.1)

Comparison of the levels of relative importance of the following RES for Maintaining Low Carbon, SO_x and NO_x Emission					
	Solar	Biomass	Geothermal	Wind	Hydropower
Solar					
Biomass					
Geothermal					
Wind					
Hydropower					

(A8)

3.2)

Comparison of the levels of relative importance of the following RES for Maintaining Environmental Sustainability					
	Solar	Biomass	Geothermal	Wind	Hydropower
Solar					
Biomass					
Geothermal					
Wind					
Hydropower					

(A9)

3.3)

Comparison of the levels of relative importance of the following RES for Minimum Impact on Public Health					
	Solar	Biomass	Geothermal	Wind	Hydropower
Solar					
Biomass					
Geothermal					
Wind					
Hydropower					

(A10)

3.4)

Comparison of the levels of relative importance of the following RES for Maintaining Social Acceptability					
	Solar	Biomass	Geothermal	Wind	Hydropower
Solar					
Biomass					
Geothermal					
Wind					
Hydropower					

(A11)

APPENDIX B

EXPERT 1'S SURVEY DATA

The PCM of criteria with respect to the objective is given in Equation (B1).

PCM_1 = (B1)

	Energy Goals	Environmental Goals
Energy Goals	1	1
Environmental Goals	1	1

The PCM of sub-criteria with respect to *Energy Goals* is given in Equation (B2).

$PCM_{1,1-4}$ = (B2)

	Maintaining Security for Electricity Supply	Supplying Electricity with Low Prices	Maintaining Stability for Electricity Generation	Maintaining Economic Development
Maintaining Security for Electricity Supply	1	1/2	1	3
Supplying Electricity with Low Prices	2	1	3	5
Maintaining Stability for Electricity Generation	1	1/3	1	6
Maintaining Economic Development	1/3	1/5	1/6	1

The PCM of alternatives with respect to "Maintaining Security for Electricity Supply" is given in Equation (B3).

$PCM_{1,1,1-5}$ = (B3)

	Solar	Biomass	Geothermal	Wind	Hydropower
Solar	1	2	3	1	1
Biomass	1/2	1	3	1/3	1/4
Geothermal	1/3	1/3	1	1/2	1/3
Wind	1	3	2	1	1/4
Hydropower	1	4	3	4	1

The PCM of alternatives with respect to "Supplying Electricity with Low Prices" is given in Equation (B4).

$PCM_{1,2,1-5} =$ (B4)

	Solar	Biomass	Geothermal	Wind	Hydropower
Solar	1	2	3	1	1
Biomass	1/2	1	2	1/3	1/2
Geothermal	1/3	1/2	1	1/4	1/6
Wind	1	3	4	1	1/2
Hydropower	1	2	6	2	1

The PCM of alternatives with respect to "Maintaining Stability for Electricity Generation" is given in Equation (B5).

$PCM_{1,3,1-5} =$ (B5)

	Solar	Biomass	Geothermal	Wind	Hydropower
Solar	1	1/3	2	2	2
Biomass	3	1	1	1	1
Geothermal	1/2	1	1	1	1
Wind	1/2	1	1	1	1
Hydropower	1/2	1	1	1	1

The PCM of alternatives with respect to "Maintaining Economic Development" is given in Equation (B6).

$PCM_{1,4,1-5} =$ (B6)

	Solar	Biomass	Geothermal	Wind	Hydropower
Solar	1	3	4	2	1
Biomass	1/3	1	3	1/2	1/3
Geothermal	1/4	1/3	1	1/4	1/5
Wind	1/2	2	4	1	2
Hydropower	1	3	5	1/2	1

The PCM of sub-criteria with respect to *Environmental Goals* is given in Equation (B7).

$PCM_{2,1-4}$ =

	Maintaining Low Carbon SO_x, and NO_x Emission	Maintaining Environmental Sustainability	Minimum Impact on Public Health	Maintaining Social Acceptability
Maintaining Low Carbon, SO_x, and NO_x Emission	1	4	3	1
Maintaining Environmental Sustainability	1/4	1	1/2	1/4
Minimum Impact on Public Health	1/3	2	1	1/3
Maintaining Social Acceptability	1	4	3	1

(B7)

The PCM of alternatives with respect to "Maintaining Low Carbon, SO_x, and NO_x Emission" is given in Equation (B8).

$PCM_{2,1,1-5}$ =

	Solar	Biomass	Geothermal	Wind	Hydropower
Solar	1	5	4	2	2
Biomass	1/5	1	2	1/2	1/3
Geothermal	1/4	1/2	1	1/3	1/4
Wind	1/2	2	3	1	1/2
Hydropower	1/2	3	4	2	1

(B8)

The PCM of alternatives with respect to "Maintaining Environmental Sustainability" is given in Equation (B9).

$PCM_{2,2,1-5}$ =

	Solar	Biomass	Geothermal	Wind	Hydropower
Solar	1	1/2	2	2	1
Biomass	2	1	2	2	1
Geothermal	1/2	1/2	1	2	1
Wind	1/2	1/2	1/2	1	2
Hydropower	1	1	1	1/2	1

(B9)

The PCM of alternatives with respect to “Minimum Impact on Public Health” is given in Equation (B10).

$PCM_{2,3,1-5}$= (B10)

	Solar	Biomass	Geothermal	Wind	Hydropower
Solar	1	1	2	2	1
Biomass	1	1	2	2	2
Geothermal	1/2	1/2	1	2	1/2
Wind	1/2	1/2	1/2	1	2
Hydropower	1	1/2	2	1/2	1

The PCM of alternatives with respect to “Maintaining Social Acceptability” is given in Equation (B11).

$PCM_{2,4,1-5}$= (B11)

	Solar	Biomass	Geothermal	Wind	Hydropower
Solar	1	6	8	2	2
Biomass	1/6	1	1/3	1/4	1/6
Geothermal	1/8	3	1	1/4	1/6
Wind	1/2	4	4	1	1/3
Hydropower	1/2	6	6	3	1