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GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

RENEWABLE ENERGY POTENTIAL AND PRODUCTION OF TURKEY: 2023 VISION

M.Sc. Thesis by

Mustafa VURAL

Department of Energy Systems Engineering

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RENEWABLE ENERGY POTENTIAL AND PRODUCTION OF TURKEY: 2023 VISION

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M.Sc. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"RENEWABLE ENERGY POTENTIAL AND PRODUCTION OF TURKEY: 2023 VISION"** completed by **MUSTAFA VURAL** under the supervision of **PROF. DR. FAHRETTİN GÖKTAŞ** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Prof. Dr. Fahrettin GÖKTAŞ

Supervisor

Prof. Dr. Yıldırım AYDOĞDU

Jury Member

Doç. Dr. Metin AKTAŞ

Jury Member

Prof. Dr. Ergun ERASLAN

Director

Graduate School of Natural and Applied Sciences

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RENEWABLE ENERGY POTENTIAL AND PRODUCTION OF TURKEY: 2023 VISION

ABSTRACT

Turkey's energy demand continuously increases depending on many factors; e.g. emerging economy, population growth and the increase of urbanization rate. It is estimated that this energy demand builds up over time in the future. Turkey relies heavily on external energy resources. This situation has a strong effect on current deficit. On the other hand, when it is considered that the whole world is running out of fossil resources such as petroleum, coal and natural gas; renewable energy resources issue is very important for the sustainable energy policies of countries.

In this study, an energy analysis is made for both the world and Turkey considering the current conditions and the future. Then Turkey has been examined in terms of the potential in renewable energy resources, installed capacity and targets. Within this framework, renewable energy potential and installed capacity of Turkey; particularly solar, wind, hydraulic, geothermal and biomass potentials and the installed capacity based on these sources are studied.

Turkey uses a substantial part of its hydraulic potential at present but still a fair amount can be utilized. Moreover, it is found that there is a considerable potential in wind and solar energy. In the forthcoming period, with the advancement of technology in this field production costs will decrease. Therefore, wind and solar energy will be more economical. Regarding geothermal energy, installed power target has been achieved and a new target has been determined. In respect to biomass potential, it is examined that this potential is not utilized sufficiently.

Keywords: Energy demand, energy supply, energy resources, renewable energy resources, Turkey's renewable energy potential, installed capacity, 2023 targets

TÜRKİYE'NİN YENİLENEBİLİR ENERJİ POTANSİYELİ VE ÜRETİMİ: 2023 VİZYONU

ÖZ

Türkiye gelişen ekonomisi, artan nüfusu, kentleşme oranının artması gibi birçok faktöre bağlı olarak enerji talebi sürekli olarak artmakta olan ve bu enerji ihtiyacın önümüzdeki yıllarda daha da artması beklenen bir ülkedir. Ülkemiz enerji kaynakları açısından önemli bir oranda dışa bağımlıdır. Bu durumun cari açık üzerinde önemli bir etkisi bulunmaktadır. Diğer taraftan Dünyada petrol, doğal gaz ve kömür gibi fosil enerji kaynaklarının hızla tükeniyor olduğu düşünüldüğünde yenilenebilir enerji kaynakları ülkelerin sürdürülebilir enerji politikalarının önemli bir noktasını oluşturduğu görülmektedir.

Bu çalışmada; Dünya ve Türkiye'nin mevcut ve gelecekteki enerji analizi yapılmış olup, ülkemizin yenilenebilir enerji kaynakları açısından potansiyeli, kurulu gücü ve hedefleri incelenmiştir. Bu kapsamda; güneş, rüzgâr, hidrolik, jeotermal ve biokütle enerjisi başta olmak üzere Türkiye'nin yenilenebilir enerji kaynaklarının potansiyeli, son yıllarda bu kaynaklarda yaşanan kurulu güç artışları ve geleceğe yönelik hedefleri incelenmiştir.

Türkiye'nin hidrolik açısından potansiyelin önemli bir kısmının devrede olduğu yine de bir miktar daha değerlendirilebilecek hidrolik potansiyeli bulunmaktadır. Diğer taraftan özellikle rüzgar ve güneş enerjisinde önemli bir potansiyel olduğu ve bunun büyük bir kısmının değerlendirilmeyi beklediği, önümüzdeki dönemde özellikle rüzgar ve güneş fotovoltaik teknolojisinin gelişmesiyle birlikte üretim maliyetlerin düşebileceği ve bu kaynağın daha ekonomik olabileceği, jeotermal enerjisinde kurulu güç hedefinin geçildiği ve yeni bir hedefin belirlendiği, biokütle potansiyeli açısından ise birincil enerji kaynağı olarak yeterince değerlendirilemediği görülmüştür.

Anahtar Kelimeler: Enerji talebi, enerji arzı, enerji kaynakları, yenilenebilir enerji kaynakları, Türkiye'nin yenilenebilir enerji potansiyeli, kurulu gücü, 2023 hedefleri

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NOMENCLATURE

Acronyms

CIS	Commonwealth of Independent States
DSI	General Directorate of State Hydraulic Works
EIA	U.S. Energy Information Administration
EUAS	Electricity Generation Company
E_B	Binding energy
GDP	Gross Domestic Product
GHG	Greenhouse gas emissions
GWh	Gigawatt-hours
G-7	Group of Seven
G-20	Group of Twenty
IEA	International Energy Agency
IAEA	International Atomic Energy Agency
IGA	Intergovernmental Agreements
MENR	Republic of Turkey Ministry of Energy and Natural Resources
Mt	Million tonnes
Mtoe	Million tonnes oil equivalent
OECD	Organization for Economic Cooperation and Development
PPP	Purchasing Power Parity
PWh	Petawatt-hours
PV	Photovoltaic
R&D	Research and Development
SEM	Solar Energy Map
tb/d	Thousand barrels daily
TEIAS	Turkish Electricity Transmission Company
TCM	Trillion cubic metres
TWh	Terawatt-hours
TUIK	Turkish Statistical Institute
WEO	World Energy Outlook

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CHAPTER 1

INTRODUCTION

Energy determines the capability of physical systems to do work or heat transfer capacity. Energy is a deterministic factor of the economic, cultural and social developments of a society. We need energy for transportation, communication, lighting, industries, agriculture and almost all scientific activities. Cars, trains, planes, all run because of energy. We can't see without energy. Our nerve system can't work without energy. Our heart cannot beat and muscle system can't work without energy. The energy is a very important concept in all aspects of our life. From production to consumption as electricity at residences and also many areas energy is an indispensable factor. In recent years with an increasing world population, energy demand also has increased to a large extent. The increase in the world population, industrialization activity, technological innovation, and high living standards cause to increase in energy demand [1]. According to Organization for Economic Cooperation and Development (OECD) Economic Outlook data, Table 1.1 represented that real gross domestic product (GDP) forecast growth rate of Group of Seven (G-7) countries. According to this table, real GDP annual growth rate is 3.06 % in 2016 and predicted to rising 3.93% in the world between 2016 to 2019 years. On the other hand, Table 1.2 represented that real GDP forecast growth rate of some Group of Twenty (G-20) countries. According to this table, real GDP annual growth rate is 1.80% in 2016 and predicted to increase in 2.48% in the world a few years later [2].

Table 1.1 Real GDP forecast growth rate G-7 countries [2]

Annual growth rate (%), 2016-2019				
Country	**2016**	**2017**	**2018**	**2019**
United States	1.49	2.27	2.86	2.78
Canada	1.41	3.00	2.10	2.24
Germany	1.86	2.51	2.14	2.13
France	1.11	2.32	1.90	1.92
United Kingdom	1.94	1.79	1.39	1.31
Japan	0.96	1.66	1.18	1.21
Italy	0.97	1.57	1.42	1.13
World	**3.06**	**3.65**	**3.82**	**3.93**

Table 1.2 Real GDP forecast growth rate some G-20 countries [2]

Annual growth rate (%), 2016-2019				
Country	**2016**	**2017**	**2018**	**2019**
India	7.113	6.553	7.375	7.544
China	6.700	6.900	6.660	6.442
Indonesia	5.033	5.068	5.299	5.353
Turkey	3.220	7.359	5.097	4.987
Korea	2.929	3.063	3.036	3.048
Mexico	2.667	2.277	2.476	2.835
Australia	2.604	2.277	2.925	3.040
South Africa	0.565	1.320	1.939	2.237
Russia	-0.103	1.546	1.760	1.547
Argentina	-1.823	2.864	2.007	2.587
Brazil	-3.468	0.976	1.951	2.839
OECD	**1.80**	**2.56**	**2.55**	**2.48**

The more economic growth was associated with the more energy demand over the past century. Despite this economic growth, World Energy Outlook (WEO) analysis shows that 1.1 billion people have still deprived of electricity and 2.8 billion people do not have a reach to clean cooking opportunity in Figure 1.1 and Figure 1.2 [3].

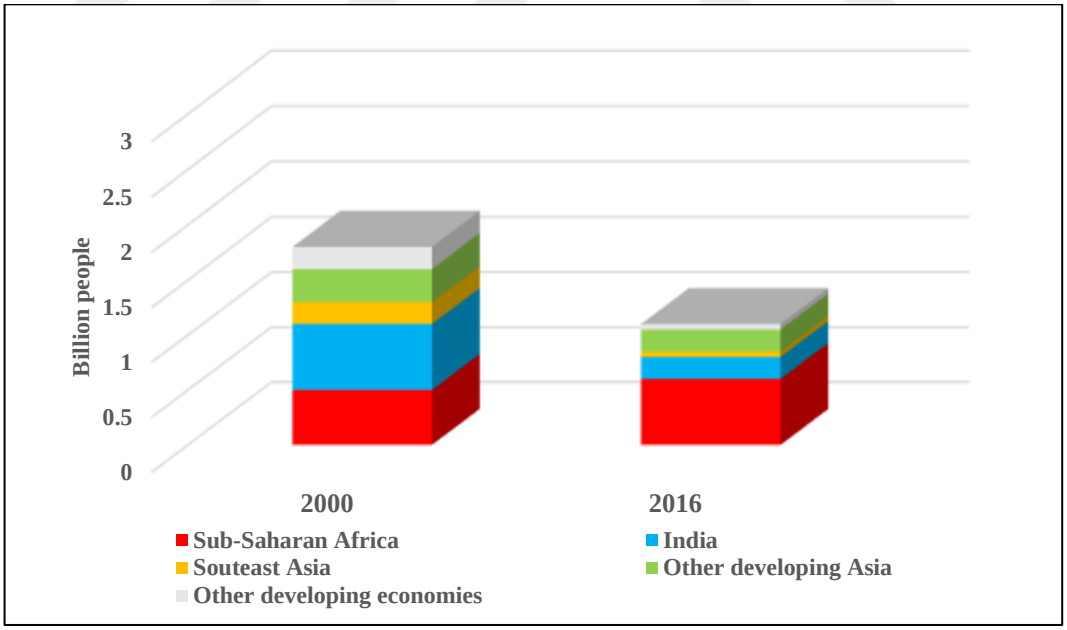


Figure 1.1 People without access to electricity [3]

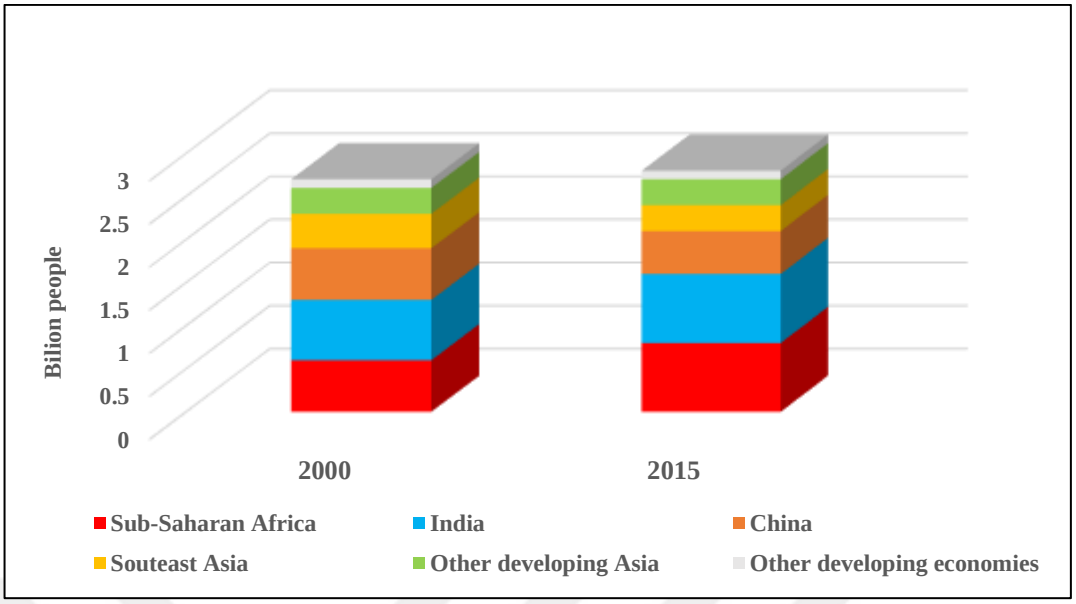


Figure 1.2 People without clean cooking facilities [3]

According to World Energy Outlook new policies scenario, get through to electricity will continue as a problem in the coming years. On the other hand, the number of people without access to electricity are decreasing, the period from 2016 to 2030 by extension with electrification rate increasing. These effects are seen both in Figure 1.3 and in Figure 1.4.

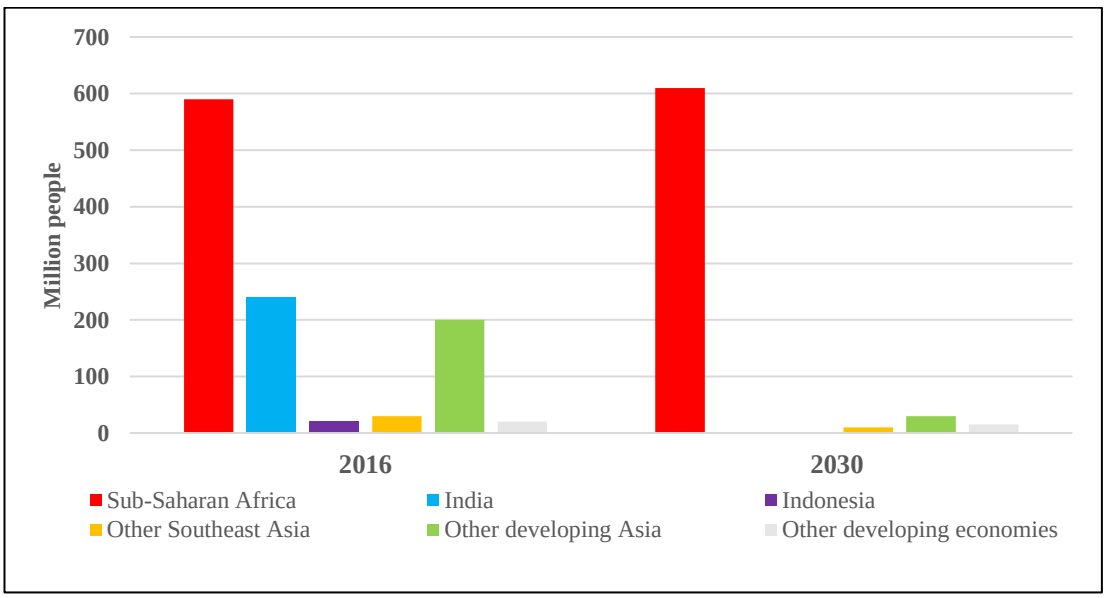


Figure 1.3 Number of people without electricity access by region in the new policies scenario [3]

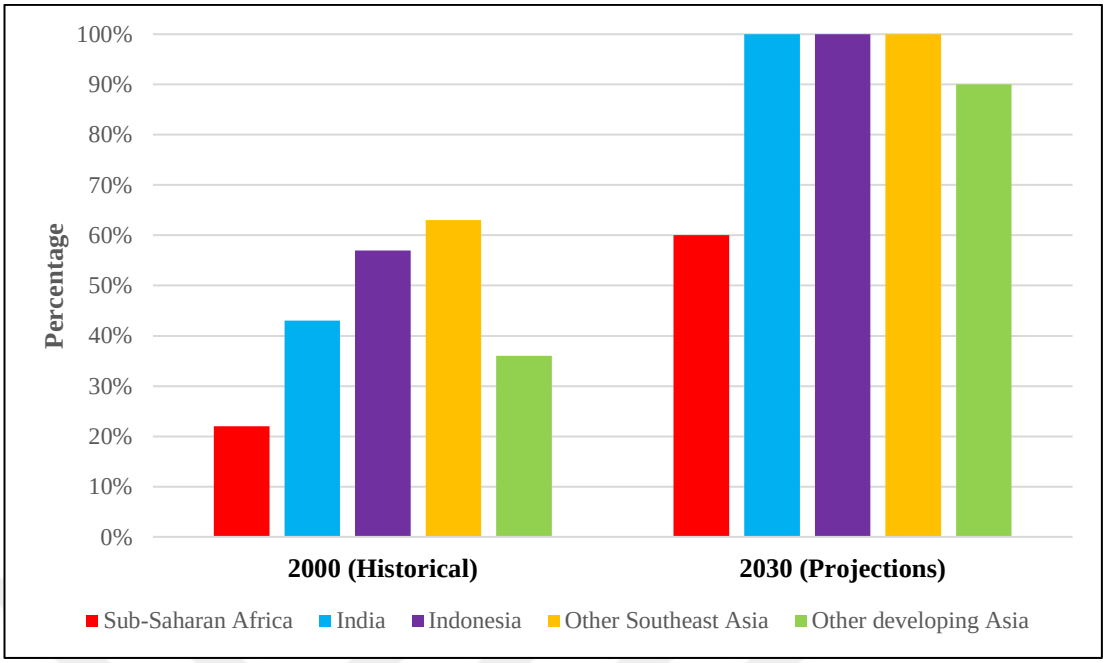


Figure 1.4 Electrification rate in the new policies scenario [3]

According to World Energy Outlook data, electricity demand goes up around 60% until 2040, with over 85% of that global growth stem from the developing economies. The main effect of these increasing technological devices is composed of about 75% global rising electricity demand [3]. On the other hand, global growth in electricity supply is about 46% from wind and gas and 20% from solar photovoltaic (PV) by the time 2040. The share of fossil fuel drop in the generation but renewables rise from 24% to 40%. Nuclear's share is also stabilized nearly 10% [3].

Electricity is an indispensable energy resource for modern economies due to the need for energy supply for many areas. Primary energy demand increased by nearly 60% from 1990 to 2016, but global electricity demand increased two times. Because of the economic growth and rising incomes will increase demand for electricity especially in developing countries [3]. Beside, the world population goes up about 0.9% per year on average. This show that the world population is expected to increase by 1.7 billion by 2040 [3]. Table 1.3 represents that population and urbanization rate by region and Table 1.4 represents that population and urbanization rate by some country.

Table 1.3 Population and urbanization assumption by region [3]

Region	Compound average annual growth rate			Population (million)		Urbanization rate	
	2000-16	2016-25	2016-40	2016	2040	2016	2040
North America	1.0%	0.8%	0.7%	487	570	81%	86%
Central South America	1.2%	0.9%	0.7%	509	599	80%	85%
Europe	0.3%	0.1%	0.1%	687	697	74%	80%
Africa	2.6%	2.4%	2.2%	1 216	2 063	41%	51%
Middle East	2.3%	1.7%	1.4%	231	321	69%	76%
Eurasia	0.4%	0.3%	0.1%	230	236	63%	67%
Asia Pacific	1.1%	0.8%	0.6%	4 060	4 658	47%	59%
World	**1.2%**	**1.0%**	**0.9%**	**7 421**	**9 144**	**54%**	**63%**

The more people are living in cities and towns, and so, global urbanization rate will increase from 54% in 2016 to 63% in 2040. This shows that extra 1.7 billion people live in cities and towns over the quarter of a century. Urbanization also affects many different areas but profounds effect from the point of energy consumption [3].

Table 1.4 Population and urbanization assumption by some country [3]

Country	Compound average annual growth rate			Population (million)		Urbanization rate	
	2000-16	2016-25	2016-40	2016	2040	2016	2040
United States	0.8%	0.7%	0.6%	328	378	82%	86%
Brazil	1.1%	0.7%	0.5%	210	236	86%	90%
European Union	0.3%	0.1%	0.0%	510	511	75%	81%
South Africa	1.5%	0.7%	0.6%	55	64	65%	75%
Russia	-0.1%	-0.2%	-0.3%	144	133	74%	79%
China	0.5%	0.3%	0.0%	1 385	1 398	57%	73%
India	1.5%	1.1%	0.9%	1 327	1 634	33%	45%
Japan	0.0%	-0.3%	-0.4%	127	114	94%	97%
Southeast Asia	1.2%	1.0%	0.7%	638	763	48%	60%
World	**1.2%**	**1.0%**	**0.9%**	**7 421**	**9 144**	**54%**	**63%**

World primary energy consumption goes up by this situation as both population and income increase. Population increase, most of them non-OECD country, will affect global energy demand. This effect can be seen both in current situation and in future projection in population, primary energy demand and income rate as shown in Figure 1.5, Figure 1.6 and Figure 1.7, respectively [4].

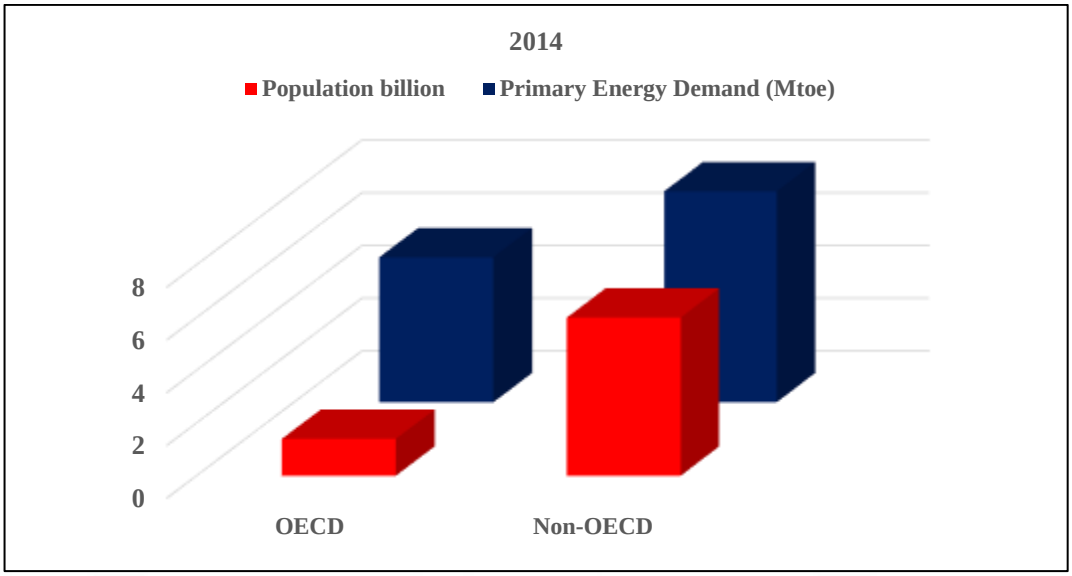


Figure 1.5 Population and primary energy demand [4]

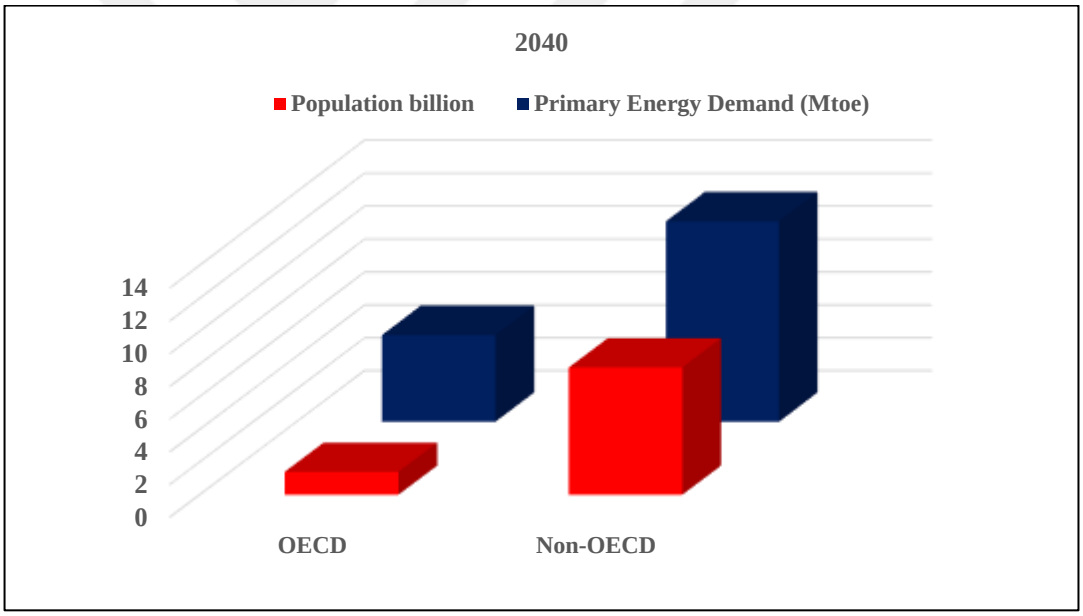


Figure 1.6 Population and primary energy demand projection [4]

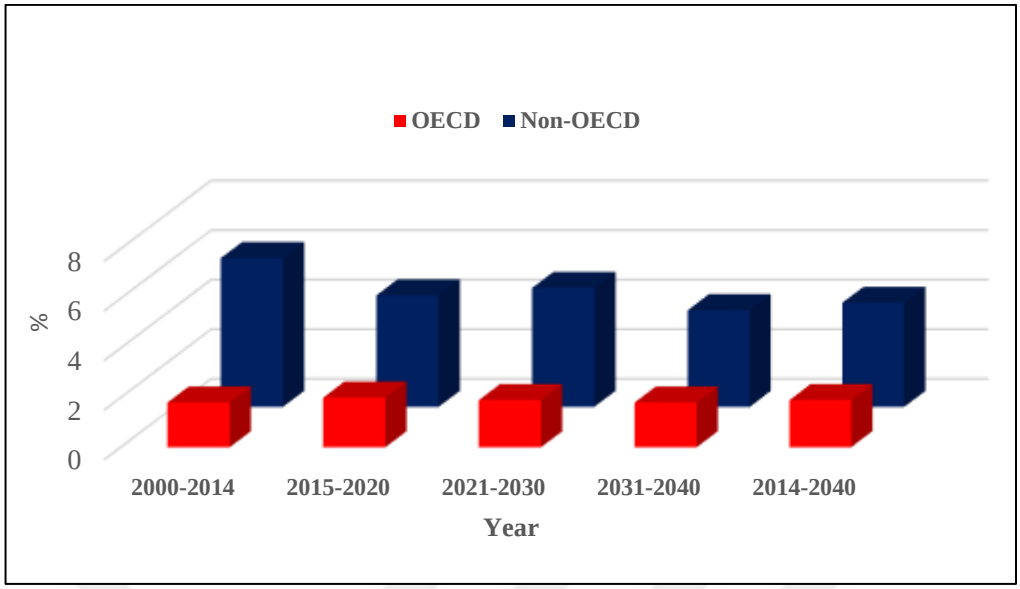


Figure 1.7 Gross national product growth rate projection [4]

Table 1.5 represents that some energy and economic parameters for one of the non-OECD country, China. As it may be seen from this table all of the economic parameters of China's increase, meanwhile the energy demand also increases as expected. Table 1.6 represents world primary energy demand by region while Table 1.7 shows world primary energy demand by some country. According to these tables world primary energy demand increase from 13,760 million ton oil equivalent (Mtoe) in 2016 to 17,584 Mtoe in 2040. This show that 3,824 Mtoe of extra energy increment is expected [3].

Table 1.5 Selected energy and economic indicators for China, 2000-2016 [3]

Indicator	2000	2005	2010	2016	Change 2000/16
GDP ($2016 billion, PPP)	5 278	8 318	14 023	21 721	312%
Share of world GDP	8%	10%	14%	18%	-
GDP per capita ($2016, PPP)	4 158	6 347	10 428	15 685	277%
Total primary energy demand (Mtoe)	1 143	1 794	2 551	3 006	163%
Primary energy demand/capita (toe)	0.90	1.37	1.90	2.17	141%
Total CO_2 emission (Mt)	3 127	5 399	7 726	8 973	187%
Energy intensity TPED/GDP (toe per $1 000, PPP)	0.22	0.22	0.18	0.14	-36%
Carbon intensity TPED CO_2 /GDP (tCO_2 per $1 000, PPP)	0.59	0.65	0.55	0.41	-30%

Table 1.6 World primary energy demand by region in the new policy scenario (Mtoe) [3]

Region	Years						2016-2040	
	2000	2016	2025	2030	2035	2040	Change	CAAGR*
North America	2678	2615	2672	2660	2652	2668	53	0.1%
Central South America	449	666	736	794	863	936	270	1.4%
Europe	2 028	1 965	1 887	1 831	1 784	1 762	-203	-0.5%
Africa	501	804	953	1 056	1 166	1 289	486	2.0%
Middle East	353	743	879	992	1 117	1 226	483	2.1%
Eurasia	743	880	919	945	981	1 016	136	0.6%
Asia Pacific	3009	5699	6679	7226	7684	8068	2369	1.5%
Bunkers**	273	388	458	506	559	617	230	2.0%
World	**10 035**	**13 760**	**15 182**	**16 011**	**16 806**	**17 584**	**3 824**	**1.0%**

* Compound average annual growth rate **Includes international marine and aviation fuels.

Table 1.7 World primary energy demand by some country in the new policy scenario (Mtoe) [3]

Country	Years						2016-2040	
	2000	2016	2025	2030	2035	2040	Change	CAAGR*
United States	2 270	2 154	2 188	2 162	2 132	2 122	-32	-0.1%
Brazil	184	290	319	345	375	405	115	1.4%
European Union	1 693	1 594	1 485	1 414	1 350	1 312	-282	-0.8%
South Africa	111	139	143	147	151	157	17	0.5%
Russia	620	699	711	721	739	755	56	0.3%
China	1 143	3 006	3 439	3 631	3 742	3 797	791	1.0%
India	441	897	1 228	1 466	1 694	1 901	1 003	3.2%
Japan	518	431	414	402	392	384	-48	-0.5%
Southeast Asia	385	643	806	892	977	1 062	419	2.1%
World	**10 035**	**13 760**	**15 182**	**16 011**	**16 806**	**17 584**	**3 824**	**1.0%**

*Compound average annual growth rate

Up to last two decades, Turkey's economy was mostly depended on agriculture. Three-quarters of the population were living in rural areas and other one-fourth of the population were living in cities. On the other hand, this situation has become reversed recently. Turkey has changed from an agricultural country to industrialized country. Nowadays, Turkey is an associate the G-20 industrialized country with a gross domestic product (GDP) about 1 trillion dollars [5].

Accompanying growth in economy and population Turkey’s primary energy consumption rises about 50% between the years of 2001-2008. According to recently announced government plan Vision 2023, Turkey aims at being include in ten major

economies with GDP at buying power parity per capita (PPP) 2 trillion dollars in the world at 2023 [6].

As shown in Figure 1.8, the population of Turkey was increased by nearly 25 million from 1990 to 2017. This effect also will be persisting in the future, as illustrated in Figure 1.9 all of the scenarios.

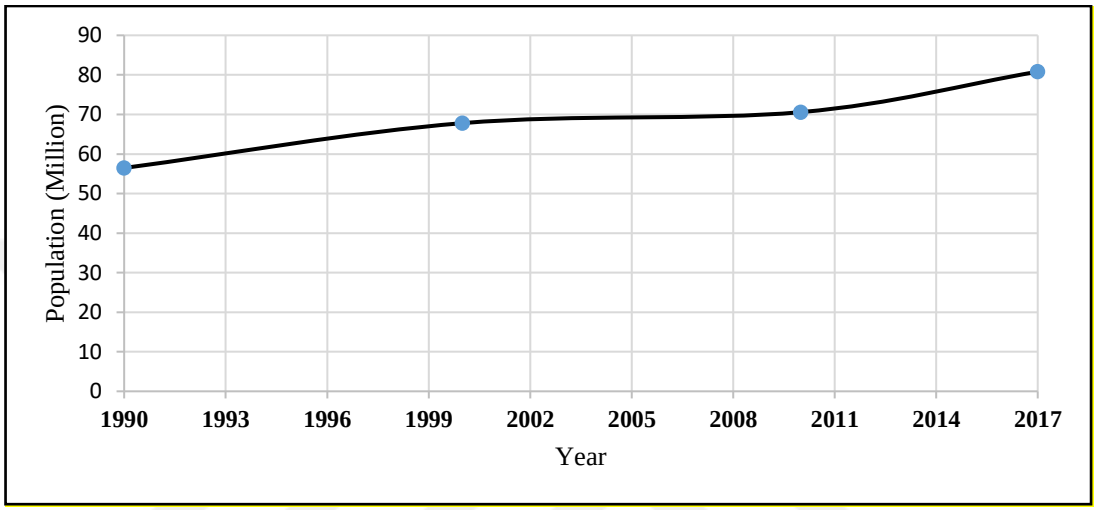


Figure 1.8 Population change of Turkey between 1990 and 2017 [7]

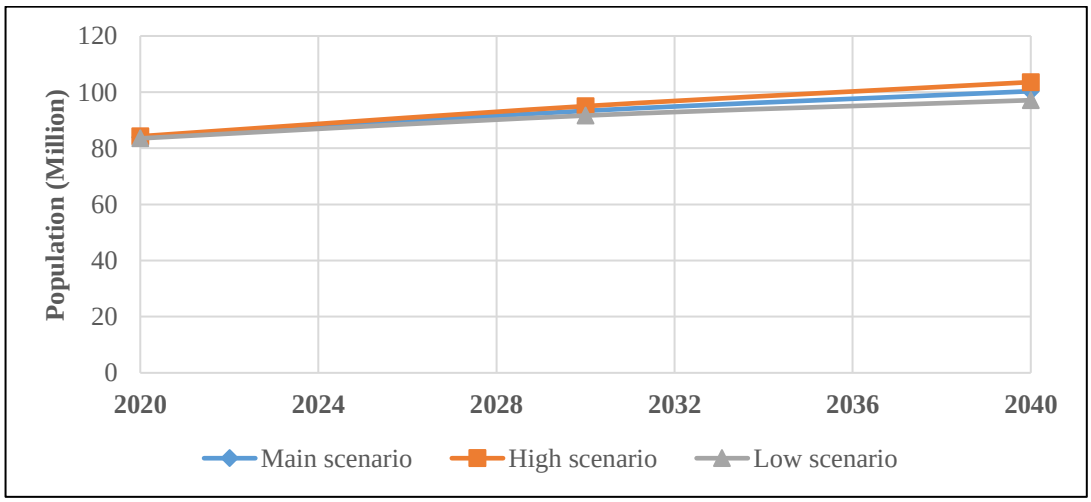


Figure 1.9 Population by scenarios of Turkey between 2018 and 2040 [7]

As expected, the more people living in cities the more energy is needed. According to Central Bank data, Turkey's current account deficit is $77.8 billion and more than half of that deficit is owing to import energy resources. As a consequence, the energy supply to cities of Turkey is a substantial load on economic growth day by day [5]. Table 1.8 represents the GDP of Turkey between 2000 to 2017. According to the Turkish Statistical Institute (TUİK) data, GDP per capita of Turkey increase from $4,229 in 2000 to $10,602 in 2017. The highest GDP / per capita was happen with a value of $12,480 in 2013.

Table 1.8 Gross domestic product of Turkey per capita**,** 2000-2017 [8]

Year	Mid-year population	In current prices	
		Value ($)	Change rate (%)
2000	64 269	4 229	5.6
2001	65 166	3 084	-27.1
2002	66 003	3 581	16.1
2003	66 795	4 698	31.2
2004	67 599	5 961	26.9
2005	68 435	7 304	22.5
2006	69 295	7 906	8.2
2007	70 158	9 656	22.1
2008	71 052	10 931	13.2
2009	72 039	8 980	-17.8
2010	73 142	10 560	17.6
2011	74 224	11 205	6.1
2012	75 176	11 588	3.4
2013	76 148	12 480	7.7
2014	77 182	12 112	-2.9
2015	78 218	11 019	-9.0
2016	79 278	10 883	-1.2
2017	80 313	10 602	-2.6

Economic growth is associated with increased energy consumption. Turkey's energy consumption will increase about fivefold between the years of 2000-2025. On the other hand, 66% of energy demand of Turkey is based import based fossil fuels despite the environmental problems induced by them [6]. Therefore, to minimize those problems and continue the economic growth trend, the Turkish government aims at generating 30% of electricity demand from renewable energy resources in 2023 [6].

It was emphasized by Zeray [9] that renewable energy sources are necessary because of the reduction of fossil fuels and increasing population. However, renewable energy sources are unbalanced resources for example wind rate, sunshine, heat rate

can be changed throughout the day. The cost of electric power generation from the renewable sources is still high. With the technological developments in renewable energy conversion, the investment cost of these resources is dropping.

Melikoglu [6] emphasized that electricity consumption of Turkey is predicted to be about 530,000 Gigawatt-hours (GWh) in 2023. According to Turkish government plans to Vision 2023, 30% of this consumption is expected to be generated from renewable energy resources. In other words, electric power of 160,000 GWh has to be produced from renewable energy resources. However, currently only 60,000 GWh of electricity can be produced from renewable energy sources. On the other hand, Turkey has technological potential and ability to cover this energy distinction, 100,000 GWh, by wind and solar energy. In order to overcome this problem, two different scenarios were suggested. According to scenario 1, supplying this demand from renewable energy resources predicted to cost about $31.000 billion and greenhouse gas emissions (GHG) of 1.05 million tonnes of CO_2. On the other hand, according to Scenario 2 supplying that demand from non-renewable energy resources may cost $8.000 billion and GHG of 71.30 million tonnes of CO_2.

Turkey’s electricity consumption is increasing based on the country's economic growth and population [10]. According to Vision 2023, the need for electricity will increase further in coming years. However, Turkey has great renewable energy potential, such as hydro, geothermal, solar and wind. In the current situation 57.5 Terawatt-hours (TWh) of electricity consumption is met by hydropower. According to official projection hydropower production is to rise to nearly 116,000 TWh. Approximately, 22% to 27% of electricity consumption of Turkey's is met from hydropower. Therefore, if the Turkish government intends to supply 30% of the country's electricity demand from renewable energy sources by 2023, electricity must be produced from other sources except for hydropower.

An analysis of hydropower potential of Turkey was made by Koç in 2014 [11]. In that study, the ratio of Turkey's technical hydropower potential to consumption have been calculated. When technical hydropower potential is taken into consideration, 77.33% of Turkey's hydropower potential has been used.

Ozturk & Yuksel [12] emphasized that the increase in non-renewable energy consumption has a harmful effect on the environment. Moreover, the price of non-renewable energy resources increase due to the diminishing of fossil fuel reserves. On the other hand, renewable energy resources develop standards of living both economically and environmentally.

It has been investigated by Urgun [13] that Turkey has a large renewable energy resources potential. However, Turkey is not using this potential in a desired level due to many reasons such as technical infrastructure. Unless Turkey develops domestic technology in the renewable energy sector, Turkey has to import this technology which increases the cost of renewable energy as expensive as oil and natural. The contribution of renewable energy resources to the economy have strategical important many aspects like the diversity of energy sources, decrease foreign source dependency and enhance the security of supply.

Melikoglu [14] indicted that according to Turkish government aim to Vision 2023, in order to reach to the planed renewable energy targets Turkey needs to $61.0 billion. Therefore, Turkey has to determine roadmap to provide fund for Vision 2023 targets. Otherwise, the Turkish Government Vision 2023 targets may be delayed in renewable energy.

Karagol & Kavaz [15] stated in 2017 that renewable energy has a key position from the point of decreasing foreign-source dependency, resources diversity and environmental benefit. Although, fossil fuel dependency is in a high level in the world at present, the utilization renewable energy increase gradually by years. As parallel to global developments, some crucial developments in the renewable energy sector also take place in Turkey. Turkey’s installed renewable energy capacity is mainly composed of hydropower energy. Although the ratio of wind and solar energy sources, defined as an unconventional renewable energy, has increased by years, it is not in a desired level yet. On the other hand, Turkey has a favorable condition in renewable energy potential by comparison with European countries. Nevertheless, the utilization of that potential has not reached to desired level. Within the scope of Turkey 2023 targets, Turkey gives priority to evaluate its current renewable energy potential.

In recent work done by Ozcan in 2018 [16], it was emphasized that renewable energy resources have an essential role in supplying self-sufficiency. According to Turkey's 2023 targets, renewable energy usage and obtainment rate from renewable energy sources are quite behind the targets as compared to other sources except hydro and geothermal. Analyses indicate that Turkey's self-sufficiency has been decreasing in both total primary energy supply and electricity generation. The rate of self-sufficiency was 25.05% and electricity generation self-sufficiency 37% in 2014. That decrease is due to many reasons such as increasing energy consumption, increasing dependency on import based energy sources and underestimation of renewable energy sources. For this reason, so as to succeed Vision 2023 renewable energy targets, Turkish government has to develop a new energy policy.

Fossil fuel energy resources come to an end rapidly. These sources have adverse effects on the environment; and increasing energy demand direct countries to alternative energy sources. For this reason, renewable energy is one of the updated topics in the World and Turkey. Therefore, many studies have been done to increase the utilization of renewable energy sources. In this context determining Turkey's renewable energy potential, current situation and recent progress in installed capacity and reaching renewable energy targets have propounded great importance. Also when it is considered Turkey is a foreign-dependent country regarding fossil fuels area to a large extent, this situation initially affects the economy and also many areas. In this thesis, an analysis of World’s and Turkey’s energy resources within the context of the reserve, production, and consumption is made. Especially, we focus on the renewable energy potential, installed capacity and future projections of Turkey.

CHAPTER 2

CLASSIFICATION OF ENERGY

The energy sector is closely related to other sectors of the economy. Especially, it has a close relationship with economic growth. Electricity energy is used almost in all manufacturing processes. As parallel to both increasing population and economic growth, producing energy with efficiency and low price is a great importance [17].

Energy demand is determined by economic growth, lifestyle, technological development, and energy price. On the other hand, energy supply is determined by reserve, production, investment cost conversion technology and the economic relationship between countries [17]. Energy has a great variety of classification due to a wide area of utilization, many production techniques, different sources, and energy trade [1]. According to convertibility, energy sources go into division primary and secondary energy. Energy has obtained from conversion of primary energy sources classification as a secondary energy. Also, according to utilization, energy sources examined renewable and non-renewable energy sources. Renewable energy sources are replenished in a short time and not exhausted for a long time. On the other hand, non-renewable energy resources which are depleted by the time may be classified in two different categories that originating from fossil fuels and nucleus [17].

2.1 Conventional and Non-Conventional Energy

The conventional energy resources are the energy resources which are being traditionally used for many decades and were in common use around oil crises in 1973. The conventional energy mainly includes fossil fuels, such as coal, petroleum, natural gas, wood, and fission based nuclear energy. Most of the thermal power plants run by using conventional fuels which are considered to exhaust in few decades [18]. The conventional energy sources are in general nonrenewable sources of energy, which are being used since a long time. These sources of energy are being used extensively in such a way that their known reserves have been depleted to a

great extent. On the other hand the sources of energy which are being produced continuously in nature and not exhaustible are called nonconventional sources of energy. Non-conventional energy resources have no defined market price yet as compared to conventional energy resources.

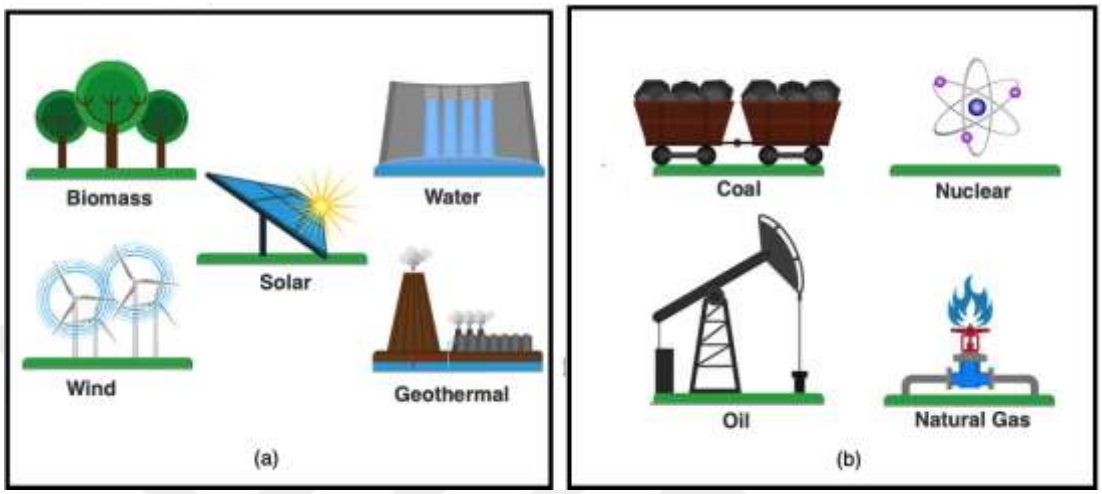


Figure 2.1. (a) Non-conventional and (b) Conventional energy sources

2.2 Primary and Secondary Energy

Based on the production processes, energy sources are classified as primary energy and secondary energy [19]. Primary energy is extracted or captured directly from the environment, while the secondary energy is converted from the primary energy in the form of electricity or fuel. The most common primary energy sources are coal, oil, natural gas, and biomass (such as wood). But the nuclear energy from radioactive substances, thermal energy stored in earth's interior, and the potential energy due to earth's gravity in the form of wind, hydraulic, and solar are also types of primary energy sources [17]. Secondary energy species are electricity, gasoline, diesel, coke coal, petroleum coke, liquefied petroleum gas [17].

Primary energy may also be classified into three distinctive groups:

- Nonrenewable energy (fossil fuels): Crude oil, natural gas, coal, nuclear fission.
- Renewable energy: Hydropower, biomass, solar energy, wind, geothermal, ocean energy, nuclear fusion.
- Waste:

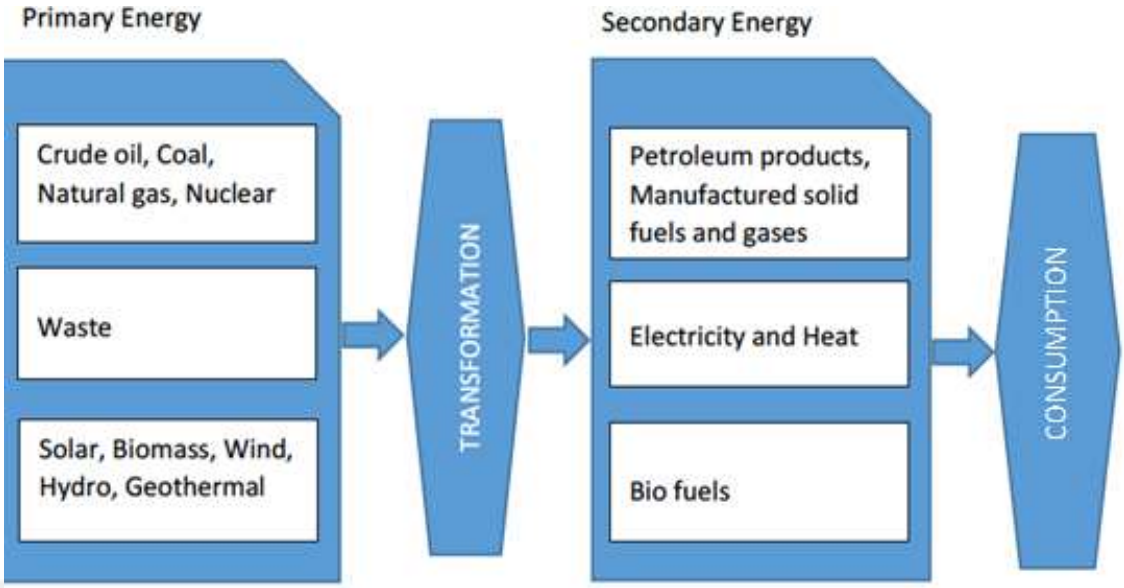


Figure 2.2 Primary and secondary energy types [20]

The energy ready for direct use is called secondary energy. The primary energy in the form of nonrenewable, renewable or waste is transformed to useful energy (secondary energy) in the form of electricity or fuel through some conversion techniques as described by Figure 2. 2. The nonrenewable sources are converted to secondary energy in the form of electrical energy or fuel, such as fuel oil, gasoline, ethanol, methanol, and hydrogen. On the other hand, the primary energy based renewable energy sources, such as sun, wind, biomass, geothermal energy, and flowing water is usually equated with either electrical or thermal energy. Although the final energy produced by primary sources is often electric energy, the sources may also be transformed to thermal, mechanical, and chemical energy as well.

2.3 Renewable and Non-Renewable Energy Resources

Non-renewable resources, mostly fossil fuels, are limited natural resources that cannot be replenished or regrown in a short period of time at a scale as compared to their consumption. On the other hand, renewable resources such as solar, wind, hydrogen, hydropower and geothermal are unlimited natural resources that can be replenished in a short period of time [17].

2.4 Renewable Energy Resources

Renewable energy sources are essentially inexhaustible and can be naturally replenished such as sun, wind, water, earth's heat, and plants. Renewable energy can be harnessed without the release of harmful pollutants. Because of many harmful effects and exhaustion of non-renewable sources, renewable energy is being used by many countries and effort is made to develop renewable energy technology covering many sectors from the transportation to agricultural [21]. Renewable energy sources have less environmental effects, and low operation and maintenance costs. They provide an indigenous energy supply for many countries [19]. Therefore, renewable energy sources intensely attract many countries due low harmful effects on the environment, reducing energy imports and providing new job opportunities [17].

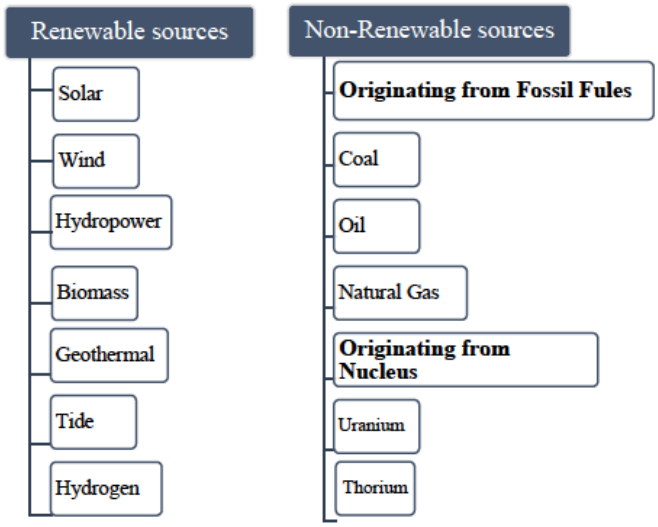


Figure 2.3 Classification of energy sources by utilization [17]

2.4.1 Solar Energy Resources

The Sun is the central star of the solar system. It consists mainly of helium and hydrogen. Its mass is so large that it contributes 99.68% of the total mass of the solar system. The pressure–temperature conditions in the center of the Sun are such that nuclear fusion can take place. In this core region, the energy is produced by the fusion of isotopes of hydrogen atoms (H) being converted into nuclei of helium (He). In order this reaction to take place, an extreme pressure of 25.33 trillion kPa and

temperature of 15.7 million kelvins that exists within the core are required. In fusion reaction, four protons (hydrogen nuclei) fuse into an alpha particle which has two protons and two neutrons bound together into a particle that is identical to a helium nucleus. In the end of the reaction, two positrons are released from this process, as well as two neutrinos (which changes two of the protons into neutrons), and finally an energy (electromagnetic radiation) is also released as given by the following reaction (2.1), (2.2) and (2.3) steps, respectively:

$$^{1}H + {}^{1}H \rightarrow {}^{2}H + v_e + e^{+} \quad \textbf{(2.1)}$$

$$^{1}H + {}^{2}H \rightarrow {}^{3}H + \gamma \quad \textbf{(2.2)}$$

$$^{3}H + {}^{3}H \rightarrow {}^{4}H + {}^{1}H + {}^{1}H \quad \textbf{(2.3)}$$

The positrons are annihilated with electrons, leading to additional radiation. The mass of the helium core is 0.635% less than that of four protons; the mass difference is converted into energy according to Einstein's equation is demonstrates in (2.4).

$$E = m_0 c^2 \quad \textbf{(2.4)}$$

The energy derived from the sun in the form of solar radiation is called solar energy. Almost 99.9% of the energy flow on the earth's surface is due to incoming solar radiation. Radiation energy of solar has effects on atmosphere system. Other sources such as wind, sea-quake, biomass, fossil fuels are also based on the solar energy [17].

The total power of the Sun is about 3.8×10^{26} W, so that every second approximately 4 million tons of mass are converted into energy. At the center of the Sun, the power density is estimated only to be about 275 W/m^3. The core of the Sun is too dense that radiation cannot travel freely but is continuously absorbed and reemitted, such that it takes the radiation between 10,000 and 170,000 years to travel to the solar surface called the photosphere which has a temperature of about 6,000 K. The photosphere behaves very closely to a blackbody and is the source of the solar radiation that hits the Earth.

The Sun releases an estimated 3,945 watts of energy in the form of light and other forms of radiation. The energy density of solar radiation at our atmosphere is approximately 1,368 W/m^2. Then it is reduced to approximately 1,000 W/m^2 at the earth's surface, for a surface perpendicular to the Sun's rays at sea level on a clear day. Green plants have the capacity to trap the solar energy and they convert the solar energy into chemical form by a process called photosynthesis. Most of the solar energy is left unused and only 0.1% of this energy could meet the total world energy requirements. The solar energy may be harvested by capturing the sun light through photovoltaic conversion into electricity, or by collectors into thermal energy (heat) for water heating or space heating and other uses.

Studies on the utilization of solar have increased especially after the 1970s energy crisis. In this way, alternative solar power systems were developed and many studies have been done to increase their efficiency and reduce their cost. Nowadays solar energy is used in many areas extensively from heat energy to electricity generation by means of a photovoltaic cell and other areas [17].

Solar energy is easily accessible and one of the securest form of sustainable energy. Solar energy technologies are divided into three groups. Firstly, solar radiation may be directly converted electricity by means of photovoltaic (PV) systems. Secondly, the solar energy may be concentrated by some collectors to get heat energy and then thermal energy drives a turbine to produce electricity. Solar energy is also used for heating and cooling facilities [12].

PV systems were initially used to supply energy to the orbiter or satellites in space. Associated with the world energy crisis, PV systems commenced to rise and their cost began to diminish. The least PV system is PV cells [12]. A PV cell is a "semiconductor diode with p–n junction. As exposed to light, the cell generates charge carriers leading to an electric current as the cell is short-circuited. In order to generate charges, the energy of the incident photon must be sufficient to detach the covalent electrons of the semiconductor, depending on the semiconductor material and on the wavelength of the incident light. PV phenomenon may simply be described as the generation of charge carriers by the absorption of solar radiation, the transport of the free carriers at the p-n junction, and the collection of these electric

charges at the terminals of the PV device. Several types of semiconductors using different processes are used to manufacture photovoltaic cells. Monocrystalline and polycrystalline silicon cells are the most common types of PV cells [9]. There are three types of silicon based PV technologies; mono-layer crystalline silicon solar cells (m-Si), multi-layer crystalline silicon solar cells (mc-Si), and ribbon silicon based solar cells used in market [12]. In general, silicon based PV cells are "composed of a thin layer of bulk Si or a thin Si film connected to electric terminals. One of the sides of the Si layer is doped to form the p–n junction. A thin metallic grid is placed on the Sun-facing surface of the semiconductor" [9]. Figure 2.4 shows simple physical structure of a PV cell [9].

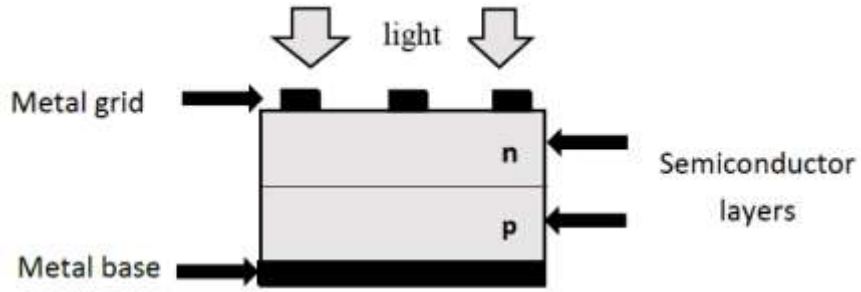


Figure 2.4 Physical structure of a PV cell

On the other hand, recently, third generation PVs such as organic solar cells, perovskite type solar cells and dye-sensitized solar cells have also been manufactured as alternative to the silicon based solar cells.

Despite their low efficiency, the main advantage of the organic solar cells is the low cost and easiness of manufacturing. In these types of cells, electron-hole pairs, also called exciton, with electrostatic bond are generated with the absorption of the light, instead of free electrons generated in inorganic PV cells. The photo generated excitons are characterized by very small lifetime. The excitons are dissociated within the range of 10 nm length in molecular chain. Exciton dissociation refers to process of splitting the electrostatically coupled electron hole pair into free charges. Donor and acceptor materials are designed to drive the exciton dissociation. Once free charges are produced, they travel through specific materials and collected at the electrodes which are connected to an external circuit leading electric current.

Perovskite solar cells have also been attracting scientists recent years. Despite their high efficiency, there are still some major problems, such as device stability, hysteresis behaviour, the presence of a toxic metal (lead), and difficulties in fabrication of large area and/or flexible devices. The Perovskite solar cells are produced by polimers in the form ABX_3 type. The properties of these materials can be tuned by changing A, B, and X where A may be alkyl ammonium, lithium, silver or cesium, 'B' may be lead, tin or titanium and 'X' may be fluride, iodide, bromide, chloride or a mixture of these.

2.4.2 Wind Energy Resources

The atmosphere gets warmer daytime and gets colder at night due to the solar radiation. This situation composed of high and low pressure domains. The difference in pressure leads air flow so that wind which can be used to generate electric energy. About 2% of the solar energy from the sun is converted to wind power.

Initially, wind energy was used in the field of agriculture, especially for water pumping windmills. Then, wind energy has been used for electricity production since last few decades [25]. In a wind power system, the energy in the wind turns two or three propeller-like blades around a rotor which is connected to the main shaft. The rotor spins a generator to create electricity. Thus, a wind turbine converts the kinetic energy in the wind into mechanical power. According to their structure, wind power systems are classified as horizontal and vertical axis wind power turbines. Wind speed and feature are the key parameters for utilization of wind turbine [12].

The main advantages of generating energy from the wind are due to being clean, safe and renewable source. On the other hand, the wind strength is not constant and varies from zero to storm force. This means that wind turbines do not produce the same amount of electricity all the time. This is considered as the main disadvantage of the wind power based energy generation [17]. Table 2.1 represents annual onshore and offshore wind potential in the world. As it may be seen from the Table, the onshore wind potential is very high as compared to offshore.

Table 2.1 Annual wind energy potential onshore and offshore for the World [22]

Areas	**Worldwide, PWh**	
	No CF* limitation	**20% CF* Limitation**
Onshore	1,100	690
Offshore 0-20 m	47	42
Offshore 20-50 m	46	40
Offshore 50-200 m	87	75
Total	1,300	840

*Capacity Factor

Global wind potential map is given in Figure 2.5. According to this figure Russia, North Europe and China have the highest wind potential [22].

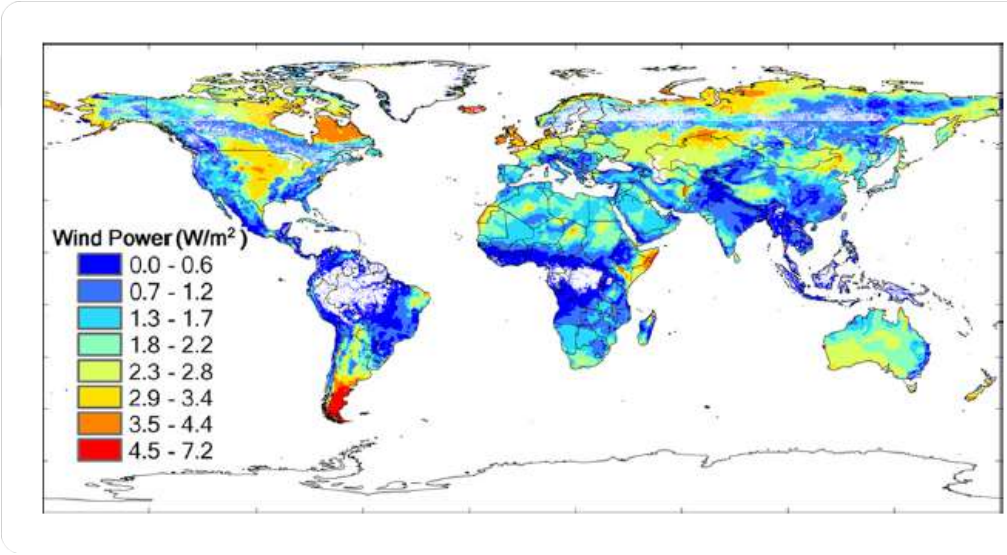


Figure 2.5 Global wind power potential [22]

The characteristics of the wind differs (in respect of time and region), based on local geographic differences and the non-homogenous temperatures of the surface of the earth. The speed of the wind rises with height, and its theoretical strength changes proportionately to its cubic speed. The initial investment costs of wind energy applications are high, and their capacity factors are low. Together with this, they have the disadvantage of inconsistent energy production. On the other hand, they have many advantages such as

- unlimited free supply within the atmosphere,
- renewable and clean source of energy,
- low cost of maintenance and repair,
- domestic materials and not dependence on imports,
- simple installation and operation technologies.

Wind turbines can only operate within a specific wind speed range to generate electricity. There is a cut-in and a cut-out speed in operation of turbine. The cut-in speeds for modern turbines are between 2-4 m/s with their nominal speeds between 10-15 m/s, and their cut out speeds range between 25-35 m/s. Wind turbines automatically stop at the cut-out speed in order to avoid system damages [23].

New generation wind turbines possess sound insulation in order to prevent noise pollution. The towers are built in the form of pipes or cages. The constructions outside the cage towers consist of two or three parts because the towers need to be enough high. In Turkey, wind plants with a capacity of 5 MW can be established at heights of 50 meters above ground level it the average wind exceeds 7.5 m/s. By taking these standard values, a Wind Potential Map (PWEM) has been prepared [23].

2.4.3 Hydropower Energy Resources

Almost all energy sources are based on solar radiation. Hydropower energy is also due to solar radiation. In a hydroelectric power plant, the kinetic energy of flowing of falling water is converted to electrical energy. According to manufacturing and working principle, these plants are classified in two groups: dam plant and run of river plant. A dam plant, as shown in Figure 2.6, uses a dam to store river water in a reservoir. Then the stored water released from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity.

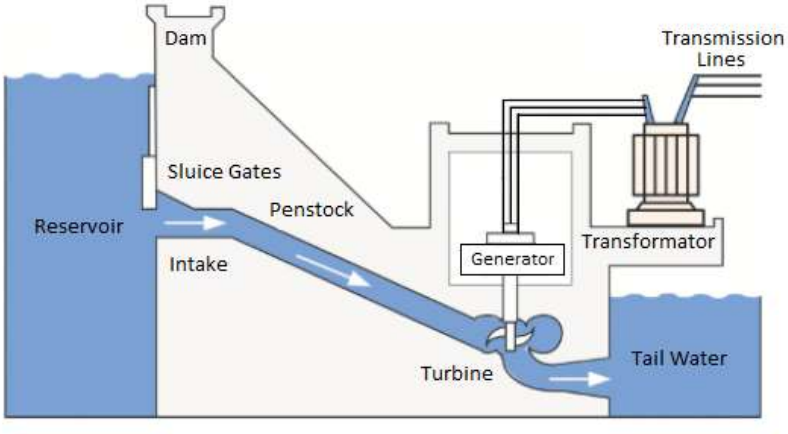


Figure 2.6 A schematic diagram of a dam plant hydroelectric power plant

The water from the dam flows through the penstock and spins the turbine. The water turbine converts hydraulic energy into mechanical energy, and the generator converts mechanical energy into electrical energy. Thus, the potential energy of the elevated water is transformed into electrical energy. The potential energy of the water in the reservoir is proportional to the mass (m) of water and the difference in height between the water impoundment and the water outflow (h)

$$U = mgh \tag{2.5}$$

Where g is the accelation of gravity. The mass of the water is simply its volume times its density. Therefore,

$$U = mgh = V\rho gh \tag{2.6}$$

The available power provided by the dam is given

$$P = \frac{U}{t} = \frac{V\rho gh}{t} = \frac{V}{t}\rho gh = q\rho gh \tag{2.7}$$

where q is called the rate of flow of the water. Hydroelectric power is considered to be a renewable energy source since it uses the continuous flow of water and does not rely on burning fossil fuels.

Hydroelectric power is evergreen credit by means of the hydrologic cycle. Both types of hydroelectric power plants require suitable geographical conditions. Some advantages of hydroelectric power are [17]:

- the energy obtain is renewable,
- do not cause greenhouse gas emission,
- construction is done by local facilities,
- technical life is long and requires no fuel cost,
- operation and maintenance cost are low,

Main disadvantages of hydroelectric power are [10]:

- the high initial investment,
- the loss of lands available for agriculturally productive,
- cause of alluvial bottomland and downstream erosion,
- alteration of ecosystem biogeochemistry,
- decline in fish species,

Among the renewable energy sources, hydropower is the most widespread sources being used in the world. Hydropower technology has not been changed noticeable for a long time and many countries have access to all technology related to hydropower [21]. New generation hydro turbines convert approximately 90% of the potential energy of the water into the electricity. On the other hand, the best fossil fuel plants can only convert about 50% of the available energy. Hydro resources are widely distributed throughout the world as compared fossil and nuclear fuel sources. Therefore, they provide energy independence for many countries [10]. The hydroelectric potential of the world is technically estimated to be 12,875 TWh per annum. However, the economically feasible hydroelectric potential is about 7,200 TWh per year. As it has been given in Figure 2.7, some developing regions of the world have the remaining technically and economically feasible hydropower potential [24].

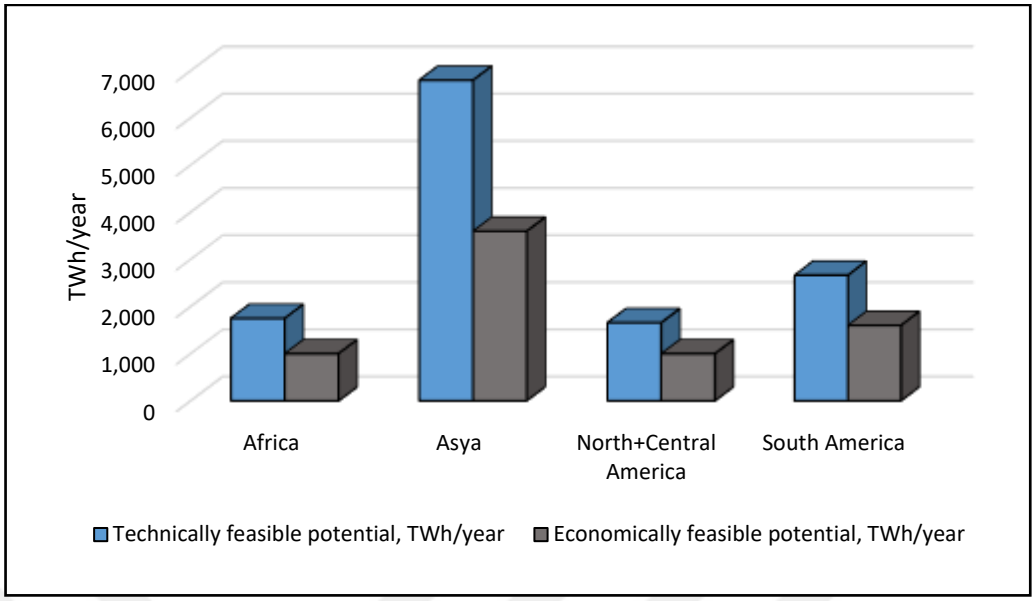


Figure 2.7 Remaining technically and economically feasible hydropower potential in the world [24]

2.4.4 Geothermal Energy Resources

Geothermal energy is based on using hot water, steam, and gases under the Earth's crust. Earth's core maintains a temperature of 5000 ºC due to gradual radioactive decay of elements. Heat energy continuously flows from the hot core to the crust and volcanic activities transports this hot material from the crust to the near surface under the earth crust and a thermal energy in the form of hot water, steam or gas is stored beneath Earth's crust. Geothermal systems use this energy either to generate electricity or for heating [12]. Geothermal power projects are in general clean and renewable with low environmental impacts such as greenhouse gas emissions, air quality, land use, and water quality. Figure 2.8 shows the global geothermal potential. As it may be seen from the figure America, Africa and North Asia have the highest geothermal potential. Turkey has also a high potential of geothermal.

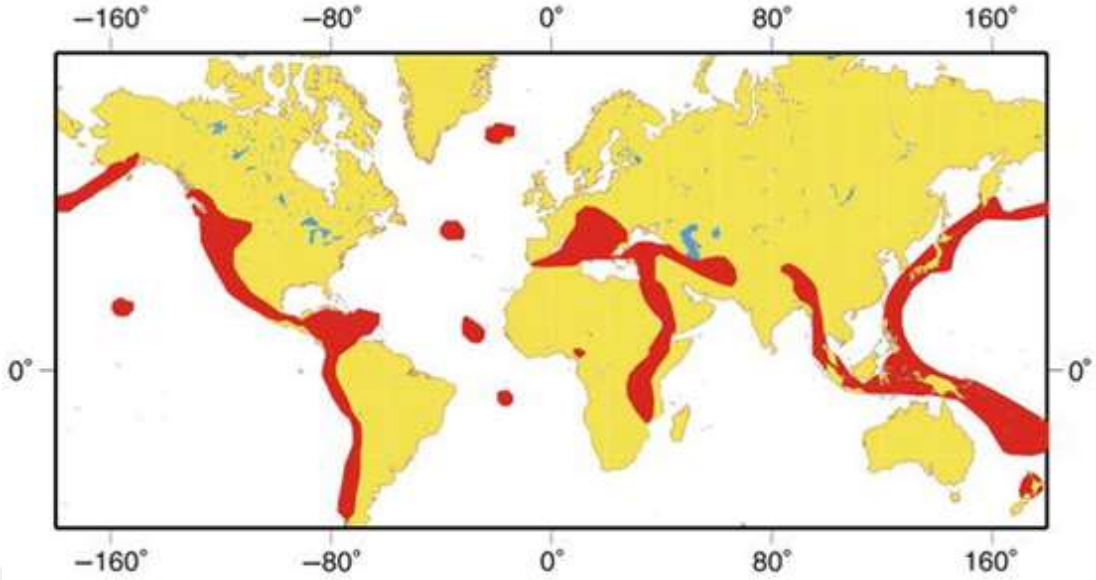


Figure 2.8 Global geothermal energy potential [26]

In electricity production, geothermal resources can be used either directly or indirectly. The most common method used to capture the electricity from the geothermal is based on using hydrothermal systems in which the steam generated from hot water extracted from earth crust is used to run a turbine and the electricity is generated from the generator connected to the turbine. The steam is converted back to the water by condenser and injected to the earth crust as shown by Figure 2.9.

Geothermal energy can also be used for direct heating in residential, commercial, and industrial sectors, for agriculture in drying fish, fruits, vegetables and timber products, washing wool, dying cloth, manufacturing paper, and pasteurizing milk.

Because the emitting rate of SO_x, CO_2, NO_x, gases is very low, geothermal sources are accepted as clean energy sources. On the other hand, geothermal energy does not depend on the weather conditions so that it is a sustainable source of the energy.

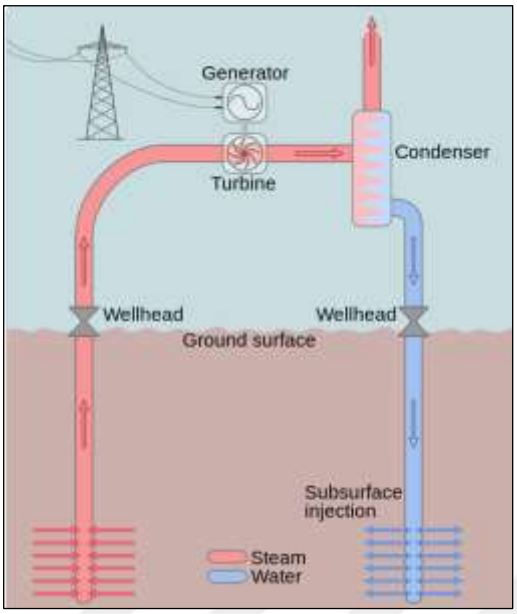


Figure 2.9 Geothermal energy generation systems [27]

2.4.5 Biomass Energy Resources

Biomass is a renewable and sustainable source of energy mainly derived from animal and plant organic matter such as wood, wood wastes, animal and industrial wastes as described in Figure 2.10. Although biomass generates carbon dioxide when utilized, it does not increase the earth's net volume of carbon dioxide because it is created from solar energy, water, and carbon dioxide, Therefore, biomass is said to be "carbon neutral. Though traditional biomass is used primarily for cooking and heating, biomass energy is also considered as a vital part of the global renewable energy mix and account for an ever-growing share of electric capacity added worldwide. In biomass power plants, wood waste or other waste is burned to produce steam that runs a turbine to make electricity.



Figure 2.10 Biomass fuel sources

Many plants such as corn, sugar cane have high potential for biofuel production and environmental benefits when the sufficient amount of land areas is available by avoiding the food versus energy conflict [28]. However, these crops have also issues of habitat suitability for cultivation and potential environmental problems. Among a few ways to use biomass, the direct combustion of biomass releases CO_2 to the environment, other cleaner ways are gasification and pyrolysis methods. Some of the recent predictions suggest that the biomass potential of the world is 1.2×10^{10} kL/year (crude oil equivalent) which may cover the world's demand (1×10^{10} kL/year) [29]. Biomass can generate not only electric power and heat directly by burning, but can also be efficiently converted to gas and liquid fuels for transportation as well. Biomass energy in the form of biogas or biodiesel is likely to make up one third of the total world energy mix by 2050.

2.5 Non-Renewable Energy Resources

Nonrenewable energy sources can be defined as the resources that are not replaced on a continuous basis or are replaced only very slowly, but dependent completely on natural processes. Fossil fuels that are considered non-renewable may continually be produced by the decay of plant and animal matter. The following energy sources are considered as nonrenewable energy sources:

- Petroleum (Oil)
- Coal
- Natural Gas
- Uranium and Thorium (Nuclear Energy)

Fossil fuels can be found in solid, liquid and gas forms, such as coal, oil, and gas. These fuels have been the world's foremost energy sources for the last several decades, and it is expected to remain the dominant energy source worldwide at least for a few decades as well. However, their consumption rate is higher than the generation rate. The consumption is accelerated by increasing world population, urbanization and industrialization as seen in Figure 2.11 [30].

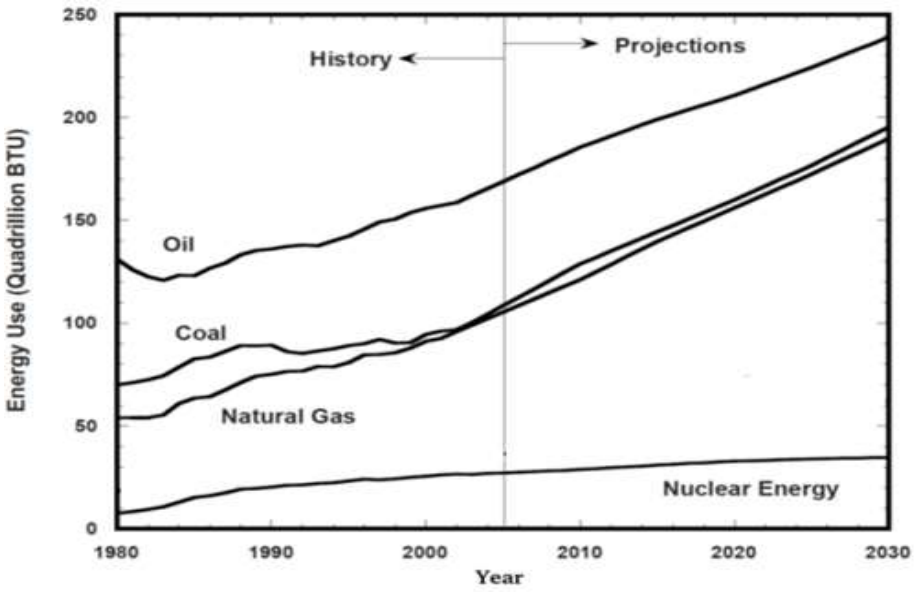


Figure 2.11 The consumption of non-renewable energy sources by years [30]

The release of carbon dioxide in the combustion of coal and oil is a challenging problem. However, natural gas has significant advantages as compared to coal and oil, because of its less environmental damage. Because of substantially increased energy demand, it is a challenging problem to reduce the CO_2 emission and the world's dependence on oil. However, great effort is spent to find alternatives to fossil fuels. The alternatives to the fossil fuels fall into two categories as nuclear sources and renewable sources.

2.5.1 Coal and Its Compositions

Coal was easily flammable rock including more than half related to carbon matter stem from pressure and thickening various disrupted plants [31].

Table 2.2 presents constituents and characteristics of some coal types. According to this table, characteristic of coal was determined by some factors like fixed carbon weight, moisture weight, bulk density, ash weight, and sulfur weight. For example, the largest fixed carbon weight has been at anthracite coal. The coal compounded more than 85% fixed carbon. Anthracite coal's fixed carbon rate was followed by bituminous coal with variable rates from 44.9% to 78.2% and lignite coal with 31.4%.

Table 2.2 Constituents and characteristics of some coal types [20]

	Anthracite coal	**Bituminous coal**	**Lignite coal**
Fixed carbon, weight %	80.5-85.7	44.9-78.2	31.4
Moisture, weight%	2.8-16.3	2.2-15.9	39
Bulk density, ıb/ft^3	50-58	42-57	40-54
Ash, weight%	9.7-20.2	3.3-11.7	3.3-11.7
Sulfur, weight%	0.6-0.77	0.7-4.0	0.4

Anthracite coal was favored for residential heating due to the several reasons. For example, that coal provides fixed, clear flame and also this coal fires longer and a more caloric value were higher than the other coal type. Some characteristic of this coals were quite firm, brilliant and also the most maturity coal type [20].

Bituminous coal ignites easily and burns for long. On the other hand, irregular ignite of this coal was characteristics associated with surplus smoke and cloying. Lignite was thought to underage coal since this coal was smoother than the other coal type. Lignite coal maturity rate is rise as long as became deeper and harder and eventually, lignite coal was named as a sub-bituminous coal [20].

2.5.2 Petroleum and Its Compositions

Petroleum is a general term for all natural hydrocarbons found in rocks in the form of natural gas, liquid, or solid. The gaseous petroleum is also called natural gas. The viscous solid petroleum is called bitumen or asphalt. Asphalt is the bituminous material left over when petroleum is refined. Petroleum is complex mixture of hundreds hydrocarbons (C_nH_{2n+2}), nitrogen, sulfur, or oxygen. Hydrocarbons range from methane (CH_4) to a series of liquids (gasoline, paraffin oil, lubricating oil), to solid paraffin wax ($C_{20}\,H_{42}$).

The crude oil (or petroleum) is available in various standards and formations. This variety of oil came from both biological and geological background. Petroleum is found both underground and beneath the seabed [32].

As shown in Table 2.3 represent that composition of petroleum. The largest element weight was carbon weight with 93-97% percentage. Carbon rate was followed by hydrogen, nitrogen with 10-14% and 0.1-2% percentage, respectively.

Table 2.3 Composition by weight of petroleum [20]

Element	Percentage (%)
Carbon, weight%	83-87
Hydrogen, weight%	10-14
Nitrogen, weight%	0.1-2
Oxygen, weight%	0.1-1.5
Sulfur, weight%	0.5-6
Metals	<0.1

The composition of petroleum involves a lot of elements. The most obtained elements are carbon, hydrogen, nitrogen, oxygen, and sulfur by a few metals. Characteristic of petroleum are identified by percentage of four hydrocarbons situated within the petroleum. This percentage for those hydrocarbons quite

extremely, but generally was found pursued percentage: paraffin's (15%-60%), naphthenes (30%-60%), aromatics (3% to 30%) [20].

Gaseous products include hydrogen, fuel gas, ethane, and propane or LPG. The main components of natural gas are given in Table 2.4. The largest component of the natural gas is methane with 95.2% percentage. Methane rate is followed by ethane, nitrogen and other trace elements, respectively. Majority of the ignitable part of natural gas arises from methane. Other hydrocarbons such as ethane, propane, and butane also present in the mix. On the other hand, incombustible elements like nitrogen (N_2) and carbon dioxide (CO_2) are found complicated with natural gas [20].

Table 2.4 Composition of natural gas in mole (%) [20]

Components	Composition
Methane	95.2
Ethane	2.5
Propane	0.2
Butane, n-butane	0.03
Iso-pentane, n-pentane, hexane plus	0.01
Nitrogen	1.3
Carbon Dioxide	0.7
Oxygen	0.02
Hydrogen	Trace

2.5.3 Nuclear Energy Sources

An atom is composed of electrons and a nucleus in which protons and neutrons are hold as shown in Figure 2.12. The electrons orbiting around the nucleus are kept in orbitals by electric force. On the other hand, nucleons are hold in nucleus by strong nuclear force.

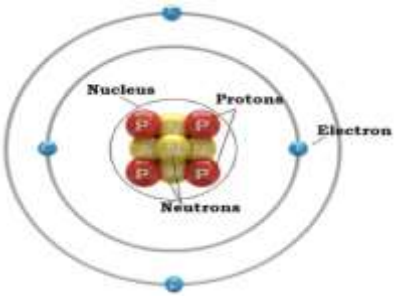


Figure 2.12 Composition of an atom

The electron structure of the atom was understood even before the composition of its nucleus was known. The reason is that the forces that hold the nucleus together are very strong as compared to the electric forces holding the electrons to the nucleus. Due to strong nuclear force inside the nucleus it is hard to break apart a nucleus to find its constituents. The changes in the electron structure of an atom that occur when a photon is emitted or absorbed or when a chemical bond is formed or broken, involve energies of only a few electron volts. However, the changes in nuclear structure, involve energies in the MeV range which is a million times greater than electric force.

Inside a nucleus, there is repulsive electric force between protons while the protons-neutrons and neutrons-neutrons act attractive strong nuclear forces on each other. If there is a balance between electric and strong nuclear force, the nucleus is stable. However, if the ratio of the neutron to proton numbers is higher than 1.5, the electric force becomes higher than strong nuclear force and the nucleus is called unstable or radioactive. As the atomic number increases, the neutron-to-proton ratio of the stable nuclei increases as illustrated in Figure 2.13.

The energy that holds nucleus is called binding energy. The binding energy for a nucleus of Z protons and N neutrons is given by

$$E_B = [(\sum_i m_i) - m]c^2 = \Delta mc^2 \qquad \textbf{(2.8)}$$

Where m_i is the mass of nucleons, m the mass of the nucleus, c is the speed of light.

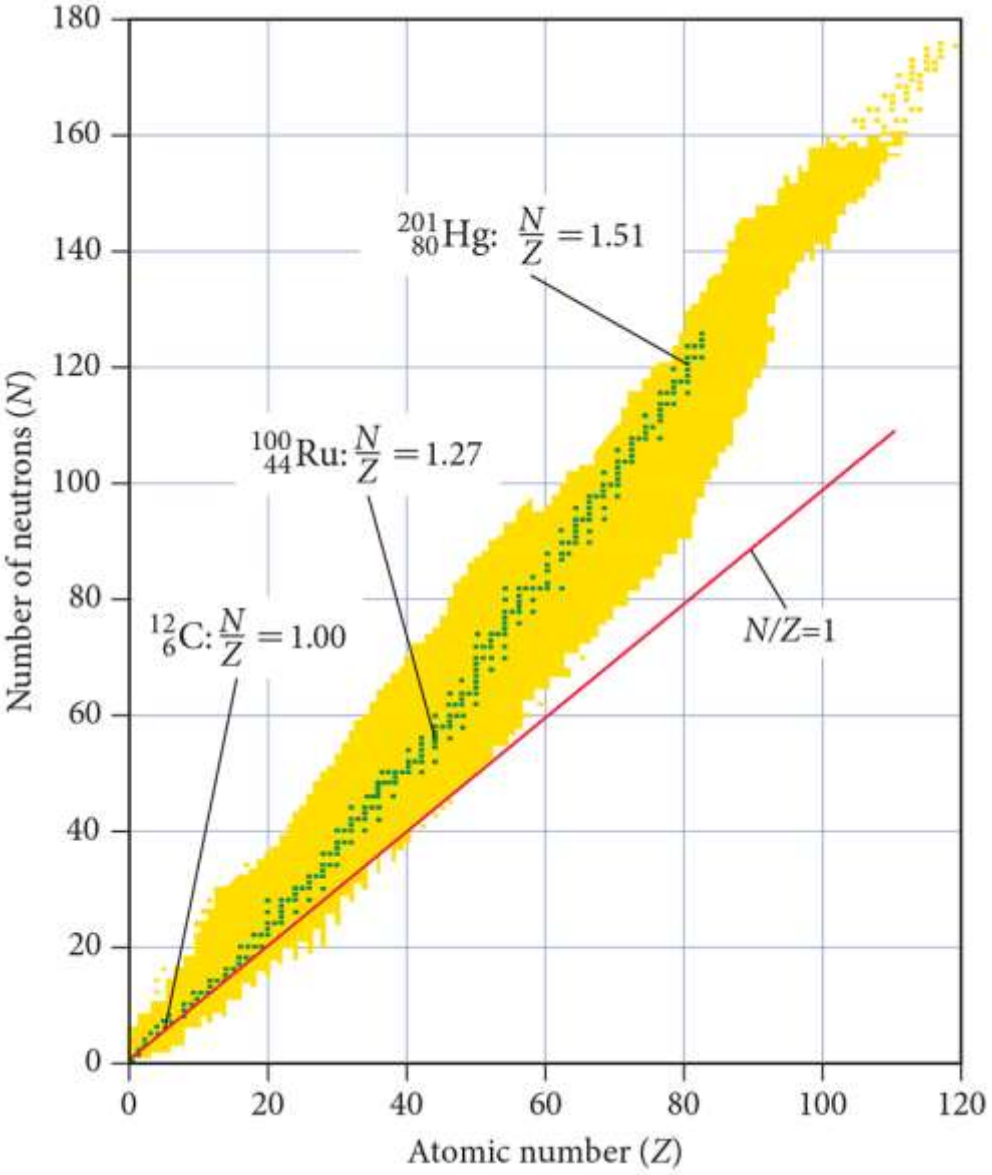


Figure 2.13 Neutron-to-proton number variations of nuclei [33]

The binding energy per nucleon (E_B/A) is a measure of stability of the nucleus. Larger the binding energy per nucleon, the greater the work that must be done to remove a nucleon from the nucleus, the more stable the nucleus. As it may be seen from Figure 2.14 the most stable nucleus is 56Fe and the stable nuclei range from 56Fe to 92Bi. The nuclei outside this band are unstable.

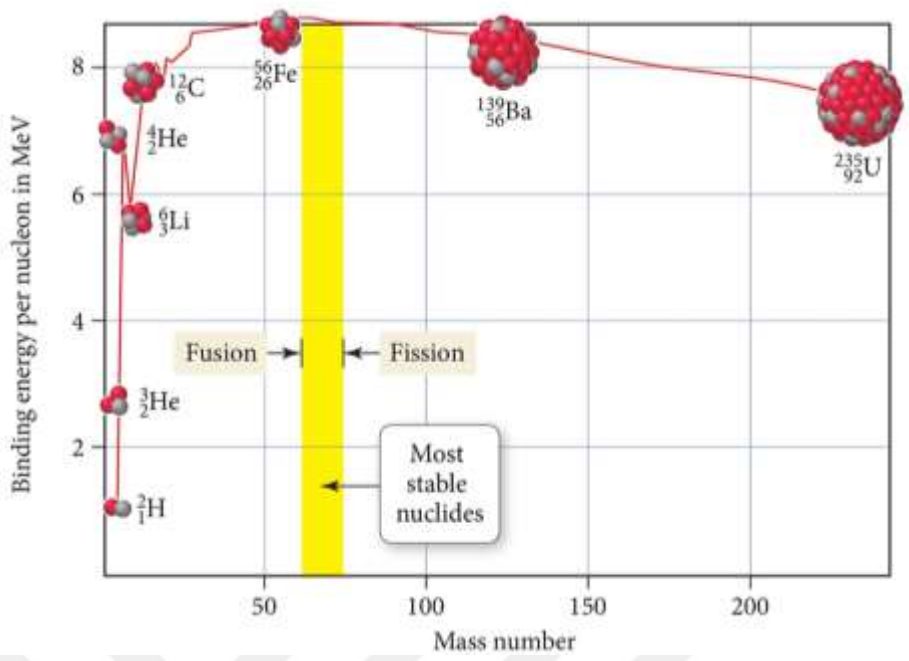


Figure 2.14 A plot of binding energy per nucleon versus mass number [34]

Many elements have several isotopes, most of which are unstable (radioactive). These radioactive isotopes usually decay (radioactive decay) on timescales from microseconds to billions of years into another element frequently with a change in the number of the nucleons. Radioactive decay only takes place if the energy of the daughter element is lowered relative to the energy of the parent, the excess energy given to the emitted particle.

A nucleus containing A number of nucleons is stable only if its mass is less than that of any other combination of A nucleons. Mathematically this is expressed with

$$ {}^{A}_{Z}X \longrightarrow R + S \tag{2.9}$$

In this case the binding energy is given as :

$$E_B = \left[m(R) + m(S) - m_{{}^{A}_{Z}X}\right] c^2 \tag{2.10}$$

It the binding energy is positive the reaction exoergic and an energy is released by this reaction. Despite criticisms arisen after the Fukushima event, nuclear energy by fission is still an alternative option of energy for several Countries. The main interest in nuclear energy is physically based on the so-called "mega factor" [35]. As compared to the energy released by a chemical reaction (in eV), as in the combustion phase of a coal (C) atom or a methane (CH_4) molecule, a nuclear reaction of a nucleus of uranium (235U isotope) by a neutron releases a significant amount of energy (in MeV).

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + 9.2\ eV \quad \textbf{(2.11)}$$

$$C + O_2 \rightarrow CO_2 + 3.6\ eV \quad \textbf{(2.12)}$$

$$^{235}U + n \rightarrow F_1 + F_2 + 212\ MeV \quad \textbf{(2.13)}$$

Therefore, on a larger scale, 5 grams of nuclear fuel (UO_2) are energetically equivalent to 640 kg of wood, or 360 m^3 of methane, or 400 kg of coal, or 350 kg of oil, moreover with no CO_2 emissions [35].

Uranium and Thorium are the main fuels used in nuclear fission reaction to provide heat energy for a nuclear power plant. Isotopic composition of uranium mine is: 234U, 0.006%; 235U, 0.712%; 238U, 99.282%. Only a small amount of natural Uranium is used in thermal nuclear reactors, since only the 235U isotope undergoes fission with thermal neutrons (slow neutron reactors). However, in fast nuclear reactors 70% of the natural content of this element is used by transmutation of the largest isotope (238U) into a fissile isotope with fast neutrons.

Technically, the production and management of nuclear fuel are very complicated as compared to coal and petroleum products. The ore of the natural uranium is mined with classical methods used in the mining industry, in open or underground mines, or is extracted by leaching. Then the ore is purified and concentrated so that all the rare earths and other are eliminated except UO_2 which represents a poison for the neutrons. In a content of natural isotopic mixture, the percentage of 235U is only

0.7%. The fuel is usually enriched up to 3–4% in order to be used in the nuclear reactor. The enrichment requires the conversion from UO_2 to UF_6, a fluorinated compound UF_6 can be transported in solid state and easily transformed into a gas (by heating it at low temperature (60°C) which is needed to mechanically enrich the fuel. Either gaseous diffusion or ultracentrifuge techniques are used for enrichment processes. Both the processes are based on the different velocity or the different centrifugal force acting on the $238UF_6$ molecules with respect to the $235UF_6$ ones. Once enriched, the UF_6 is re-converted into UO_2 to create the fuel assemblies for use. 1 gram of fissions releases an energy of 1 MWj. This is million times more than a chemical reaction. One tone of fission is enough to supply the heat needed for production of the total electric energy of 1 GWe reactor operating at full power for one year [36].

CHAPTER 3

GLOBAL ENERGY ANALYSIS

Global energy production is mainly based on fossil fuels (coal, oil and natural gas) and nuclear fission. Figure 3.1 shows the reserves to production ratio (R/P) of the remaining fossil fuels of the world. The remainig coal reserves at any year are split up by the production end of that year, according to reserves to production ratio (R/P), a lifespan of the global coal reserves has foreseen 134 years in the world remaining coal reserves. The lifespan of the total petroleum reserves is merely half-century. And also, the lifespan of the total natural gas reserves is about 52.6 years [37].

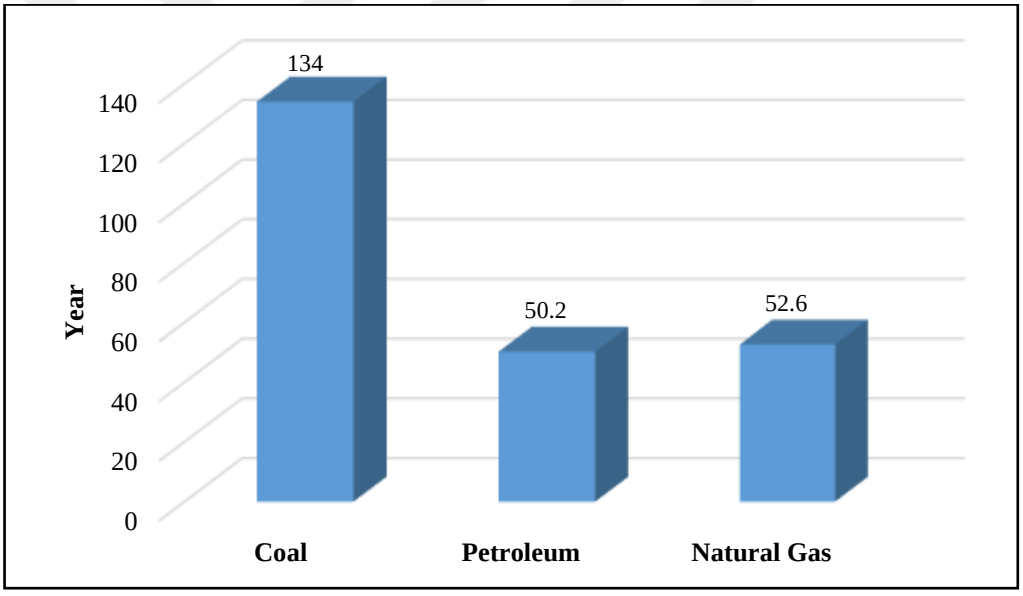


Figure 3.1 According to reserves to production ratio lifespan of the fossil fuels reserves [37]

3.1 Global Coal Analysis

3.1.1 Reserve

The World of proven coal reserves are available and evaluated economically operable by means of current technology. For this reason, this reserve can be changed in the progress of time for a variety of reason. For instance, more reserve

detection can be made, improvements in technological area and value change. Coal reserves are widespreadly dissipated around the world [3]. On the other hand, some regions posses more reserves than other regions. The largest proved coal reserves have been in the Asia Pacific region. Asia Pacific's coal reserves are followed by North America and Commonwealth of Independent States (CIS) region with 25.0% and 21.6% percentage, respectively. Table 3.1 gives global total proved coal reserves by region. As it may be seen in the table there are six main regions (North America, South & Central America, Europe, CIS, Middle East & Africa, and Asia Pacific) share of total proved coal reserves. These regions possess different percentage of coal reserves. According to this table, 424 billion tonnes (41.0%) of the coal reserves are determined in the Asia Pacific region, 259 billion tonnes (25.0%) in North America, 223 billion tonnes coal reserves (21.6%) in the CIS region, 14 billion tonnes (1.4%) in Middle East and Africa region and 1.4% in South & Central America region around the World [37].

Table 3.1 Total proved coal reserves by region at the end of 2017 (Million tonnes) [37]

Region	Anthracite and bituminous	Sub-bituminous and lignite	Total	Share of total
Asia Pacific	314325	109909	424234	41.0%
North America	226306	32403	258709	25.0%
CIS	130162	93066	223228	21.6%
Europe	24220	76185	100405	9.7%
Middle East& Africa	14354	66	14420	1.4%
South &Central America	8943	5073	14016	1.4%
World	**718310**	**316702**	**1035012**	**100.0%**

Similar situation it can be seen in countries. According to Table 3.2, some countries have more reserves than other countries. The largest part of the proved coal reserves has been in the United States with 251 billion tonnes which is 24.2% of the world total proved coal reserves. The country's coal reserves followed by Russia and Australia have represented with 15.5% and 14.0% percentage, respectively. The other abundant countries in coal reserves are China, India, and Germany with 13.4%, 9.4%, and 3.5% percentage, respectively. In this way, more than 80% of the world proved coal reserved has accumulated within of this six countries. On the other hand, Turkey represents only 1.1% share of in the world with regard to coal reserves which most of them sub-bituminous and lignite type [37].

Table 3.2 Total proved coal reserves by some country at the end of 2017 (Million tonnes) [37]

Country	Anthracite and bituminous	Sub-bituminous and lignite	Total	Share of total
United States	220800	30182	250916	24.2%
Russian	69634	90730	160364	15.5%
Australia	68310	76508	144818	14.0%
China	130851	7968	138819	13.4%
India	92786	4942	97728	9.4%
Germany	8	36100	36108	3.5%
Ukraine	32039	2336	34375	3.3%
Kazakhstan	25605	-	25605	2.5%
Poland	19808	6003	25811	2.5%
Indonesia	15068	7530	22598	2.2%
Turkey	378	10975	11353	1.1%
World	**718310**	**316702**	**1035012**	**100.0%**

3.1.2 Production

As can be shown in Table 3.3 global coal production reached to 3,663 Mtoe in 2016, increased to 3,768 Mtoe in 2017. While global coal production growth rate per annum was 1.5% between the years of 2006-2016 some regions perform more production than other regions. The largest coal production has been at the Asia Pacific region in the world which is 71% percentage of the global coal production. Asia Pacific's coal production is followed by North America and CIS region with 10.8% and 7.2% percentage, respectively. As can be seen in this table, 2,702 Mtoe (71.7%) of the coal production is produced in Asia Pacific region, 407 Mtoe coal production in the North America and 271 Mtoe coal production in CIS region at the end of 2017 [37].

Table 3.3 Coal production by region at the end of 2017 (Mtoe) [37]

Region	2016	2017	Growth rate per annum		Share 2017
			2017	2006-16	
Asia Pacific	2639.6	2702.3	2.7%	3.2%	71.7%
North America	386.2	407.9	5.9%	- 4.4%	10.8%
CIS	258.1	271.8	5.6%	1.6%	7.2%
Europe	161.3	164.6	2.3%	-3.1%	4.4%
Africa	149.6	154.5	3.6%	0.6%	4.1%
South&Central America	67.8	66.8	-1.3%	2.4%	1.8%
World	**3663.5**	**3768.6**	**3.2%**	**1.5%**	**100.0%**

According to Figure 3.2 and Table 3.4, some countries perform more production than other countries. The largest part of the coal production is in China with 1,747 Mtoe in 2017. China's coal production represented almost one-half of the world total coal production. That country alone provides half of the world total coal production. China's coal production is followed by the United States and Australia with 9.9% and 7.9% of global production, respectively. The other abundant countries in coal production are India, Indonesia, and Russia with 7.8%, 7.2%, and 5.5% percentage, respectively. In this way, almost 85% of the world coal production has provided within of this six countries. On the other hand, Turkey has represented only 0.6% share of with regard to coal production in the world [37].

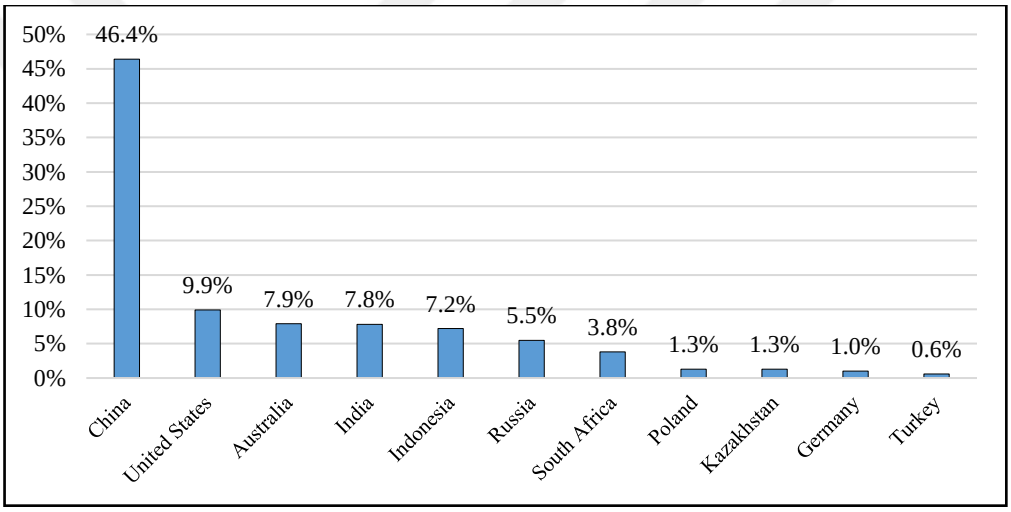


Figure 3.2 Share of coal production by some country at the end of 2017 (%) [37]

Table 3.4 Coal production by some country at the end of 2017 (Mtoe) [37]

Country	2016	2017	Growth rate per annum	
			2017	2006-16
China	1691.4	1747.2	3.6%	2.4%
United States	348.3	371.3	6.9 %	- 4.7%
Australia	307.7	297.4	-3.1%	3.4%
India	284.9	294.2	3.5%	3.7%
Indonesia	268.8	271.6	1.3%	8.9%
Russia	194.0	206.3	8.5%	0.7%
South Africa	142.4	143.0	0.7%	0.3%
Poland	52.1	49.6	-4.4%	-2.6%
Kazakhstan	44.3	47.9	8.5%	0.7%
Germany	39.8	39.6	-0.3%	-2.9%
Turkey	15.5	20.8	34.8%	1.6%
World	**3663.5**	**3768.6**	**3.2%**	**1.5%**

3.1.3 Consumption

As the total coal consumption is taken into consideration in the world. According to Table 3.5, global coal consumption rises from 3,706 Mtoe in 2016 to 3,732 Mtoe in 2017. While global coal consumption was roared by 1.3% per year on average between 2006 to 2016 years, coal consumption was also increased in 2017. Some regions perform more consumption than other regions. The largest coal consumption has been at the Asia Pacific region in the world with %75 percentage of the global coal consumption. Asia Pacific's coal consumption is followed by North America and Europe region with 9.7% and 7.9% percentage, respectively. According to Table 3.5, 2,780 Mtoe (74.5%) of the global coal is consumed in Asia Pacific region, 363 Mtoe coal consumption in the North America, 296 Mtoe coal consumption in Europe region at end 2017 [37].

Table 3.5 Coal consumption by region at the end of 2017 (Mtoe) [37]

Region	2016	2017	Growth rate per annum		Share 2017
			2017	2006-16	
Asia Pacific	2744.0	2780.0	1.6%	3.1%	74.5%
North America	371.9	363.8	- 1.9%	-4.3 %	9.7%
Europe	295.1	296.4	0.7%	- 2.2%	7.9%
CIS	156.2	157.0	0.8%	- 0.7%	4.2%
Africa	94.9	93.1	- 1.7%	0.5%	2.5%
South &Central America	34.9	32.7	- 5.9%	3.7%	0.9%
World	**3706.0**	**3731.5**	**1.0%**	**1.3%**	**100.0%**

According to Table 3.6, some countries perform more consumption than other countries. The largest part of the coal consumption has been in China with 1,892 Mtoe. China's coal consumption has represented almost one-half of the world total coal consumption. China's coal consumption followed by India and the United States have represented with 11.4% and 8.9% part, respectively. Thus, above 70 % of the world coal consumption was accumulated within of this three countries. On the other hand, Turkey represents only 1.2% share in coal consumption in the world [37].

Table 3.6 Coal consumption by some country at the end of 2017 (Mtoe) [37]

Country	2016	2017	Growth rate per annum		Share 2017
			2017	2006-16	
China	1889.1	1892.6	0.5%	2.6%	50.7%
India	405.6	424.0	4.8%	6.3%	11.4%
United States	340.6	332.1	-2.2%	-4.5%	8.9%
Russia	89.2	92.3	3.8%	-0.8%	2.5%
South Africa	84.7	82.2	-2.7%	0.4%	2.2%
Germany	75.8	71.3	-5.8%	-1.1%	1.9%
Indonesia	53.4	57.2	7.4%	6.3%	1.5%
Poland	49.5	48.7	- 1.4%	-1.5%	1.3%
Turkey	38.5	44.6	16.3%	3.9%	1.2%
Australia	43.6	42.3	-2.8%	-1.9%	1.1%
Kazakhstan	33.9	36.2	7.0%	1.8%	1.0%
World	**3706.0**	**3731.5**	**1.0%**	**1.3%**	**100.0%**

3.2 Global Petroleum Analysis

3.2.1 Reserve

Globally, the total proved petroleum reserves were 1,696 thousand million barrels (tmb) at the end of 2017. Proved Petroleum reserves increased from 1,427 tmb to 1,697 tmb from 2007 to 2016. On the other hand, total proved petroleum reserves increased in a very small ratio in comparison with over the last decade. That is, proved petroleum resources have not changed substantially in the world in last decade. The lifespan of the total petroleum reserves is merely half-century. This situation is given in Table 3.7 [37].

The table presents that by the end of 2017 seven main regions (Middle East, North America, Africa, South & Central America, Asia Pacific, CIS and Europe) share of total proved oil reserves. Some regions possess more reserves than other regions. The largest proved petroleum reserves have been at Middle East region in the world with about one-half of the world total proved reserves. Middle East's oil reserves were followed by South & Central America and North America region with 19.5% and 13.3% percentage, respectively. As may be seen in Table 3.7, 807 thousand million barrels (47.6%) of the total petroleum reserves are determined in the Middle East region, 330 thousand million barrels petroleum reserves in the South & Central America region, 226 thousand million barrels petroleum reserves in North America,

144 thousand million barrels petroleum reserves in CIS region and 7.5% in Africa region [37].

Table 3.7 Total proved petroleum reserves by region at the end of 2017 (Thousand Million barrels) [37]

Region	At end 2007	At end 2016	At end 2017	
			Total	Share of total
Middle East	754.9	807.7	807.7	47.6%
South &Central America	125.3	328.9	330.1	19.5%
North America	221.5	227.7	226.1	13.3%
CIS	145.3	144.9	144.9	8.5%
Africa	119.7	126.5	126.5	7.5%
Asia Pacific	45.3	48.3	48.0	2.8%
Europe	15.1	13.1	13.4	0.8%
World	**1427.1**	**1697.1**	**1696.6**	**100.0%**

Table 3.8 shows total proved oil reserves of some countries with high share in the world. Some countries possess more petroleum reserves than other countries. The largest part of the proved oil reserves has been in Saudi Arabia with 266 thousand million barrels. Saudi Arabia oil reserves represents 15.7% of the world total proved oil reserves. Saudi Arabia oil reserves followed by Iran and Iraq with 9.3% and 8.8% percentage, respectively. The other abundant countries in petroleum reserves are Russia, Kuwait and the United Arab Emirates with 6.3%, 6.0%, and 5.8% percentage, respectively. That is to say more than half of the world proved petroleum reserve have gathered within of this six countries [37].

Table 3.8 Total proved petroleum reserves by some country at the end of 2017 (Thousand Million barrels) [37]

Country	At end 2007	At end 2016	At end 2017	
			Total	Share of total
Saudi Arabia	264.2	266.2	266.2	15.7%
Iran	138.2	157.2	157.3	9.3%
Iraq	115.0	148.8	148.8	8.8%
Russia	106.4	106.2	106.2	6.3%
Kuwait	101.5	101.5	101.5	6.0%
United Arab Emirates	97.8	97.8	97.8	5.8%
United States	30.5	50.0	50.0	2.9%
China	20.8	25.7	25.7	1.5%
World	**1427.1**	**1697.1**	**1696.6**	**100.0%**

3.2.2 Production

Average growth rate of global petroleum production per annum between 2006 to 2016 years was 1.1%. Global oil production reached to 92649 thousand barrels daily (tb/d) at the end of 2017. Global Petroleum production was 0.7% growth rate compared to the 2016 year. On the other side, many region's oil productions fell in comparison with in 2016, except for the North America, Africa and CIS region. As can be seen in the Table 3.9 the largest decreases were to be seen in South &Central America and Asia Pacific region, on the other hand, the largest increases were to be seen in the Africa in 2017 [37].

Table 3.9 Oil production by region at the end of 2017 (Thousand barrels daily) [37]

Region	2016	2017	Growth rate per annum		Share 2017
			2017	2006-16	
Middle East	31849	31597	-0.8%	2.1%	34.1%
North America	19292	20112	4.3%	3.5%	21.7%
CIS	14162	14288	0.9%	1.4%	15.4%
Africa	7687	8072	5.0%	-2.5%	8.7%
Asia Pacific	8050	7879	-2.1%	0.2%	8.5%
South &Central America	7418	7182	-3.2%	-0.1%	7.8%
Europe	3566	3519	-1.3%	- 3.9%	3.8%
World	**92023**	**92649**	**0.7%**	**1.1%**	**100.0%**

Table 3.10 and also Figure 3.3 demonstrate the oil production value and the growth rate by countries. The largest part of the oil production has been in the United States with 13057 thousand barrels daily (tb/d). The United States and Saudi Arabia oil production have represented almost the one-quarter of the world total oil production. The other abundant countries in oil production are Russia, Iran, and Canada with 12.2%, 5.4%, and 5.2% percentage, respectively. In this way, almost 50% of the world oil production was provided by these countries [37].

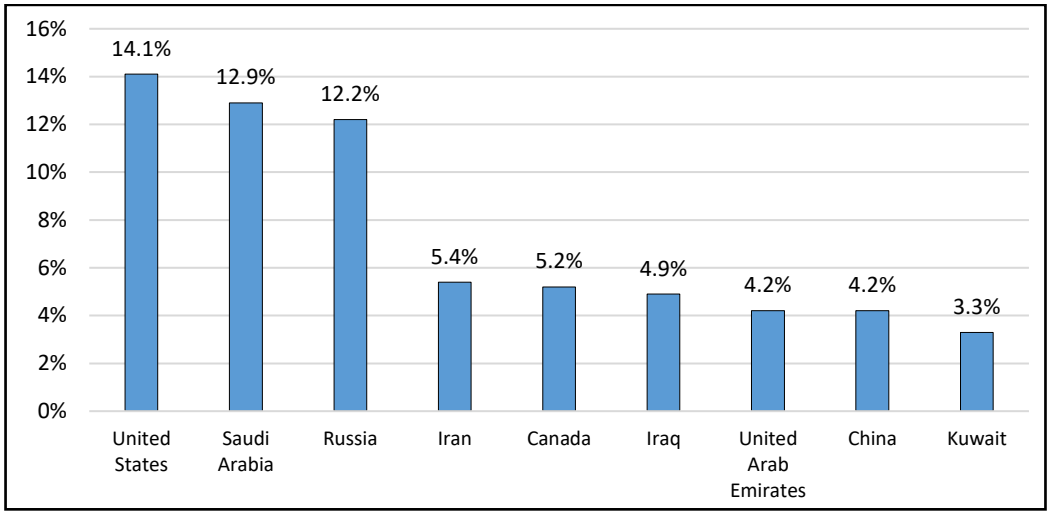


Figure 3.3 Share of oil production by some country at the end of 2017 (%) [37]

Table 3.10 Oil production by some country at the end of 2017 (Thousand barrels daily) [37]

Country	2016	2017	Growth rate per annum	
			2017	2006-16
United States	12366	13057	5.6%	6.1%
Saudi Arabia	12402	11951	-3.6%	1.5%
Russia	11269	11257	-0.1%	1.4%
Iran	4602	4982	8.2%	0.7%
Canada	4470	4831	8.1%	3.4%
Iraq	4423	4520	2.2%	8.3%
United Arab Emirates	4020	3935	-2.1%	2.5%
China	3999	3846	-3.8%	0.8%
Kuwait	3145	3025	-3.8%	1.4%
World	**92023**	**92649**	**0.7%**	**1.1%**

3.2.3 Consumption

When the total petroleum consumption is taken into consideration in the world. Global oil consumption by region is given in Table 3.11. Global oil consumption had a 1.2% average growth rate per annum between 2006 to 2016 years. Globally, oil consumption reached to 98186 tb/d at the end of 2017. As can be seen in this table, South &Central America region oil consumption fell as compared to 2016. On the other hand, the largest increasing demand was seen in the Asia Pacific region in 2017. Some regions perform more consumption than other regions. The largest oil consumption has been in the Asia Pacific region with 35% of the global oil consumption. Asia Pacific's oil consumption is followed by North America and

Europe region with 24.7% and 15.3% percentage, respectively. According to Table 3.11 , 34574 tb/d of the oil was consumed in Asia Pacific region, 24219 tb/d in North America and 14980 tb/d in Europe region at the end of 2017 [37].

Table 3.11 Oil consumption by region at the end of 2017 (Thousand barrels daily) [37]

Region	2016	2017	Growth rate per annum		Share 2017
			2017	2006-16	
Asia Pacific	33562	34574	3.0%	2.9%	35.2%
North America	24065	24219	0.6%	-0.4%	24.7%
Europe	14696	14980	1.9%	-1.2%	15.3%
Middle East	9161	9290	1.4%	3.1%	9.5%
South & Central America	6811	6794	-0.2%	-2.2%	6.9%
CIS	4243	4282	0.9%	1.1%	4.4%
Africa	3950	4047	2.5%	3.1%	4.1%
World	**96488**	**98186**	**1.8%**	**1.2%**	**100.0%**

Table 3.12 demonstrates the world oil consumption by some countries. The largest partion of the oil consumption was in the United States with 19880 tb/d at the end of 2017. United States oil consumption represented about 20% of the world total oil consumption. This country oil consumption was followed by China represented with 13.0% percentage. On the other hand, Turkey has represented only 1.0% share of with regard to oil consumption in the world [37].

Table 3.12 Oil consumption by some country at the end of 2017 (Thousand barrels daily) [37]

Country	2016	2017	Growth rate per annum		Share 2017
			2017	2006-16	
United States	19687	19880	1.5%	0.5%	20.2%
China	12302	12799	4.0%	5.2%	13.0%
India	4560	4690	2.9%	5.2%	4.8%
Japan	4031	3988	-1.1%	-2.5%	4.1%
Saudi Arabia	3939	3918	-0.5%	5.6%	4.0%
Russia	3193	3224	1.0%	1.5%	3.3%
Brazil	3013	3017	0.1%	3.4%	3.1%
South Korea	2771	2796	0.9%	1.8%	2.8%
Germany	2378	2447	2.9%	-0.9%	2.5%
Turkey	972	1007	3.5%	3.6%	1.0%
World	**96488**	**98186**	**1.8%**	**1.2%**	**100.0%**

3.3 Global Natural Gas Analysis

3.3.1 Reserve

The total proved natural gas reserves were 193 trillion cubic metres (tcm) at the end of 2017 as seen in Table 3.13. Proved natural gas reserves have reached to over 193 tcm in 2017, up from 163 tcm in 2007. So that total proved natural gas reserves have increased about 30 tcm by comparison with over the past decade. The lifespan of the total natural gas reserves is about 52.6 years [37].

On the other hand, some regions possess more natural gas reserves than other regions. Middle East region has the largest proved natural gas reserves in the world with 41% of the world total proved natural gas reserves. Middle East's natural gas reserves were followed by CIS and Asia Pacific region with 30.6% and 10.0% percentage, respectively. As can be seen in Table 3.13, 79.1 tcm with 40.9% of the world's total natural gas reserves are located in the Middle East region, 59.2 tcm with 30.6% of natural gas reserves in CIS region, 19.3 tcm with 10.0% of natural gas reserves in Asia Pacific, 13.8 tcm of natural gas reserves in Africa region, 10.8 tcm of natural gas reserves in North America and lastly about 4.2% in South &Central America region [37].

Table 3.13 Total proved natural gas reserves by region at the end of 2017 (Trillion cubic metres) [37]

Region	At end 2007	At end 2016	At end 2017	
			Total	Share of total
Middle East	73.6	78.8	79.1	40.9%
CIS	41.2	59.0	59.2	30.6%
Asia Pacific	13.6	19.2	19.3	10.0%
Africa	14.0	13.8	13.8	7.1%
North America	8.4	10.9	10.8	5.6%
South &Central America	7.8	8.3	8.2	4.2%
Europe	5.0	3.0	3.0	1.5%
World	**163.5**	**193.1**	**193.5**	**100.0%**

Table 3.14 shows the total proved natural gas reserves of some countries and the total reserves in the world. As it may be seen from the table some countries have large amount natural gas reserves. The largest part of the proved natural gas reserves has been in Russia with 35.0 trillion cubic metres (tcm). Iran has 17.2% of the world's total proved natural gas reserves. Qatar and Turkmenistan have represented with

12.9% and 10.1% percentage, respectively. The other abundant countries are the United States, Saudi Arabia with 4.5% and 4.2% percentage in natural gas reserves respectively. Six countries have almost two-thirds of the world proved natural gas reserves [37].

Table 3.14 Total proved natural gas reserves by some country at the end of 2017 (Tcm) [37]

Country	At end 2007	At end 2016	At end 2017	
			Total	Share of total
Russia	33.9	34.8	35.0	18.1%
Iran	27.7	33.2	33.2	17.2%
Qatar	26.4	24.9	24.9	12.9%
Turkmenistan	2.6	19.5	19.5	10.1%
United States	6.4	8.7	8.7	4.5%
Saudi Arabia	6.9	8.0	8.0	4.2%
Venezuela	5.4	6.4	6.4	3.3%
United Arab Emirates	6.3	5.9	5.9	3.1%
China	2.3	5.5	5.5	2.8%
Nigeria	5.0	5.2	5.2	2.7%
Algeria	4.3	4.3	4.3	2.2%
World	**163.5**	**193.1**	**193.5**	**100.0%**

3.3.2 Production

When the total natural gas production is taken into consideration in the world, Table 3.15 represents that global natural gas production by region. Globally natural gas production was a 2.2% growth rate per annum between the years of 2006-2016. Production of global natural gas was reached to 3,680 billion cubic metres (bcm) at the end of 2017. Global natural gas production was 4.0% growth rate compared to the one in 2016 [37].

Table 3.15 Natural gas production by region at the end of 2017 (Billion cubic metres) [37]

Region	2016	2017	Growth rate per annum		Share 2017
			2017	2006-16	
North America	944.6	951.5	1.0%	2.6%	25.9%
CIS	769.8	815.5	6.2%	*	22.2%
Middle East	630.8	659.9	4.9%	6.5%	17.9%
Asia Pacific	580.3	607.5	5.0%	4.0%	16.5%
Europe	238.6	241.9	1.7%	-2.3%	6.6%
Africa	207.0	225.0	9.0%	1.1%	6.1%
South &Central America	178.8	179.0	0.4%	1.4%	4.9%
World	**3549.8**	**3680.4**	**4.0%**	**2.2%**	**100.0%**

Table 3.16 and also Figure 3.4 demonstrates that some countries natural gas production value and the growth rate by some countries. The largest part of natural gas production has been in the United States with 734 billion cubic metres (bcm). The United States and Russia natural gas production have represented over the one-third of the world total natural gas production. The other abundant countries in natural gas production are Iran, Qatar, and Canada with 6.1%, 4.8% and 4.8% percentage, respectively. In this way, almost more than half of the world natural gas production has provided within of these countries [37].

Table 3.16 Natural gas production by some country at the end of 2017 (Billion cubic metres) [37]

Country	2016	2017	Growth rate per annum	
			2017	2006-16
United States	729.3	734.5	1.0%	3.8%
Russia	589.3	635.6	8.2%	-0.3%
Iran	203.2	223.9	10.5%	6.3%
Qatar	177.0	175.7	-0.5%	12.9%
Canada	171.6	176.3	3.0%	-0.4%
China	137.9	149.2	8.5%	8.9%
Norway	115.8	123.2	6.7%	2.8%
Saudi Arabia	105.3	111.4	6.1%	4.2%
Australia	96.4	113.5	18.0%	9.0%
Algeria	91.4	91.2	0.1%	1.2%
World	**3549.8**	**3680.4**	**4.0%**	**2.2%**

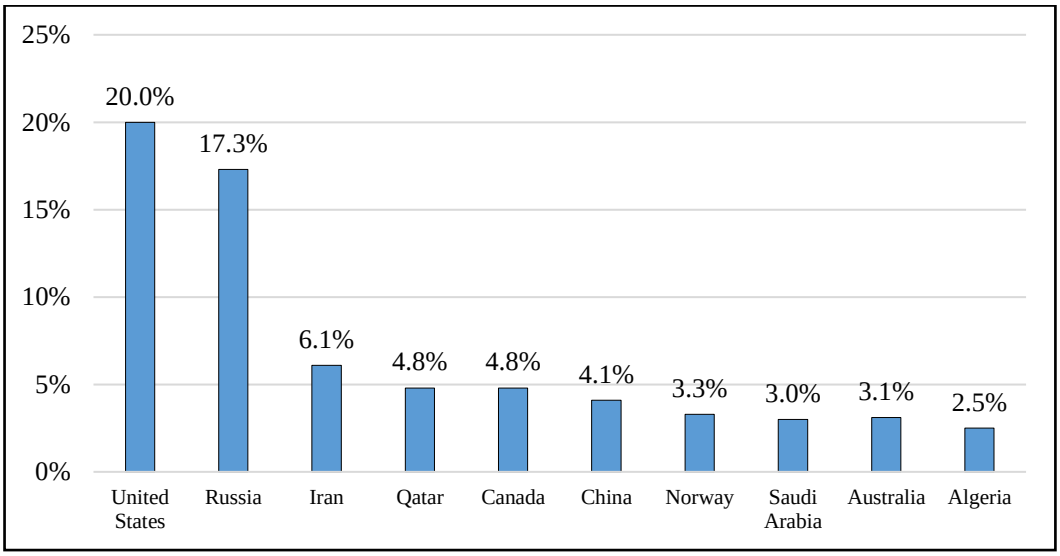


Figure 3.4 Share of natural gas production by some country at the end of 2017 (%) [37]

3.3.3 Consumption

Global natural gas consumption by region can be seen in Table 3.17. Global natural gas consumption was a 2.3% growth rate per annum between the years of 2006-2016. Globally, natural gas consumption reached to 3670 bcm at the end of 2017. As can be seen in Table 3.17, the largest increasing demand was seen in the Africa and Asia Pacific region. On the other side, South & Central America region natural gas consumption was fall by comparison with in 2016 [37].

Some regions perform more consumption than other regions. The largest natural gas consumption was been at North America region. That region comes to hand about 26% of the global natural gas consumption. North America natural gas consumption was followed by Asia Pacific and CIS region with 21.0% and 15.7% respectively. According to this table, about 943 bcm of the natural gas consumption are made in North America region, 769 bcm natural gas consumption in Asia Pacific, 574 bcm natural gas consumption in CIS region at end 2017 [37].

Table 3.17 Natural gas consumption by region at the end of 2017 (Billion cubic metres) [37]

Region	2016	2017	Growth rate per annum		Share 2017
			2017	2006-16	
North America	951.6	942.8	-0.7%	2.7%	25.7%
Asia Pacific	727.0	769.6	6.2%	5.2%	21.0%
CIS	572.9	574.6	0.6%	-0.4%	15.7%
Middle East	508.9	536.5	5.7%	5.9%	14.6%
Europe	505.6	531.7	5.5%	-0.9%	14.5%
South and Central America	175.1	173.4	-0.7%	2.3%	4.7%
Africa	133.2	141.8	6.8%	4.3%	3.9%
World	**3574.2**	**3670.4**	**3.0%**	**2.3%**	**100.0%**

Table 3.18 demonstrates that some countries natural gas consumption value and those countries growth rate. The largest part of the natural gas consumption has been in the United States with about 739 billion cubic metres (bcm). United States natural gas consumption was represented 20% of the world total natural gas consumption. This country natural gas consumption followed by Russia was represented with 11.6% percentage. While Turkey's local natural gas production was negligible, but Turkey's natural gas consumption was a 2.3% growth rate per annum between the years of 2006-2016 [37].

Table 3.18 Natural gas consumption by some country at the end of 2017 (Billion cubic metres) [37]

Country	2016	2017	Growth rate per annum		Share 2017
			2017	2006-16	
United States	750.3	739.5	-1.2%	2.5%	20.1%
Russia	420.2	424.8	1.4%	*	11.6%
China	209.4	240.4	15.1%	13.7%	6.6%
Iran	201.4	214.4	6.8%	6.2%	5.8%
Japan	116.4	117.1	0.8%	2.9%	3.2%
Canada	109.5	115.7	6.0%	2.5%	3.2%
Saudi Arabia	105.3	111.4	6.1%	4.2%	3.0%
Germany	84.9	90.2	6.5%	-0.8%	2.5%
United Kingdom	81.0	78.8	-2.4%	-1.5%	2.1%
United Arab Emirates	72.5	72.2	-0.2%	5.5%	2.0%
Turkey	44.4	51.7	16.6%	4.3%	1.4%
World	**3574.2**	**3670.4**	**3.0%**	**2.3%**	**100.0%**

*Less than 0.05%

3.4 Global Nuclear Electricity Production

According to the International Atomic Energy Agency (IAEA) data, 30 countries use nuclear electricity power to supply energy demand. As can be seen in the Table 3.19, United States has the highest nuclear electricity capacity in the world with 805647 GWh in 2017, followed by France and China with 381846 GWh and 232796 GWh nuclear electricity supplier respectively. In this way, these countries have supplied almost half of the world nuclear electricity production [38].

Table 3.19 Nuclear electricity supplied some countries in 2017 (GWh) [38]

Country	Nuclear Electricity Supplied (GWh)	Country	Nuclear Electricity Supplied (GWh)
United States	805647.33	Bulgaria	14872.26
France	381846.02	Czech Republic	26784.68
China	232796.74	Finland	21573.97
Japan	29285.05	Hungary	15218.92
Russia	190115.15	Mexico	10571.92
Korea	141278.32	Netherlands	3263.18
Canada	95131.20	Pakistan	8108.93
Ukraine	84005.85	Romania	10580.15
Germany	72162.80	Slovakia	14015.92
Sweden	60062.89	Slovenia	5967.83
India	20004.34	South Africa	15087.29
Argentına	5716.27	Spain	55627.75
Armenıa	2411.39	Switzerland	19590.70
Belgıum	40186.70	United Kingdom	63886.83
Brazil	14854.33	Iran	6366.21
World			**2487981.29**

Table 3.20 and also Figure 3.5 demonstrates that some countries nuclear energy production value and the share percent by some countries. The largest share of nuclear energy production has been in France with 71.6% percentage. Ukraine nuclear electricity production have represented more than half of the electricity generation obtain from nuclear power. The other abundant countries in nuclear share of electricity production are Korea, Spain and United States with 27.1%, 21.2%, and 20.0% percentage, respectively [38].

Table 3.20 Nuclear share of electricity production some countries in 2017 (%) [38]

Country	Nuclear Share (%)
France	71.6
Ukraine	55.1
Korea	27.1
Spain	21.2
United States	20.0
United Kingdom	19.3
Russia	17.8
Canada	14.6
Germany	11.6
China	3.9

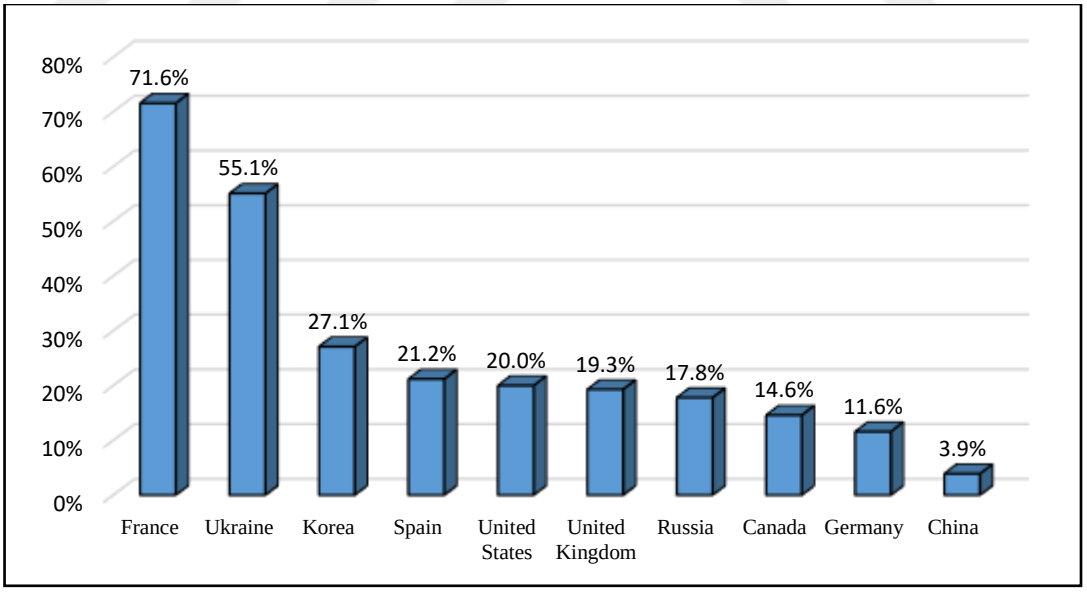


Figure 3.5 Nuclear share of electricity generation some countries in 2017 (%) [38]

3.5 Global Nuclear Electricity Installed Capacity

According to International Atomic Energy Agency (IAEA) data, 450 nuclear power reactors were totally in operation with 393836 MW net electrical capacity in the world. As can be seen in Table 3.21, by the end of 2018, United States has the highest nuclear capacity with 99 nuclear power reactors and 99952 MW electrical capacity in the world by May 29, 2018. Then France is the second with 58 reactors and 63130 MW electrical capacity [39].

The other countries following United States and France are Japan, China, and Russia with 42, 39 and 37 numbers of reactors and 39752 MW, 34514 MW and 28264 MW electrical capacity, respectively. It may be concluded from this table that about 67% of the world nuclear electrical capacity or 61% of the world number of nuclear power reactors is owned by these countries [39].

Table 3.21 Global nuclear electricity net electrical capacity by May, 29 2018 [39]

Country	Number of Reactors	Total Net Electrical Capacity (MW)
United States	99	99952
France	58	63130
Japan	42	39752
China	39	34514
Russia	37	28264
Korea	24	22494
Canada	19	13554
Ukraine	15	13107
Germany	7	9515
Sweden	8	8622
India	22	6255
Argentına	3	1633
Armenıa	1	375
Belgıum	7	5918
Brazil	2	1884
Bulgaria	2	1926
Czech Republic	6	3930
Finland	4	2769
Hungary	4	1889
Mexico	2	1552
Netherlands	1	482
Pakistan	5	1318
Romania	2	1300
Slovakia	4	1814
Slovenia	1	688
South Africa	2	1860
Spain	7	7121
Switzerland	5	3333
United Kingdom	15	8918
Iran	1	915
World	**450**	**393836**

According to the International Atomic Energy Agency (IAEA) data, there are 59 nuclear power reactors under construction in the world by the end of 2018. As it is seen from the Table 3.22 and also Figure 3.6, with 18 under constrution reactors, China is the first in the world. In other words, China is constructing one-third of the under-construction nuclear power plants in all over the world. The other countries are India and Russia with 7 and 6 under construction nuclear power plants, respectively. It is seen that more than half of the under-construction nuclear power plants has accumulated by these three countries.

Table 3.22 Numbers of under construction nuclear power plants in the world by May, 29 2018 [40]

Country	Under Construction Numbers
China	18
India	7
Russia	6
United Arab Emirates	4
Korea	4
United States	2
Ukraine	2
Slovakia	2
Pakistan	2
Japan	2
Belarus	2
Turkey	1
Finland	1
France	1
Brazil	1
Argentına	1
Bangladesh	1
World	**59**

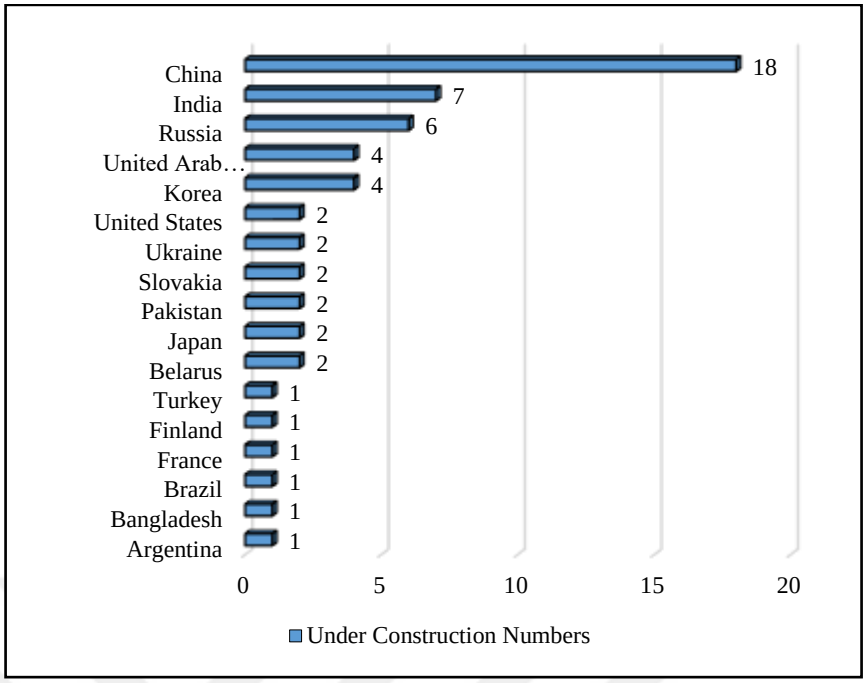


Figure 3.6 Number of under construction nuclear power plants in the world by May, 29 2018 [40]

When it comes to Turkey, Turkey makes an effort to launch the progress of nuclear power plants more than a half-century. Turkey is planning to have at least 10.000 MWe installed nuclear capacity in the next 10-15 years. The construction of two nuclear power plants in Turkey has been signed by Russia and Japan. The first power plant is already under construction in Akkuyu while the second one is expected to be constructed in Sinop [41].

The Agreement between the Government of the Republic of Turkey and the Government of the Russian Federation on cooperation in the area of construction and operation of the nuclear power plant at “Akkuyu” site in the Republic of Turkey was signed in 2009. The power plant implemented on build-own-operate principles consists of 4 power units with total capacity of 4.800 MW.

An intergovernmental agreement was signed with Japan on 3 May 2013 in order to constract the second nuclear power plant in Sinop side of Turkey. The technical project of this power plant is under progress by Japan authorities. The power plant consisting of four units will generate 4480 MW of electricity at full operation [41].

3.6 Global Renewable Energy Installed Capacity and Recent Progress

Figure 3.7 shows the global renewable energy capacity by sources at the end of 2018. According to this figure, hydropower has the largest contribution to global renewable energy capacity. The second highest contribution to the renewable energy capacity is wind power. It may be seen that a significant progress has also been made in solar PV energy [42].

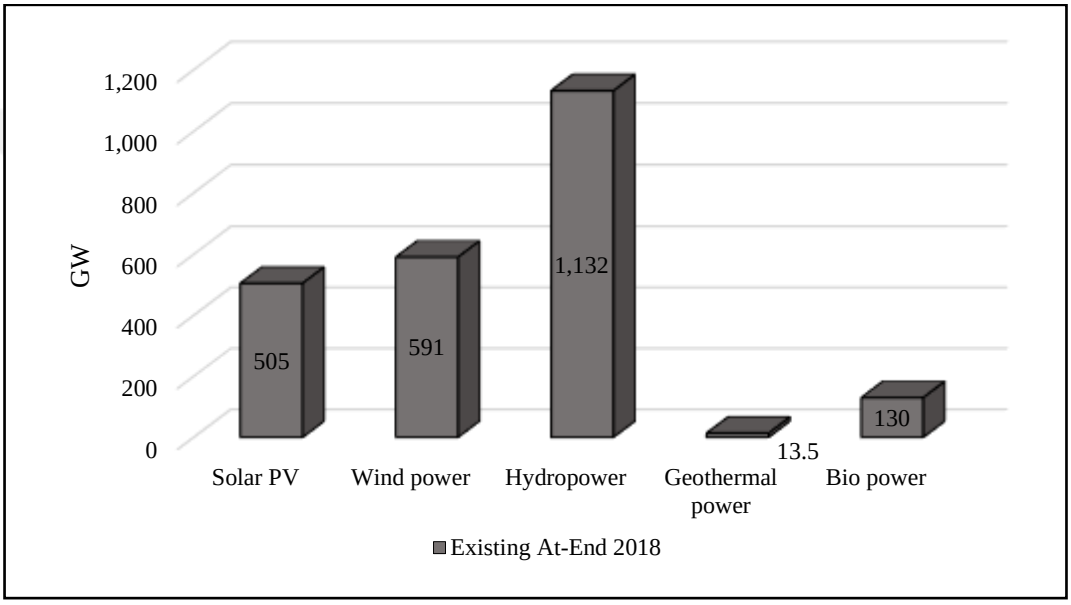


Figure 3.7 Global renewable energy capacity at the end of 2018 (GW) [42]

Figure 3.8 shows that top countries and their capacities using renewable power at end 2018. China has the highest renewable power capacity with 727 GW and this country is followed by the United States with 260 GW [42].

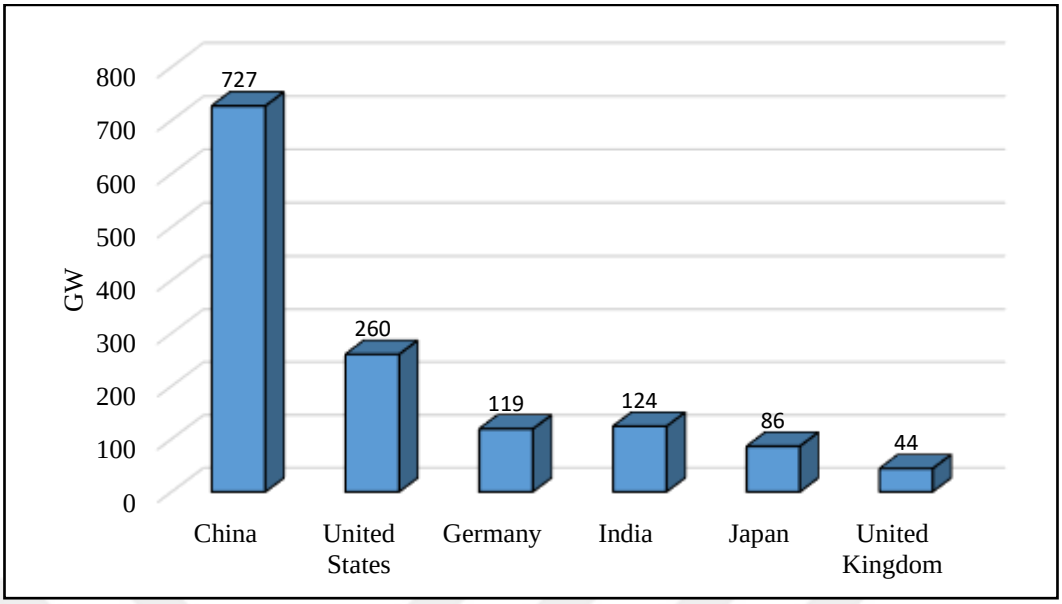


Figure 3.8 Renewable power global capacity top countries at the end of 2018 (GW) [42]

China's electricity generation in terms of the fuels is given in Figure 3.9. According to this figure, about 74.95% of the China's electricity in 2017 was generated from fossil fuels (nuclear included). In other words, the percentage of renewable is just 25.05% of the total production. Among the sources coal is the primary fuel with 67.1% led by hydroelectric with 17.8% in electricity generation [37].

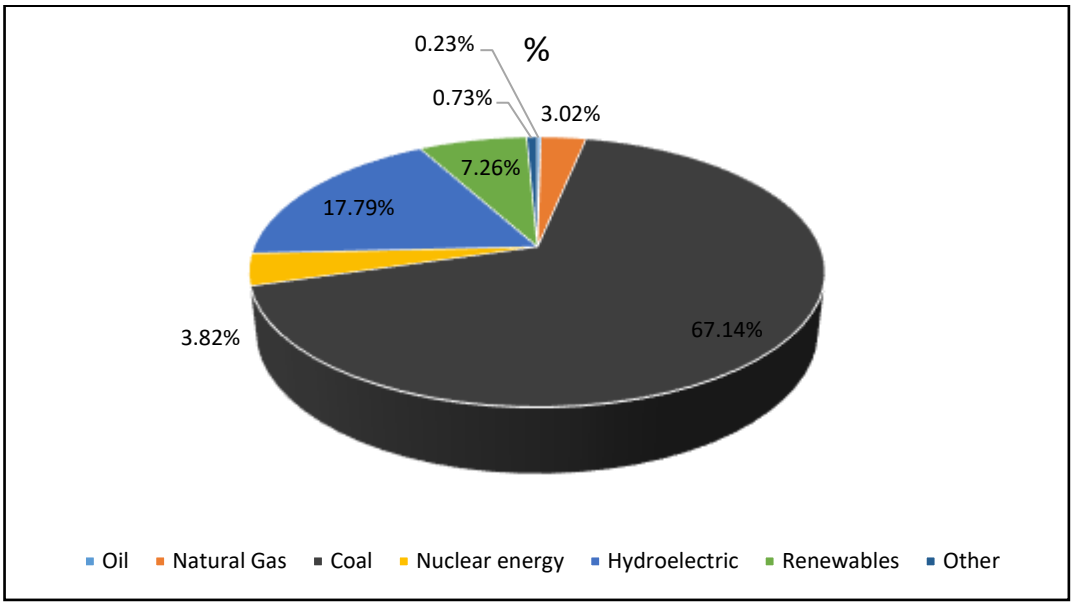


Figure 3.9 Electricity generation by fuel China in 2017 (TWh) [37]

Table 3.23 shows top countries using solar PV; their capacities, total renewables shares in electricity production at end 2017. According to this table, China is the leading country with the largest contribution to solar PV capacity of 176.1 GW. However, the total electricity production from all renewable sources, excluding hydroelectric, is only 7,2% percentage of the total electricity production at the end of 2017. It means that though China has the highest solar PV capacity, its electricity generation is still highly based on non-renewable energy sources [37, 42]. This table presents that developed counties put large investment in order to increase their solar energy capacity or in other words to decrease their dependency to the fossil based sources.

Table 3.23 Global solar PV capacity and renewables share in electricity production at the end of 2017 [37, 42]

	Total Installed Solar PV Capacity (end 2018)	**Share of electricity generation from renewables***
Countries	GW	(%)
China	176.1	7,2%
United States	62.4	9,8%
Japan	56	9,7%
Germany	45.3	30,3%
India	32.9	6,4%
Italy	20.1	23,1%
World	**505**	**8,4%**

*excluding hydroelectric

Table 3.24 shows the wind capacities of to six countries, total renewables share in electricity production at end of 2017. According to this table, China is the leading country with total capacity of 184 GW. However, the renewables share in total electricity generation are below the world average. On the other hand, in overall renewable sources, Germany has the largest share of total electricity production from renewables, excluding hydroelectric, with 30,3% percentage at the end of 2017 [37, 42].

Table 3.24 Global wind capacity and renewables share in electricity production at the end of 2017 [37, 42]

	Total Installed wind Capacity (end 2018)	**Share of electricity generation from renewables***
Countries	GW	%
China	184.3	7,2%
United States	96.5	9,8%
Germany	59.3	30,3%
India	35.1	6,4%
Spain	23.5	25,2%
United Kingdom	21	27,6
World Total	**591**	**8,4%**

*excluding hydroelectric

Table 3.25 shows the top countries with hydropower global capacity and its share in electricity generation and at the end of 2017. According to this table, China has the largest hydropower capacity of 322 GW in 2018. The share of electricity production from hydroelectric is 17,8% in total electricity production and the hydroelectric share is approximately at the world average level at the end of 2017. This country is followed by Brazil with 104 GW of total hydropower capacity and electricity generation is mostly based on hydroelectric with 63% percentage at the end of 2017 [37, 42].

Table 3.25 Global hydropower capacity and its share in electricity generation at the end of 2017 [37, 42]

	Total Installed Hydropower Capacity (end 2018)	**Share of electricity generation from hydroelectric**
Countries	GW	(%)
China	322	17,8%
Brazil	104	62,5%
Canada	81	57,2%
United States	80	6,9%
Russia	47	16,8%
India	45	9,0%
World	**1,132**	**16,0%**

Table 3.26 presents top countries having geothermal power capacity with renewables share in total electricity generation at the end of 2017. According to this table, while the United States has the largest geothermal power total capacity, Turkey has the fourth highest capacity with 1.28 GW at the end of 2018 [37, 42].

Table 3.26 Global geothermal capacity and renewables share in electricity generation at the end of 2017 [37,42]

	Total Installed Geothermal Capacity (end 2018)	**Share of electricity generation from renewables***
Countries	GW	(%)
United States	2.54	9,8%
Indonesia	1.95	5,0%
Philippines	1.93	-
Turkey	1.28	9,9%
Mexico	0.92	6,2%
Italy	0.76	23,1%
World	**13.3**	**8,4%**

*excluding hydroelectric

Table 3.27 shows the world CO_2 emissions of some countries. CO_2 emission in China (9232.6 million tonnes) is very high with 27,6% percentage of total CO_2 emission in the World in 2017. China and the United States CO_2 emissions represents about 43% of the world total CO_2 emissions. The other abundant countries in carbon emissions are India, Russia, and Japan with 7.0%, 4.6%, and 3.5% percentages, respectively. Table shows that more than half of the world CO_2 is generated by these countries [37].

Table 3.27 Carbon dioxide emissions of some country at the end of 2017 (Million tonnes of CO_2) [37]

Country	**2017**	**Share in the world emission 2017**
China	9232.6	27.6%
United States	5087.7	15.2%
India	2344.2	7.0%
Russia	1525.3	4.6%
Japan	1176.6	3.5%
Germany	763.8	2.3%
World	**33444.0**	**100.0%**

3.7 Global Electricity Generation

Table 3.28 demonstrates that global electricity generation by regions. Globally electricity generation has a 2.7% growth rate per annum between the years of 2006 to 2016. Electricity generation reached to 25551.3 TWh at end of 2017. On the other

hand, global electricity generation growth rate was a 2.8% in 2017 as compared to 2016 [37]. The largest electricity generation has been in the Asia Pacific region in the world. That region generates 45% of the global electricity generation. The following region with high electricity generation are North America and Europe with 20.7% and 15.3% percentage, respectively. However, the Africa region had the least electricity generation with 3.3% [37].

Table 3.28 Electricity generation by region at the end of 2017 (Terawatt-hours) [37]

Region	2016	2017	Growth rate per annum		Share 2017
			2017	2006-16	
Asia Pacific	10940.3	11462.9	5.1%	5.4%	44.9%
North America	5332.9	5290.2	-0.5%	0.3%	20.7%
Europe	3857.8	3901.3	1.4%	0.1%	15.3%
CIS	1532.6	1539.5	0.7%	0.8%	6.0%
South &Central America	1303.5	1315.8	1.2%	2.8%	5.1%
Middle East	1165.1	1210.9	4.2%	5.4%	4.7%
Africa	798.0	830.7	4.4%	3.1%	3.3%
World	**24930.2**	**25551.3**	**2.8%**	**2.7%**	**100.0**%

Table 3.29 demonstrates that the world electricity generation by some countries. The largest part of the electricity generation is done by China with 6495.1 TWh. China and the United States electricity generation represents about 40% of the world electricity generation. The other abundant countries in electricity generation are India, Russia, and Japan with 5.9%, 4.3%, and 4.0% percentage, respectively. Table shows that almost more than half of the world electricity is generated by these developed countries [37].

Table 3.29 Electricity generation by some country at the end of 2017 (TWh) [37]

Country	2016	2017	Growth rate per annum		Share 2017
			2017	2006-16	
China	6133.2	6495.1	6.2%	7.9%	25.4%
United States	4347.9	4281.8	-1.3%	*	16.8%
India	1421.5	1497.0	5.6%	6.7%	5.9%
Russia	1091.0	1091.2	0.3%	1.0%	4.3%
Japan	1002.3	1020.0	2.0%	-1.5%	4.0%
Canada	664.6	693.4	4.6%	0.8%	2.7%
Germany	649.1	654.2	1.1%	0.1%	2.6%
South Korea	561.0	571.7	2.2%	3.4%	2.2%
France	556.2	554.1	-0.1%	-0.3%	2.2%
United Kingdom	339.4	335.9	-0.8%	-1.6%	1.3%
World	**24930.2**	**25551.3**	**2.8%**	**2.7%**	**100.0**%

*Less than 0.05%

3.7.1 Global Electricity Generation by Sources

As it can be seen in Figure 3.10, global electricity generation was based on fossil fuels with 65% by the end of 2016. However, according to the estimations the fossil fuel's share in the world electricity generation is expected to drop from 65% to 50% in 2040. The renewable energy sources share will replace the fossil fuel. The renewable energy share is expected to increase from 24% to 40% in the same period of time. That is, fossil fuel-based electricity generation is expected to increase only approximately 3000 TWh by 2040, but renewables-based electricity generation more than doubles between the years of 2016-2040 [3].

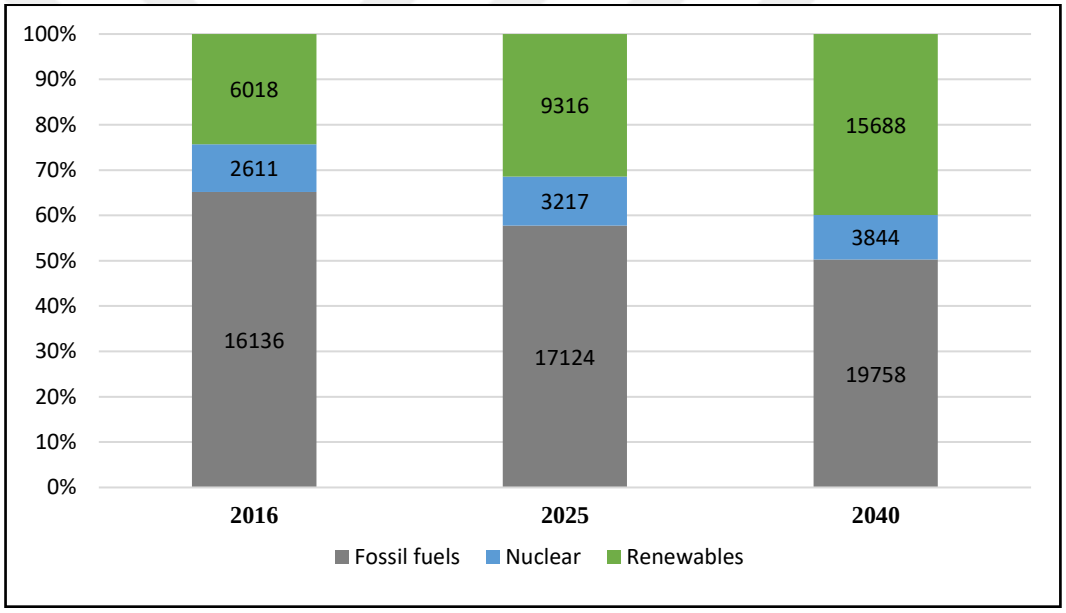


Figure 3.10 World electricity generation by sources in the new policy scenario (TWh) [3]

Gas's share is expected to show a slight reduction while oil's share drop 4% to 1% during the same time. Figure 3.11 shows the renewable energy generation shares by sources at the end of 2016 and their estimated values in 2015 and 2040. According to International Energy Agency (IEA) new policies scenario, electricity generation from renewable energy sources. It is expected the electricity generation from wind will increase from 4% to 11% and from solar PV will increase from 1% to 8% percentage [3].

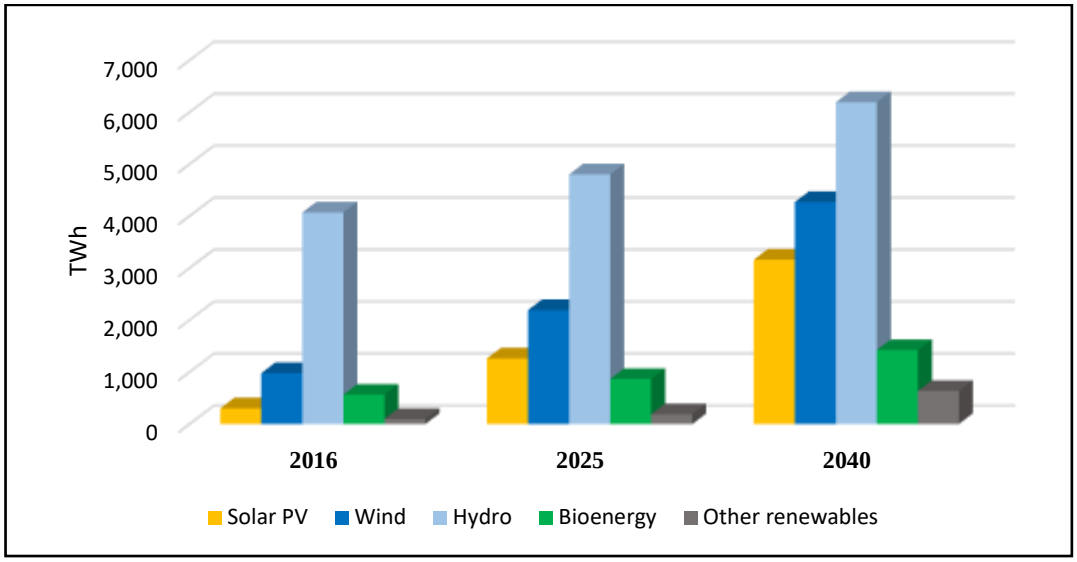


Figure 3.11 World renewables electricity generation by sources in the new policy scenario (TWh) [3]

3.7.2 Global Electricity Demand

Table 3.30 demonstrates the global electricity demand by region and Table 3.31 is the global electricity demand by some countries. Electricity demand is defined as the total gross volume of electricity generated, less own use in the production of electricity, plus net trade (imports less exports), less transmission and distribution losses. According to these tables global electricity demand is expected to increase from 21,375 TWh in 2016 to 34,467 TWh in 2040. This show that 13,092 TWh of extra electricity demand increment is expected [3].

Table 3.30 Global electricity demand by region in the new policy scenario (TWh) [3]

Region	Years				
	2000	2016	2025	2040	CAAGR* 2016-2040
North America	4 261	4 694	5 017	5 651	0.8%
Central South America	660	1 063	1 308	1 858	2.4%
Europe	3 114	3 555	3 790	4 194	0.7%
Africa	385	655	885	1 707	4.1%
Middle East	359	910	1 118	1 798	2.9%
Eurasia	809	1 065	1 193	1 432	1.2%
Asia Pacific	3 611	9 433	12 551	17 827	2.7%
World	**13 199**	**21 375**	**25 861**	**34 467**	**2.0%**

*Compound average annual growth rate

Table 3.31 Global electricity demand by some country in the new policy scenario (TWh) [3]

Country	Years				
	2000	**2016**	**2025**	**2040**	**CAAGR* 2016-2040**
United States	3 590	3 886	4 131	4 570	0.7%
Brazil	327	512	617	852	2.1%
European Union	2 605	2 857	2 980	3 178	0.4%
South Africa	190	207	240	335	2.0%
Russia	677	865	934	1 069	0.9%
China	1 174	5 320	7 018	9 230	2.3%
India	376	1 102	1 880	3 606	5.1%
Japan	1 005	969	967	1 005	0.2%
Southeast Asia	322	837	1 214	1997	3.7%
World	**13 199**	**21 375**	**25 861**	**34 467**	**2.0%**

*Compound average annual growth rate

CHAPTER 4

ENERGY ANALYSIS OF TURKEY AND INSTALLED RENEWABLE CAPACITY WITH RECENT PROGRESS

4.1 Total Primary Energy Supply by Years

Energy demand of Turkey has been increasing due to its population and economic growth. Despite having fastest growth in electricity demand among OECD members, Turkey's energy markets depends largely on imports. Turkey's primary energy supply development is given in Table 4.1. It may be seen from the table that primary energy consumption is ever-growing with a few exceptions in the past years. However, indigenous production is not growing enough in the same time [43].

Table 4.1 Primary energy supply development in Turkey (toe) [43]

Year	Primary Energy Supply	Indigenous Production
2002	77.075	24.430
2003	82.720	24.530
2004	85.665	24.250
2005	88.672	24.235
2006	96.165	26.274
2007	104.067	27.514
2008	102.825	28.758
2009	100.739	29.606
2010	105.888	31.558
2011	113.371	30.771
2012	117.312	30.445
2013	116.314	29.106
2014	120.505	28.591
2015	129.139	30.936
2016	136.229	35.374
2017	145.305	35.357

Turkey's total primary energy supply development is given in Figure 4.1. As shown in this figure Turkey's primary energy supply is 77,075 toe and share of indigenous production is about 31% in 2002. However, in the end of 2017, Turkey's primary energy supply increased to 145,305 toe while share of indigenous production dropped from 31% to 24%. In other words, at the same time while our country primary energy supply increased about 68,000 toe, the indigenous production increased only about 11,000 toe [43].

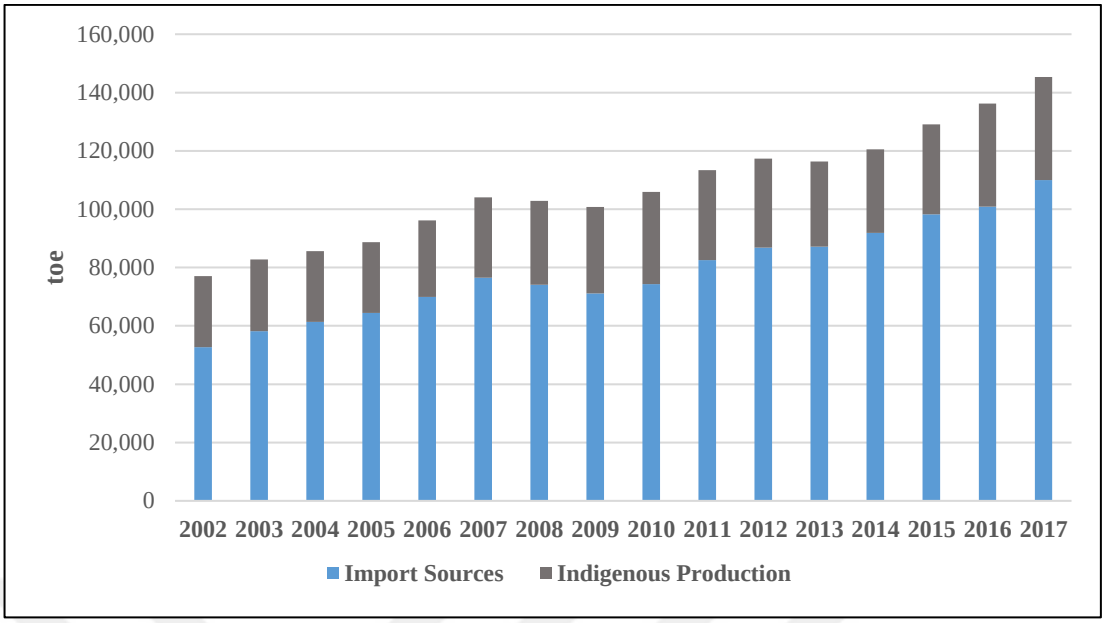


Figure 4.1 Primary energy supply development by import and indigenous production in Turkey (toe) [43]

In Turkey, primary energy supply is mostly met from fossil fuels like coal, petroleum and natural gas. The natural gas and crude oil consumption were 44,319 toe and 29,491 toe in 2017, respectively. The more important point is that about 90% of these sources are imported [43].

4.1.1 Indigenous Production Ratio in Turkey's Primary Energy Supply

The progress in Turkey's indigenous energy production is given in Figure 4.2. Although the indigenous production energy supply has increased, the indigenous production percentage has decreased [43].

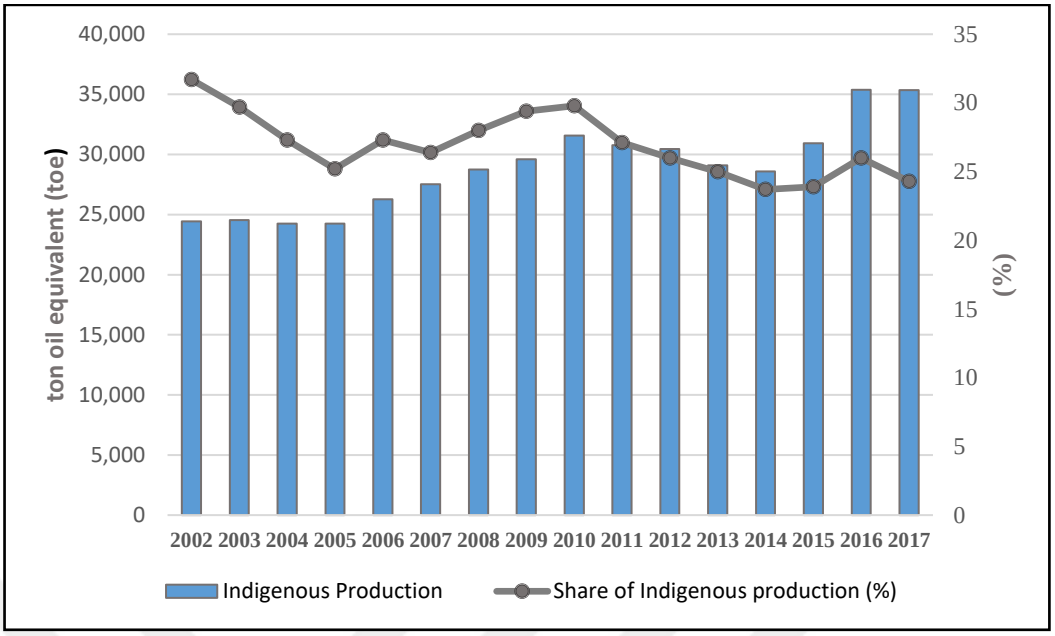


Figure 4.2 Indigenous production and share of total primary energy supply in Turkey (toe) [43]

4.1.2 Forecasting Total Primary Energy Supply in 2023

Turkey's annual primary energy consumption and forecast for 2023 are given in Figure 4.3. As it is seen from figure that Turkey's primary energy consumption will almost double in 2023. That is, Turkey needs approximately 100,000 toe extra supply in 2023 [44].

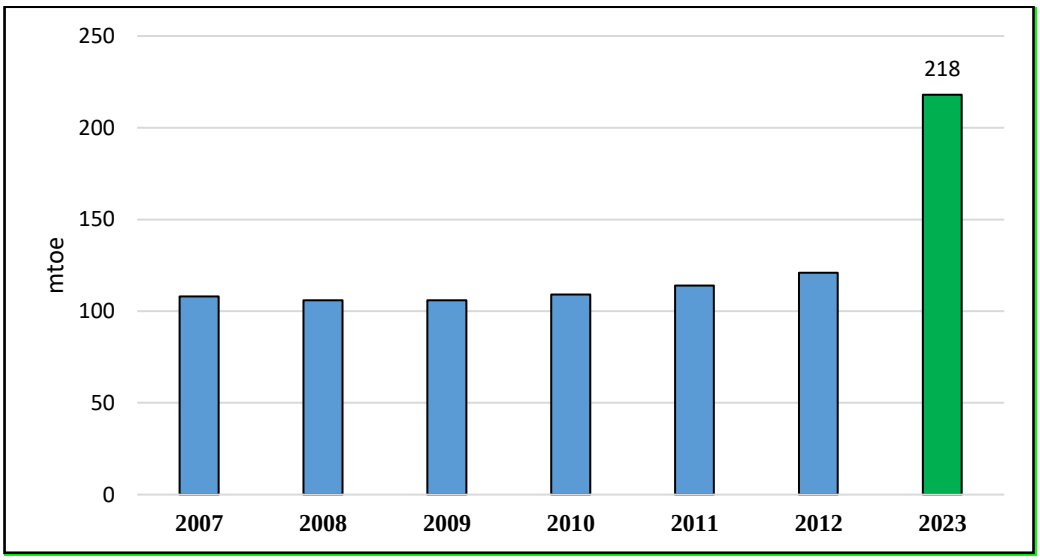


Figure 4.3 Turkey's primary energy consumption, actual data and forecast for 2023 (mtoe) [44]

4.2 Electricity Generation and Consumption of Turkey

Turkey's electricity generation development from 2003 to 2017 is given in Figure 4.4. As it may be seen from the figure, Turkey’s electricity generation increased from 140,580.5 GWh in 2003 to 297,277.5 GWh at the end of 2017 [45].

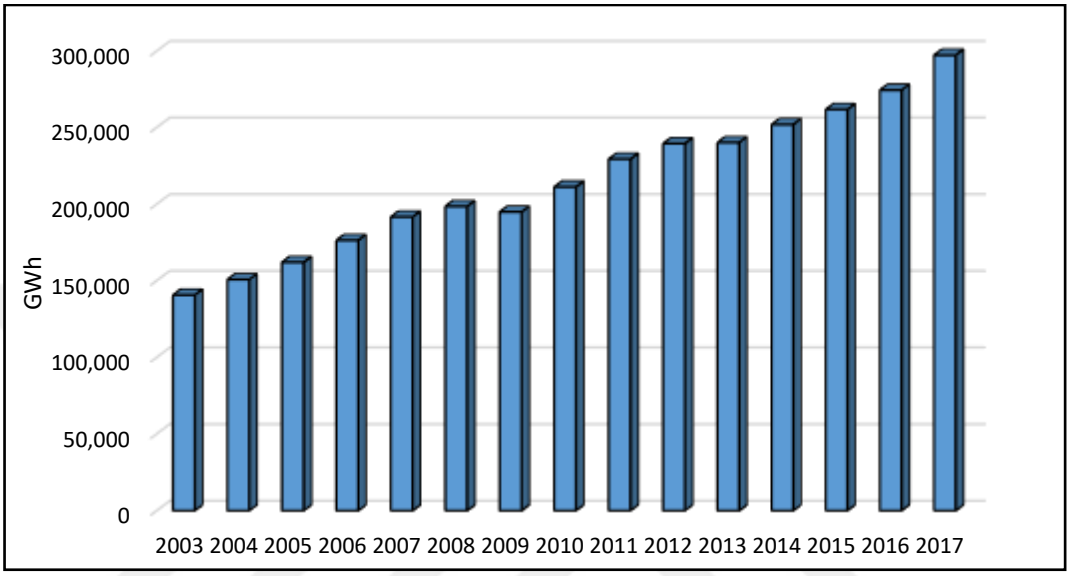


Figure 4.4 Turkey’s electricity generation by years [45]

Turkey's electricity generation in terms of the sources are given in Figure 4.5. It is seen that this electricity generation is mostly based on non-renewable energy sources (fossil fuels). According to this figure, about 70% of the Turkey’s electricity in 2017 was generated from fossil fuels. Among the sources natural gas is the primary fuel with 37.2% led by coal with 32.8% in electricity generation [46].

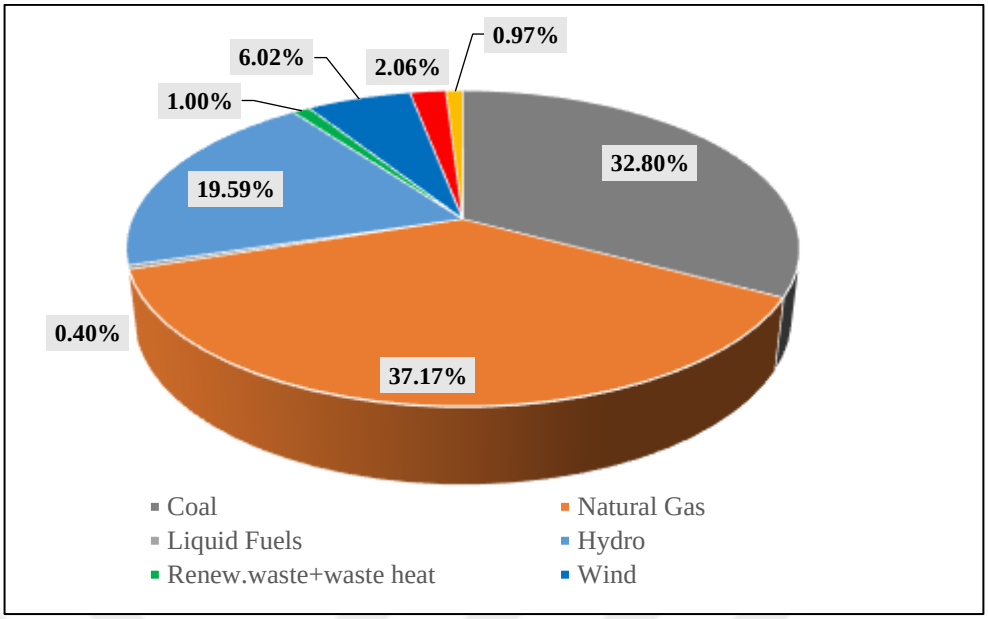


Figure 4.5 Distribution of Turkey's electricity generation by energy sources in 2017 [46]

Table 4.2 gives in details the sources used in generating electricity. Despite the strong dependency of Turkey's electricity generation on coal, Turkey is significantly poor in coal. 52.4% of the coal used for generating electricity is imported. According to this table among the renewable energy sources hydro is by far the largest share with 19.6% followed by wind and geothermal with 6.02% and 2,06% percentage in electricity production, respectively [46].

By the end of the 2017, 37,2% of Turkey's electricity was generated from natural gas, 32,8% from coal, 19,6% from hydropower, 6,02% from wind, 2,06% from geothermal, 0,97% from solar energy and 1,4% from other sources [46].

Table 4.2 Electricity production by energy sources of Turkey in 2017 [46]

Sources	Generation, GWh	Share 2017 (%)
Imported Coal	51.118,1	17,20%
Hard Coal + Asphaltite	5.663,8	1,91%
Lignite	40.694,4	13,69%
Natural Gas	110.490,0	37,17%
Liquid Fuels	1.199,9	0,40%
Hydro	58.218,5	19,59%
Wind	17.903,8	6,02%
Renew.waste +waste heat	2.972,3	1,00%
Geothermal	6.127,5	2,06%
Solar	2.889,3	0,97%
TOTAL	**297.277,5**	**100,0%**

Table 4.3 shows the electricity generation of Turkey by years. According to this table, Turkey's electricity generation was ever-growing from 2002 to 2017 year with an annual growth rate of 5,7%, except for in 2009 with electricity generation increase rate of minus 1,8%. On the other hand, the highest increase rate happened with 8,9% in electricity generation in 2006 [46].

Table 4.3 Electricity generation in Turkey (GWh) [46]

Year	Electricity Generation, GWh	Increase (%)
2002	129,399.5	5,4%
2003	140,580.5	8,6%
2004	150,698.3	7,2%
2005	161,956.2	7,5%
2006	176,299.8	8,9%
2007	191,558.1	8,7%
2008	198,148.0	3,6%
2009	194,812.9	-1,8%
2010	211,207.7	8,4%
2011	229,395.1	8,6%
2012	239,496.8	4,4%
2013	240,154.0	0,3%
2014	251,962.8	4,9%
2015	261,783.3	3,9%
2016	274,407.7	4,8%
2017	297.277,5	8,3%

Turkey's indigenous and import based electricity generation development from 2000 to 2017 is given in Figure 4.6. It is seen by this figure that import based electricity generation increased from 45,0% to 54,8%, while indigenous based electricity generation decreased from 55,0% to 45,2% during these years [46].

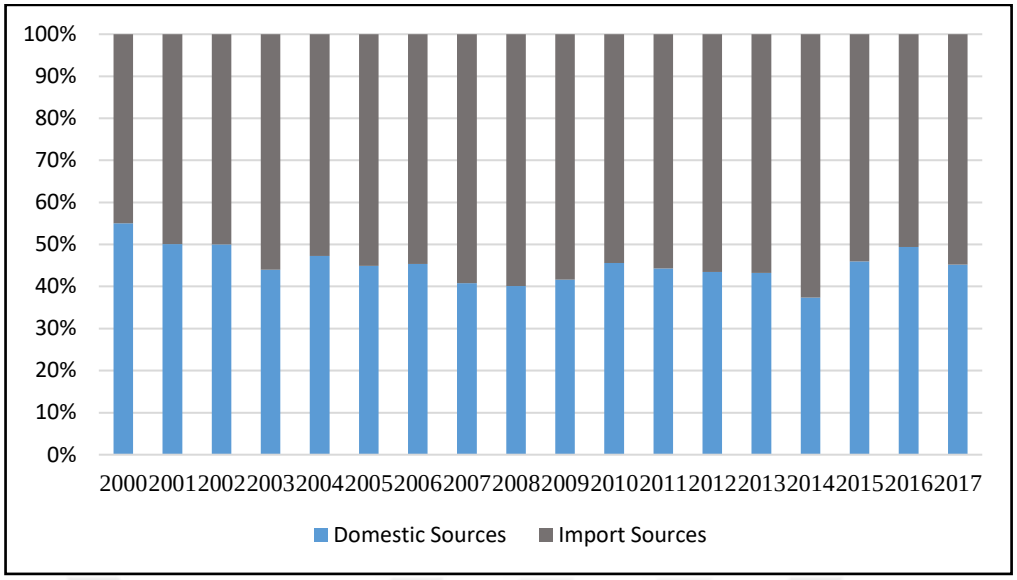


Figure 4.6 Indigenous and import based electricity generation share in Turkey [46]

Table 4.4 represents the electricity demand of Turkey by years. According to this table, Turkey's electricity demand is continuously increasing from 2002 to 2017, except for in 2009. On the other hand, the highest increase rate found with 9,4% in electricity consumption in 2011 [46].

Table 4.4 Electricity demand in Turkey (GWh) [46]

Year	Gross Electricity Demand*	Increase (%)
2002	132552.6	4,5%
2003	141150,9	6,5%
2004	150017,5	6,3%
2005	160794,0	7,2%
2006	174637,3	8,6%
2007	190000,2	8,8%
2008	198085,2	4,3%
2009	194079,1	-2,0%
2010	210434,0	8,4%
2011	230306,3	9,4%
2012	242369,9	5,2%
2013	246356,6	1,6%
2014	257220,1	4,4%
2015	265724,4	3,3%
2016	279286,4	5,1%
2017	297277,5	6,2%

*Gross demand=Apparent consumption= Gross generation + Import - Export

4.3 Installed Capacity of Turkey

Figure 4.7 shows Turkey's installed electricity capacity developments by years. The installed electricity capacity of Turkey has increased from 40,835 MW in 2007 to 85,200 MW at the end of 2017 [47].

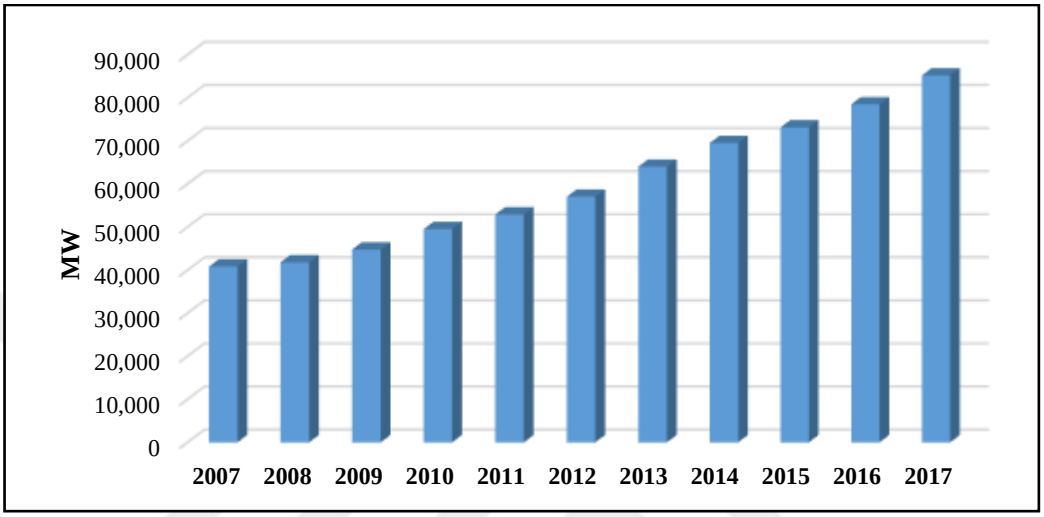


Figure 4.7 Electricity installed capacity of Turkey by years [47]

The installed electricity capacity of Turkey is heavily depending on hydro, natural gas and coal power plants. As shown in Figure 4.8 the hydropower capacity has increased nearly 13,800 MW from 2007 to 2017. Hydropower was followed by natural gas, coal and wind power with about 10,354 MW, 8,508 MW and 6,370 MW raises, respectively [49]. In the last decade, installed capacity based on renewable energy sources such as hydro, geothermal, wind and solar sources has considerable increased. However, as the energy supplies, energy production and energy demand are taken into account, this increase is inadequate for Turkey's 2023 Targets.

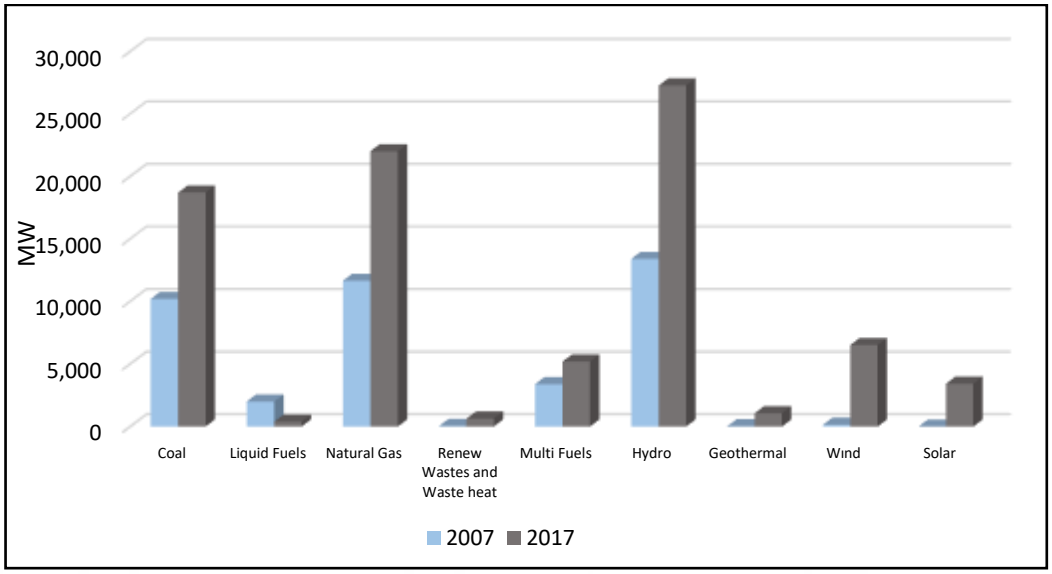


Figure 4.8 Electricity installed capacity of Turkey by primary energy sources [49]

Turkey's electricity installed capacity progress development by primary energy sources can be seen in Figure 4.9 from 2007 to 2017 [48]. It is seen that ratio of renewable based capacity has slightly increased while the ration of non-renewable has decreased.

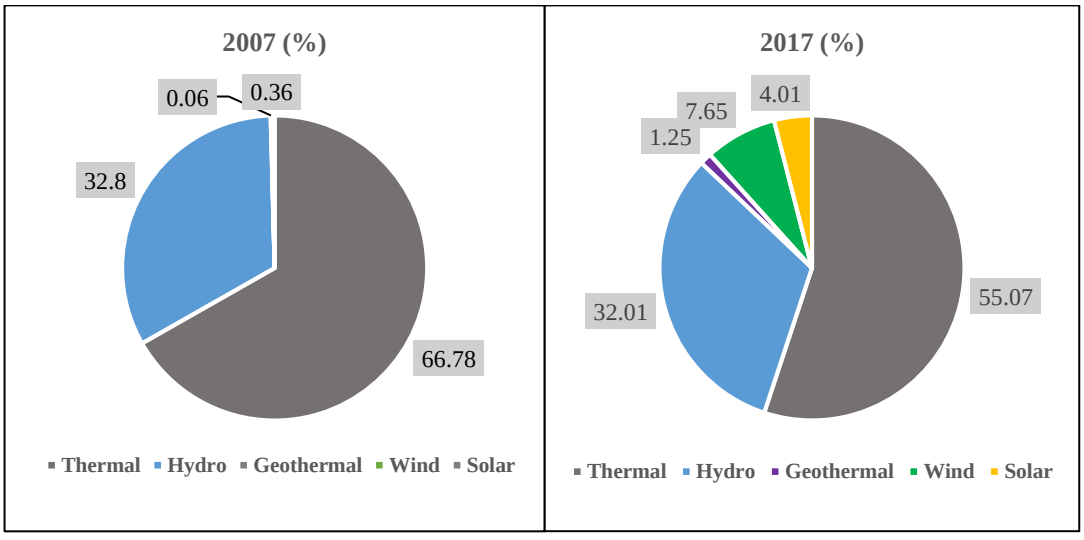


Figure 4.9 Electricity installed capacity progress of Turkey by primary energy sources [48]

Turkey's indigenous and import based installed capacity development from 2000 to 2017 can be seen in Figure 4.10. As shown in the figure during these years import

based installed capacity increased from 34% to 43%, while indigenous based installed capacity decreasing from 66% to 57%, although the economic growth and increasing population are the key points in this comparison, some precautions, such as installing more renewable based power plants, have to be done in order reduce import based capacity. In 2000, 66% of Turkey's electricity installed capacity was stem from domestic sources, 34% percentage of electricity installed capacity stem from import sources. The domestic sources of share were 56,8% in installed capacity of Turkey, the import based sources share were 43,2% as of the end of 2017 [49].

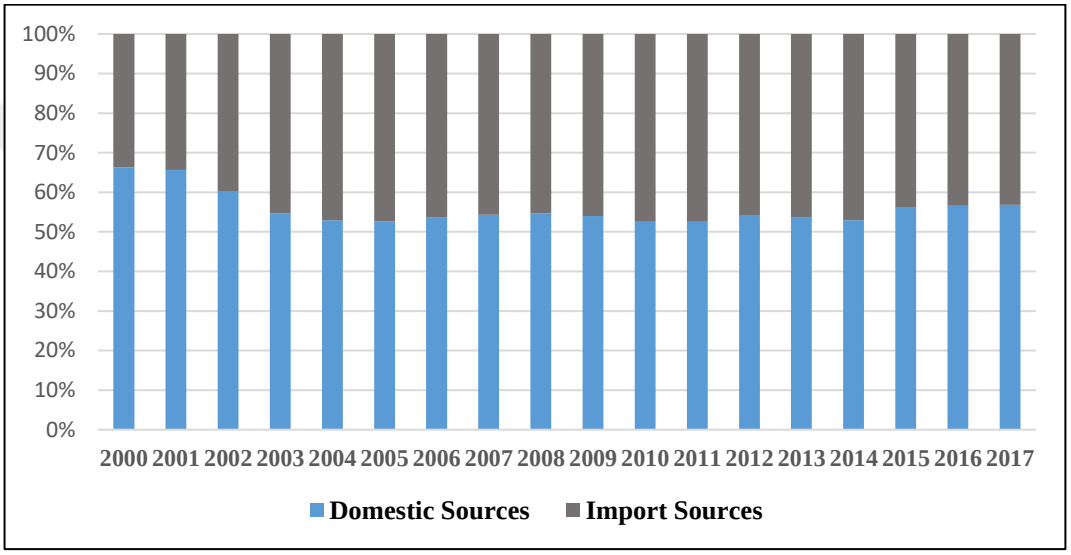


Figure 4.10 Indigenous and import based installed capacity share in Turkey [49]

It is seen that Turkey's energy consumption is expected to increase at least five times between 2002 and 2023. The dependency on imported sources (fossil fuels) also increases. Based on the current energy market progress, the majority of this energy demand in Turkey at the year 2023 has to be supplied from fossil fuels. However, being a very poor in fossil fuels, continuously increasing price of the fossil fuels and major environment problems such as global warming caused by fossil fuels, lead Turkey to change its energy policy [6]. Therefore, Turkey pay effort to increase the share of renewable energy capacity by 2023. Turkey has been already using a large part of its hydropower capacity. About 71.1% of renewable energy-based electricity is supplied from hydropower. However, the share of other renewable energy sources in the country's annual total electricity production is not in a desired level yet.

4.4 Recent Progresses on the Installed Renewable Capacity in Turkey

By the end of 2017, Turkey's installed electricity capacity was 85,200 MW. Among this capacity, 27,273 MW hydraulic, 6.516 MW wind, 3.420 MW solar, 1.063 MW geothermal and 477 MW is biomass based installation [50].

According to 2023 Vision, 100th anniversary of the Republic of Turkey, at least 30% of Turkey's energy demand is planned to be generated from renewable energy resources. However, the current renewable installed capacity is only 60,000 GWh [6].

Turkey's installed annual renewable energy capacity from 2007 to 2017 is given in Table 4.5 and Figure 4.11. On the other hand, Turkey's installed annual fossil fuel power plants capacity by sources is given in Table 4.6. As it may be seen, Turkey's renewable energy installed capacity increased from 13,586 MW in 2007 to 38,751 MW in 2017. As it may be seen Turkey's fossil fuel power plants capacity increased from 27,271 MW to 46,926 MW at the this interval. Among the renewable energy sources, hydropower has by far the biggest share of installed capacity in Turkey [50, 71]. The hydropower capacity is about three-quarters of Turkey renewable energy power [12]. Although there is a significant increment in wind, the progress is very slow and it is difficult to reach the 2023 targets.

Table 4.5 Annual development of renewable based installed capacity in Turkey [50]

Years	Hydro	Geothermal	Wind	Solar	Biomass*	Renewable Installed Capacity
2007	13,394.9	23.0	147.5	-	21.2	13,586.6
2008	13,828.7	29.8	363.7	-	38.2	14,260.4
2009	14,553.3	77.2	791.6	-	65.0	15,487.1
2010	15,831.2	94.2	1,320.2	-	85.7	17,331.3
2011	17,137.1	114.2	1,728.7	-	104.2	19,084.2
2012	19,609.4	162.2	2,260.6	-	147.3	22,179.5
2013	22,289.0	310.8	2,759.7	-	178.0	25,537.5
2014	23,643.2	404.9	3,629.7	40.2	227.0	27,945.0
2015	25,867.8	623.9	4,503.2	248.8	277.1	31,520.8
2016	26,681.1	820.9	5,751.3	832.5	363.8	34,449.6
2017	27,273.1	1,063.7	6,516.2	3,420.7	477.4	38,751.1

*Includes Industrial Waste

Table 4.6 Annual development of fossil fuel based installed capacity in Turkey [71]

Years	Hard Coal*	Lignite	Natural Gas	Multi fuel fired	Other**	Thermal Installed Capacity
2007	1,986	8,211	11,647	3,384	2,043	27,271
2008	1,986	8,205	10,657	4,869	1,878	27,595
2009	2,391	8,199	11,826	5,138	1,786	29,339
2010	3,751	8,199	13,302	5,326	1,701	32,279
2011	4,351	8,199	13,144	6,811	1,426	33,931
2012	4,383	8,193	14,116	6,881	1,454	35,027
2013	4,383	8,223	17,171	8,020	851	38,648
2014	6,533	8,281	18,724	7,369	894	41,801
2015	6,825	8,697	18,528	6,961	893	41,903
2016	8,229	9,127	19,564	6,551	942	44,412
2017	9,576	9,129	22,002	5,197	1,022	46,926

*Included imported coal and asphaltit fired p.p.
** Fuel Oil+Diesel Oil+LPG+Naphtha+Waste heat

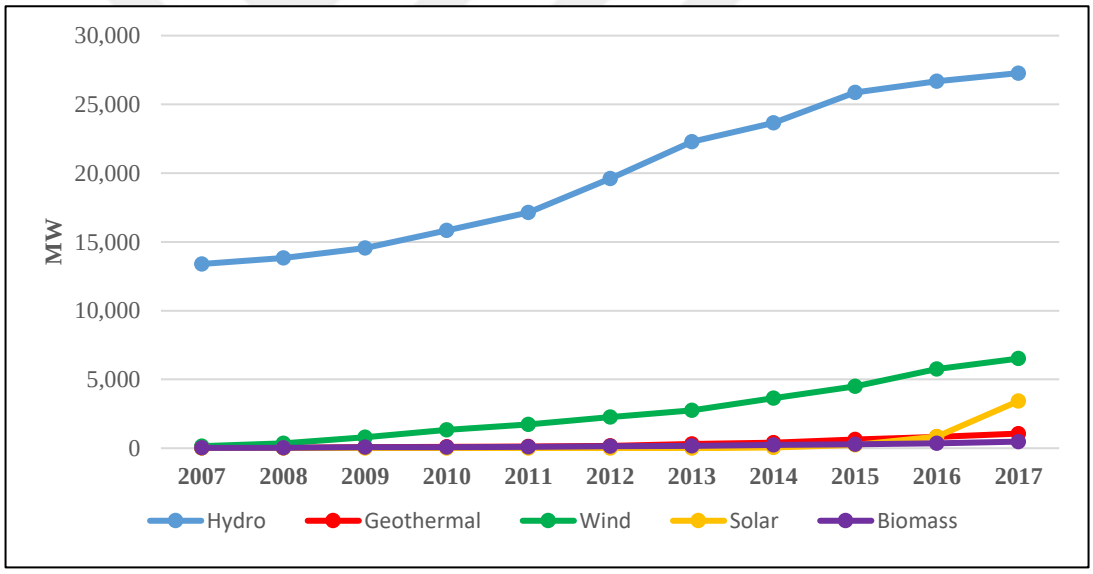


Figure 4.11 Annual development of renewable based installed capacity by sources [50]

4.4.1 Solar Energy

Solar energy has so far been used traditionally for many purposes such as cooking and water heating. However, since last decades it has been widely used for generating electricity through photovoltaic systems [14].

Turkey's installed solar energy capacity development from 2007 to 2017 is given in Figure 4.12. As it may be seen from the figure that, the installed solar capacity of Turkey in 2014 was only 40.2 MW. But in the end of 2017 it was reached to 3,420 MW. Although the installed capacity of Turkey has increased by years, the increment is significantly slow compared to the solar energy potential of Turkey [50].

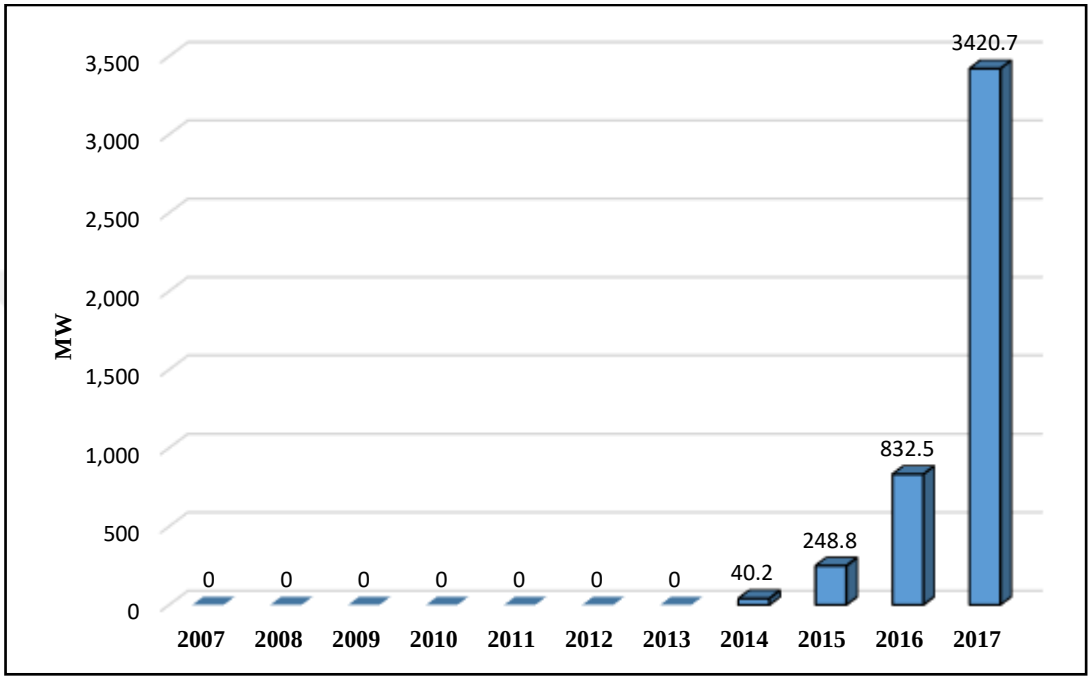


Figure 4.12 Solar energy installed capacity by years [50]

4.4.2 Wind Energy

The wind energy production in Turkey started at the early of 21st century with very slow progress due to the lack of renewable energy law. However, rapid progress in wind energy after the law was passed in 2005 [14].

Turkey's installed wind energy capacity development from 2007 to 2017 is given in Figure 4.13. As it may be seen from the figure, the Turkey's wind energy installed capacity was increased from 147.5 MW in 2007 and to 6,516 MW at the end of 2017. The increment is significantly high as compared to installed sun energy capacity. The progress in installed wind energy is especially grown in last decade with highest growing rate in 2009 [50].

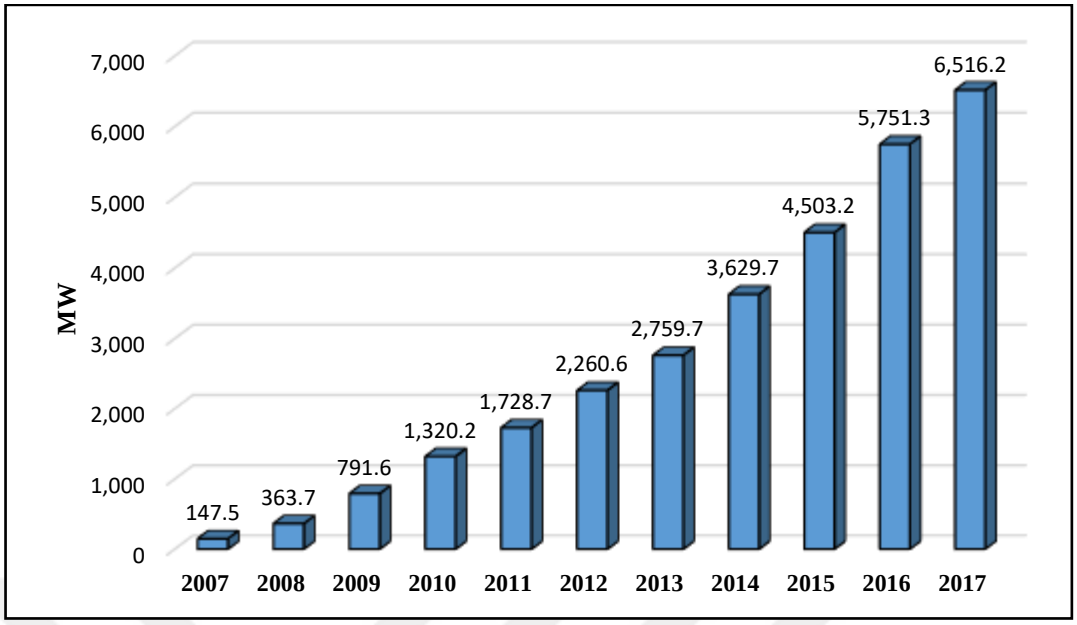


Figure 4.13 Wind energy installed capacity by years [50]

4.4.3 Hydraulic Energy

The construction of hydroelectric power plants in Turkey started in the second half of the 20th century. Since the hydropower is considered to be the most important renewable energy source, much effort has been made to build hydroelectric power plants [10]. Turkey's installed hydraulic energy capacity from 2007 to 2017 is given in Figure 4.14. As it may been seen from the figure that the hydroelectric energy installed capacity of Turkey increased from 13,394 MW in 2007 to 27,273 MW at the end of 2017 [50]. The installed hydraulic capacity of Turkey significantly increased after 2009.

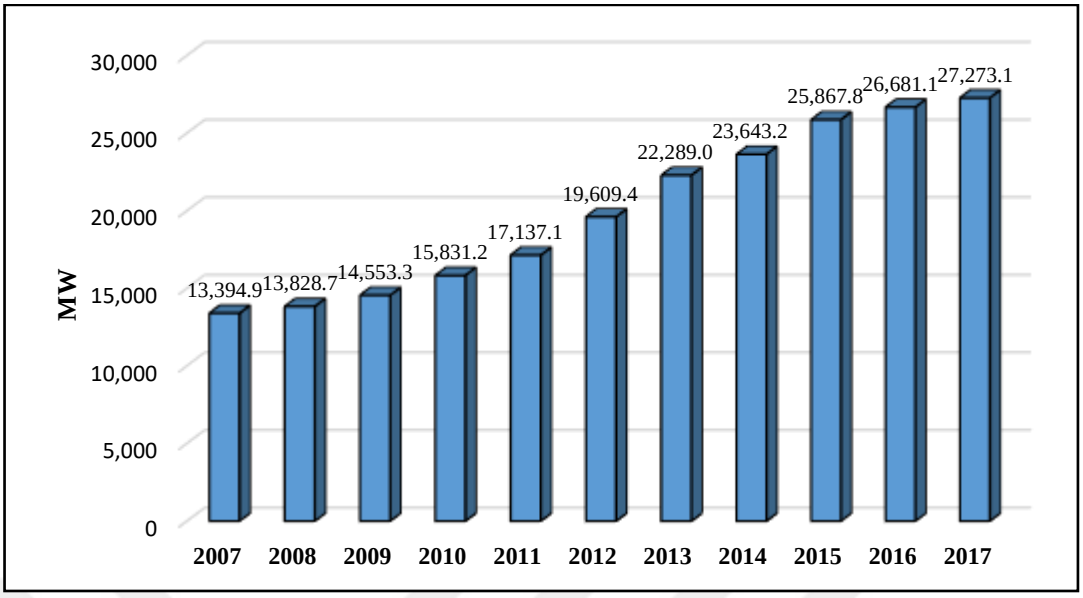


Figure 4.14 Hydroelectric energy installed capacity by years [50]

636 hydroelectric power plants with total capacity of 27,912 MW were installed in Turkey by the end of June 2018. Table 4.7 shows some installed power plants with high capacity. The installed capacity so far is the 32% the total potential. In the end of June 2018, the total hydroelectric production was 33 billion kWh which is 22.4% of Turkey's electricity production [52].

Table 4.7 Installed capacity of some hydroelectric power plant [12]

Name of Power Plant	Installed capacity (MW)	Name of Power Plant	Installed capacity (MW)
Ataturk	2,405	Kılıçkaya	120
Karakaya	1,800	Muratlı	115
Keban	1,330	Akköprü	115
Altınkaya	702	Dicle	110
Berke	510	Torul	103
Hasan Uğurlu	500	Köklüce	90
Ermenek	302	Kurtun	85
Borcka	300	Kesikköprü	76
Sir	283	Kadıncık-1	70
Gökçekaya	278	Demirköprü	69
Obruk	210	Suat Ugurlu	69
Batman	198	Adıgüzel	62
Karkamış	189	Seyhan-1	60
Özlüce	170	Kadıncık-2	56
Çatalan	169	Kapulukaya	54
H.P.Sarıyar	160	Kemer	48
Aslantaş	138	Manavgat	48
Hirfanlı	128	Karacaören-2	46
Menzelet	124	Karacaören-1	32

4.4.4 Geothermal Energy

Turkey is one of the richest countries in geothermal potential. However, geothermal energy was used for long time for thermal tourism. But most of the geothermal reserves of Turkey is not suitable for electricity generation.

Turkey's geothermal energy installed capacity development from 2007 to 2017 is shown in Figure 4.15. As seen from the figure Turkey's geothermal energy installed capacity is only 23.0 MW in 2007. It was then increased to 1,063.7 MW at the end of 2017. While overall installed capacity varies during this period, it has a significant rise after 2009 [50].

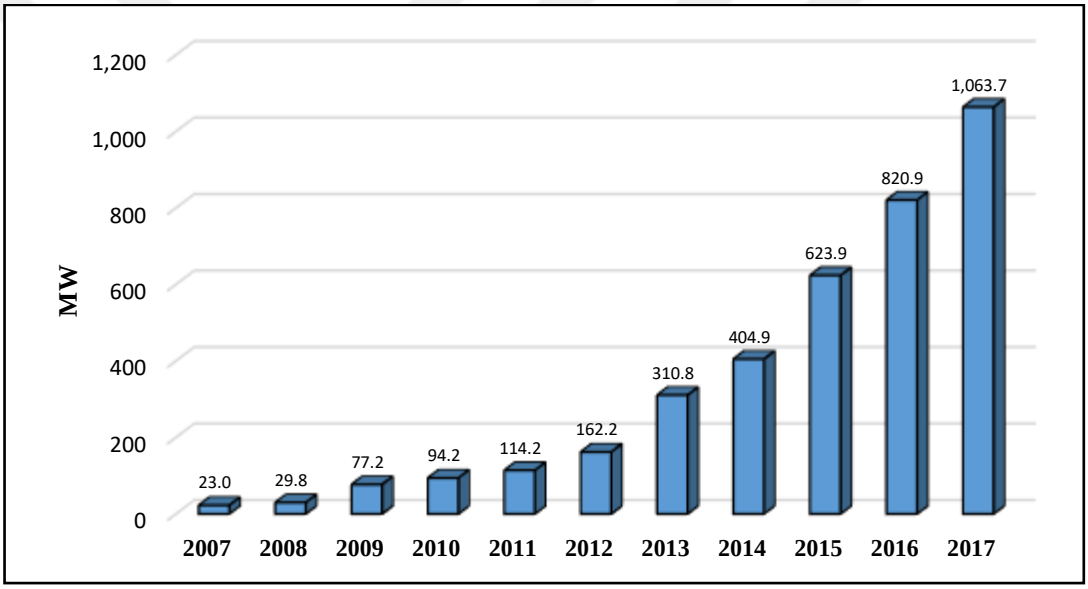


Figure 4.15 Geothermal energy installed capacity by years [50]

4.4.5 Biomass Energy

The main source of energy before the industrial revolution was wood and other organic materials of animal or plant origin, which is a secondary form of solar energy. Biomass energy is the solar energy absorbed by photosynthesis and stored as chemical energy in plants. Whenever these plants are consumed by animals, this energy is passed on to them. Hence, any organic material of plant or animal origin including cellulosic or lignocellulosic materials contains energy and is generally termed as biomass. Biomass has the potential to create bioenergy in the form of

electricity, heat, steam, and biofuels [53]. Bioenergy is produced from a variety of biomass feed stocks, including forest, agricultural and livestock residues; short-rotation forest plantations; energy crops; the organic component of municipal solid waste; and other organic waste streams.

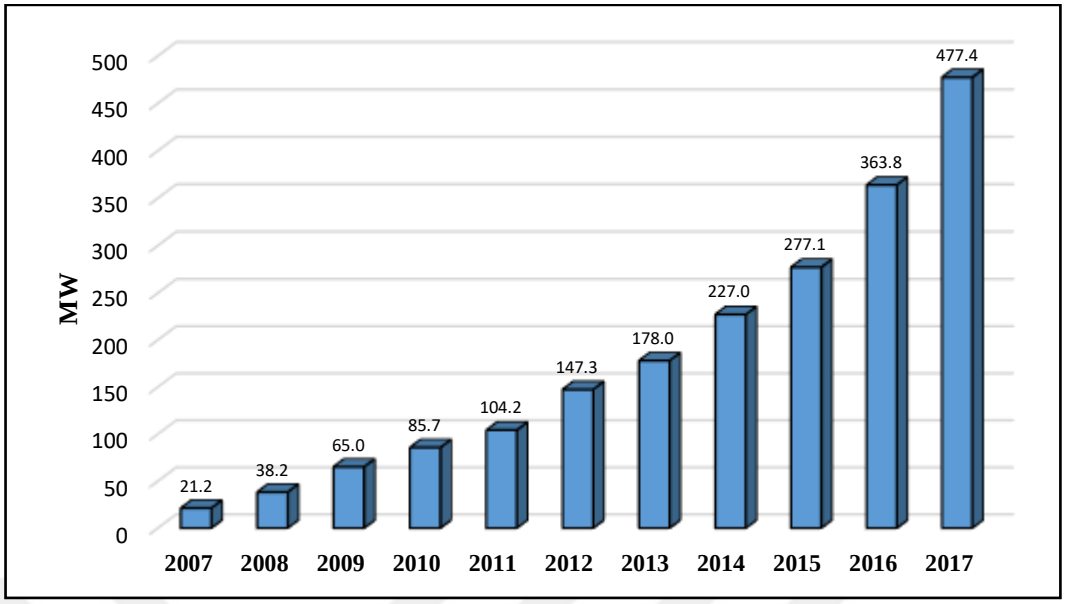
Biomass is converted to bioenergy by some thermal processes. The thermal processes used to generate bioenergy are given in Table 4.8 [53].

Table 4.8 Thermal processes to convert biomass to bioenergy

Conversion technology	Examples of fuels	Intermediate products	End use	Technology status
Combustion	Wood logs, chips and pellets, agricultural residues, chicken litter	Heat and steam	Heat, electricity (steam turbine, stirling engine, reciprocating steam engine)	Commercial (boilers and steam turbines)
Gasification	Wood chips and pellets, agricultural residues	Heat and gas	Heat (boiler), electricity (engine, gas turbine, fuel cell, combined cycles), transport fuels (methanol, hydrogen)	Demonstration/ early commercial
Pyrolysis	Wood chips and pellets, agricultural residues	Pyrolysis oil + by-products (product gas, char)	Heat (boiler), electricity (engine, turbine)	Commercial (slow), demonstration (fast)

Biomass accounts for a major share of primary energy consumption among renewable sources and represents the main source of energy in many least developed and developing countries. According to estimates, the conversion from biomass might globally provide 23×10^{10}MWh (2×10^{4} Mtep) per year [53].

Figure 4.16 shows the progress in installed biomass energy capacity of in Turkey from 2007 to 2017. It is seen that Turkey's installed biomass energy capacity has significantly increasing during this period. The total capacity in 2017 was 477.4 MW and it was increased to 811 MW in 2018. 3,216 GWh electricity was generated from biomass power plants in 2018 [54].



*Includes Industrial Waste

Figure 4.16 Biomass energy installed capacity by years [50]

CHAPTER 5

RENEWABLE ENERGY CAPACITY AND 2023 TARGETS OF TURKEY

Turkey's energy consumption is mainly based on imported fossil fuels in other words renewable sources supplied only 10% of this energy consumption in 2010. The bulk of that figure came from hydropower and biomass. The ratio of renewable energy resources in primary energy has been decreasing as of the 1970s [55].

Turkey has an important potential in renewable energy resources. Especially hydropower, wind, solar, biomass and geothermal energy potentials are very high [56]. Table 5.1 demonstrates the renewable energy potential of Turkey according to the type of sources. It is seen from the table that wind and solar economic potential constitute nearly 70% of the Turkey renewable energy potential [16].

Table 5.1 Renewable energy resources potential of Turkey [16]

Renewable Energy Resources	Economic potential (MW)
Solar	50,000
Wind	48,000
Hydropower	36,000
Geothermal	2,000
Biomass	2,000
Total	**138,000**

The share of renewable energy resources in electricity production reached to 20% in Turkey in the past decade. However, more than 95% renewable energy based on only hydropower and share of other renewable energy resources is less than 1%. For this reason, Turkey's majority of new renewable investments are expected to be especially in solar, wind, biomass and geothermal energy area [6].

5.1 Solar Energy Capacity of Turkey

Geographicaly, as it may be seen in Figure 5.1, Turkey is located in the Mediterranean sun belt. Solar Energy Map (SEM) of Turkey is given in Figure 5.2. According to the Solar Energy Map prepared by Renewable Energy General Directorate, the total annual insolation time is 2,741 hours or avarage insolation is 7,5 hours per day. The total derived solar energy is 1,527 kWh/m^2 per year or 4,18 kWh/m^2 per day. Theoretically, Turkey's estimated annual solar energy potential is 6,150 TWh. However, the predicted economical potential is 305 TWh. According to the figure, Turkey's average global solar radiation is 1,500 kWh/m^2 per year [6, 51, 57]. Therefore, Turkey is fortunate and has a perfect position for solar power plants.

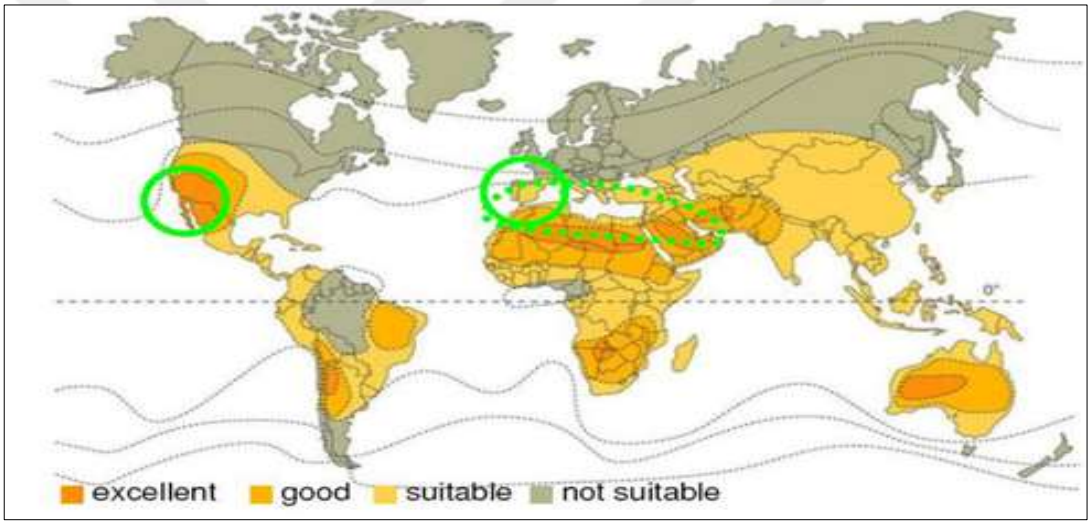


Figure 5.1 Turkey solar energy potential and geographical location [57]

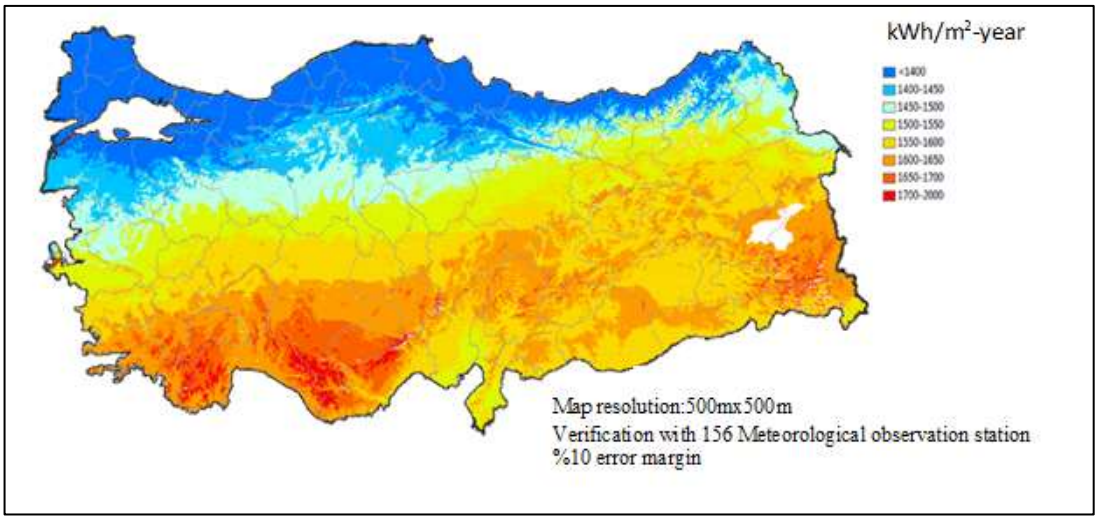


Figure 5.2 Global solar radiation of Turkey [57]

The average monthly solar energy and sunshine duration potential in Turkey can be seen in Figure 5.3. It is seen from figure that monthly average sunshine durations in July (365 h/month), August (343 h/month) and June (325 h/month) are the highest. On the other hand, the potential in December (103 h/month), January (103 h/month) and February (115 h/month) is the lowest. A similar situation may also be seen for both average monthly radiation energy and sunshine duration [12].

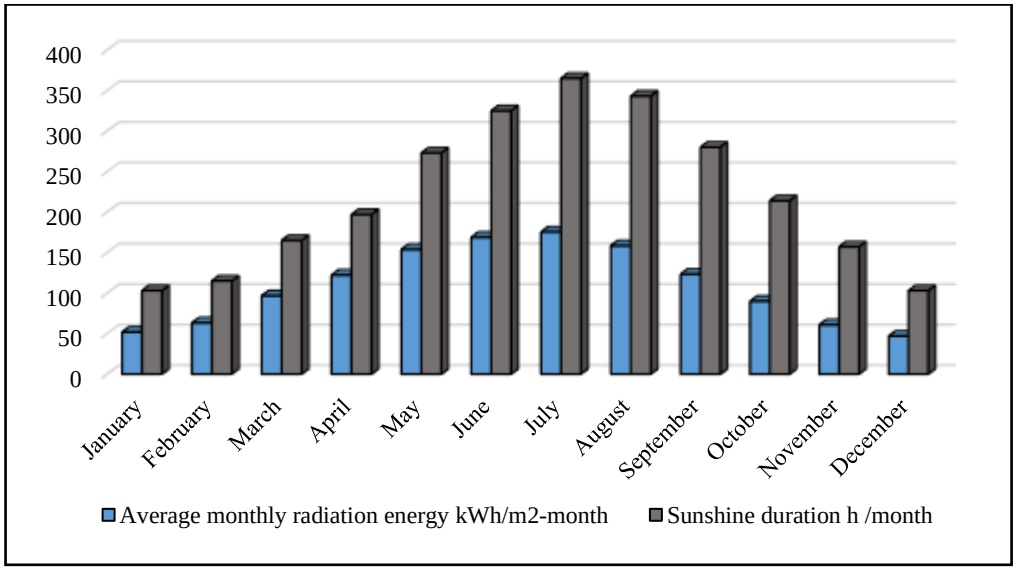


Figure 5.3 Average monthly solar energy and sunshine duration in Turkey [12]

Until last decade, the solar energy was mainly used for water heating. However, a lot of effort has been made in last decade in generation electricity from solar. There are two main technologies used for producing electricity from solar energy. The first one is Photovoltaic Technology in which semi-conducting materials convert the sunlight directly into electricity. The second technology is Photo-emissive Solar Technologies and Concentrated Solar Power in which heat is obtained from solar energy. Then, the heat can be used either directly or in the generation of electricity [51].

By the end of 2018, the total established solar collector area within Turkey was calculated as 20,200,000 m^2. In 2018, approximately 876,720 TEP heat energy was produced by using solar collectors [51].

The Renewable Energy Resources Legislation necessary in order for the use of photovoltaic systems was completed and released in 2013.

There are many small-scale photovoltaic solar energy systems, which have already been established in Turkey either for the purpose of meeting small quantities of power or for research purposes. The total number of installed solar power plants are about 5,863 with installed capacity 5,063 MW. However, 4,981.2 MW of the installed capacity is unlicensed. That is, only 81.8 MW are licensed. Electricity production from the solar energy in Turkey increased to 2.5% with 7,477.3 GWh in total electricity production [51].

Especially, in 2018, it was decided to construct a solar power plant of 1,000 MWe capacity in Konya-Karapınar region which will be one of the world's largest solar power plant. At same time, 60% of the solar panels is to be produced in a local factory established in the same region [51].

5.2 Wind Energy Capacity of Turkey

Turkey has a great potential for electricity production from wind energy. Turkey's wind power capacity is prediction to 160 TWh, per year in theory. Moreover, nearly 77% of this potential is technically feasible [6].

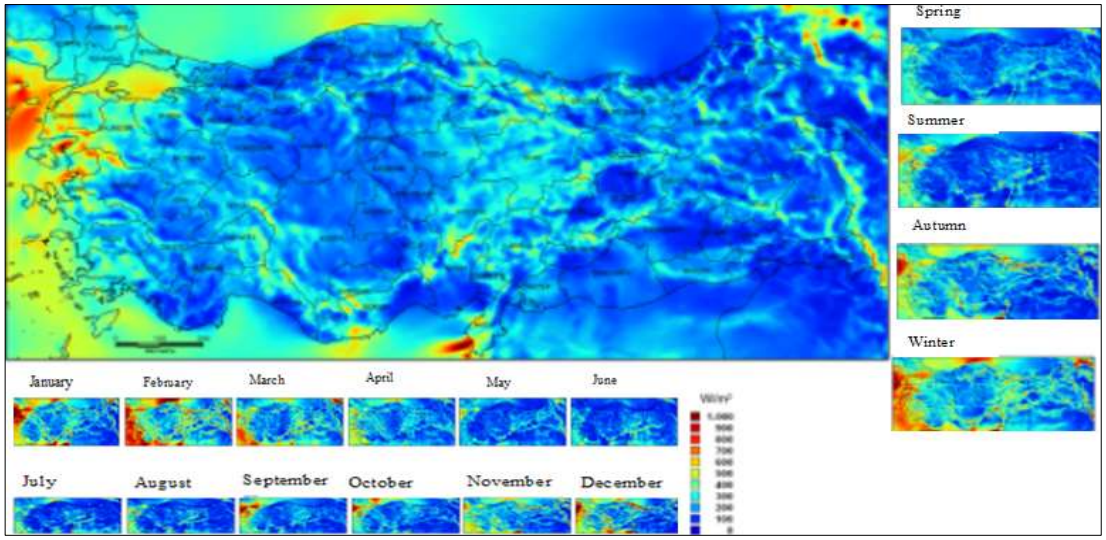


Figure 5.4 Wind power density map of Turkey (50 m) [58]

Turkey's wind power density map relative to 50 m hight from the ground is given in Figure 5.4 by month while Turkey's wind speed map is given in Figure 5.5. Turkey's wind power density map relative to 100 m hight from the ground can be seen in Figure 5.6, while Turkey's wind speed map can be seen in Figure 5.7 monthly. According to these figures north Aegean region is more advantages than the other regions from the point of wind power [58].

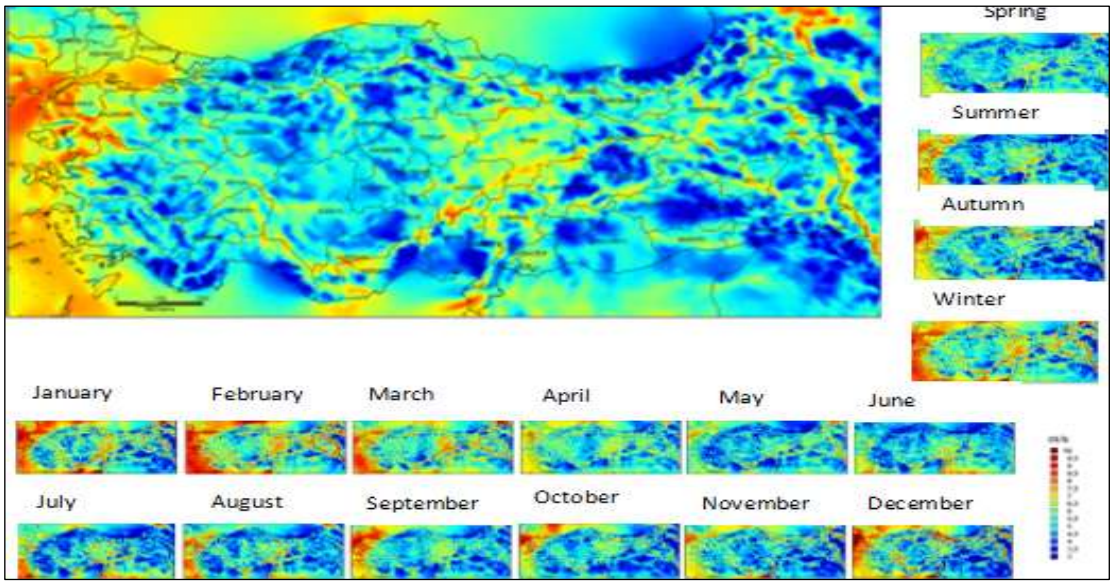


Figure 5.5 Wind speed map of Turkey (50 m) [58]

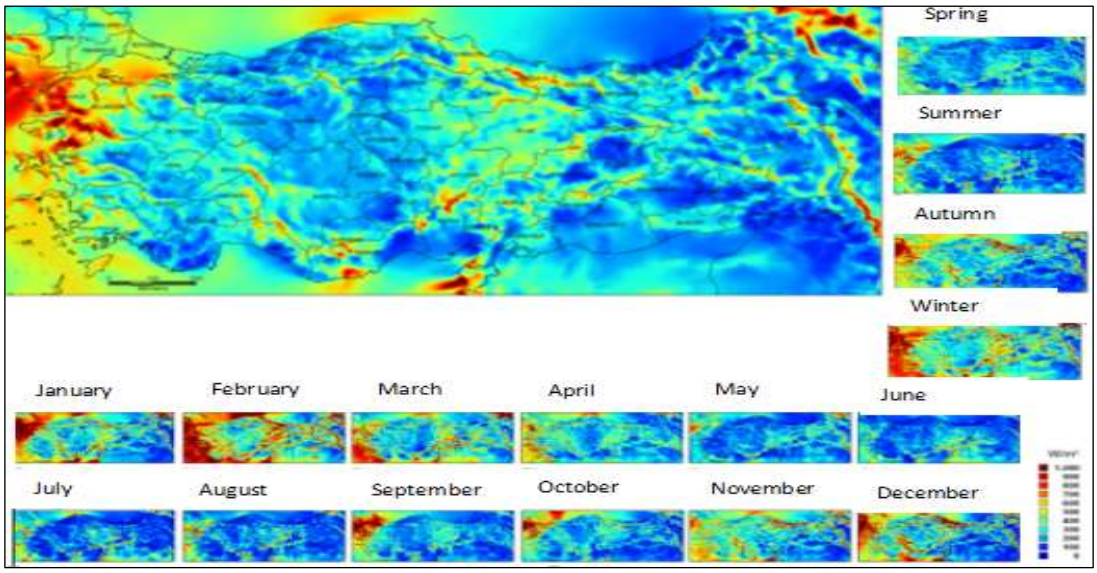


Figure 5.6 Wind power density map of Turkey (100 m) [58]

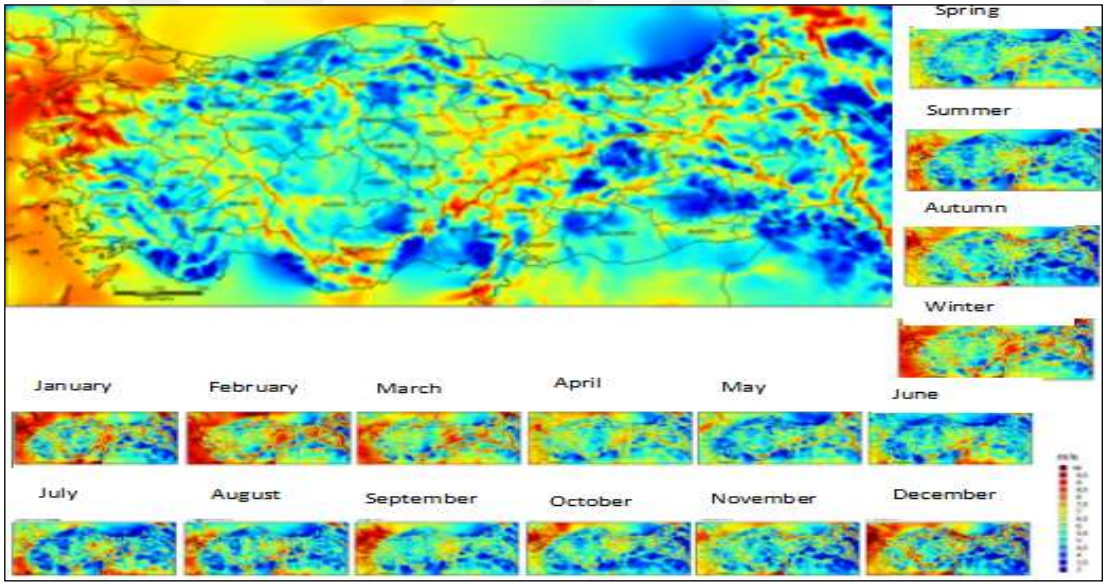


Figure 5.7 Wind speed map of Turkey (100 m) [58]

Table 5.2 shows the wind energy potential of Turkey with respect to wind class, wind power density, wind speed, and total capacity [57].

Table 5.2 Wind potential of Turkey [57]

Resource potential	Wind class	Annual wind power density (W/m^2)	Annual wind speed (m/s)	Total capacity (MW)
Good	4	400-500	7.0-7.5	29,259.36
Excellent	5	500-600	7.5-8.0	12,994.32
Outstanding	6	600-800	8.0-9.0	5,399.92
Superb	7	> 800	> 9.0	195,84
TOTAL CAPACITY				**47,849.44**

The wind power development in the country was initiated last decade. As seen in Figure 5.8, Turkey's installed wind capacity has been significantly increasing since 2008. However, as compared to the Turkey's total wind capacity, the installed capacity is still very low. At the end of 2018 Turkey's wind power installed capacity exceeds 7 GW, with an economic potential estimated at 38 GW onshore and 10 GW offshore [59]. Figure 5.9 shows the annual installations for wind power plants in Turkey. As it may be seen from the figure, the installation in 2016 is the highest. The installation rate significantly decreases after 2016 and reaches to 497.2 MW in 2018. This is considered to be related to the recent economical developments in Turkey and expected to recover very soon [59].

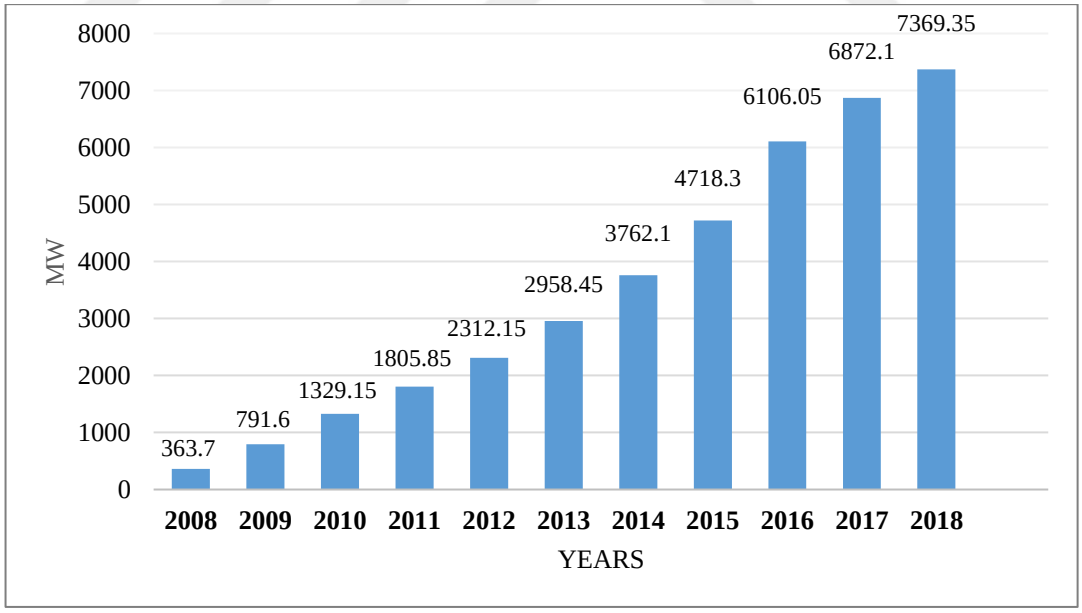


Figure 5.8 Wind power installed capacity in Turkey [59]

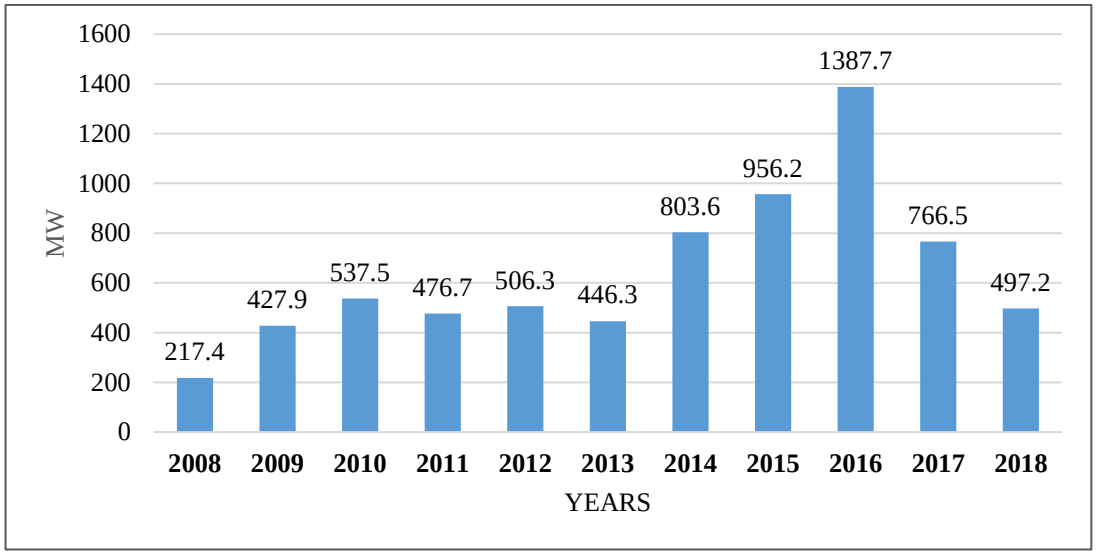


Figure 5.9 Annual installations for wind power plants in Turkey [59]

Wind power in Turkey is gradually growing in capacity. 20 TWh of electricity was generated in 2018 which was about 7% of Turkey's electricity generation. Figure 5.10 shows the electricity generation from the wind power per month in 2018. It is seen that the electricity generation from wind power varies monthly depending on the wind power. Although it has highest value in August, it is significant in all other months of the year [59].

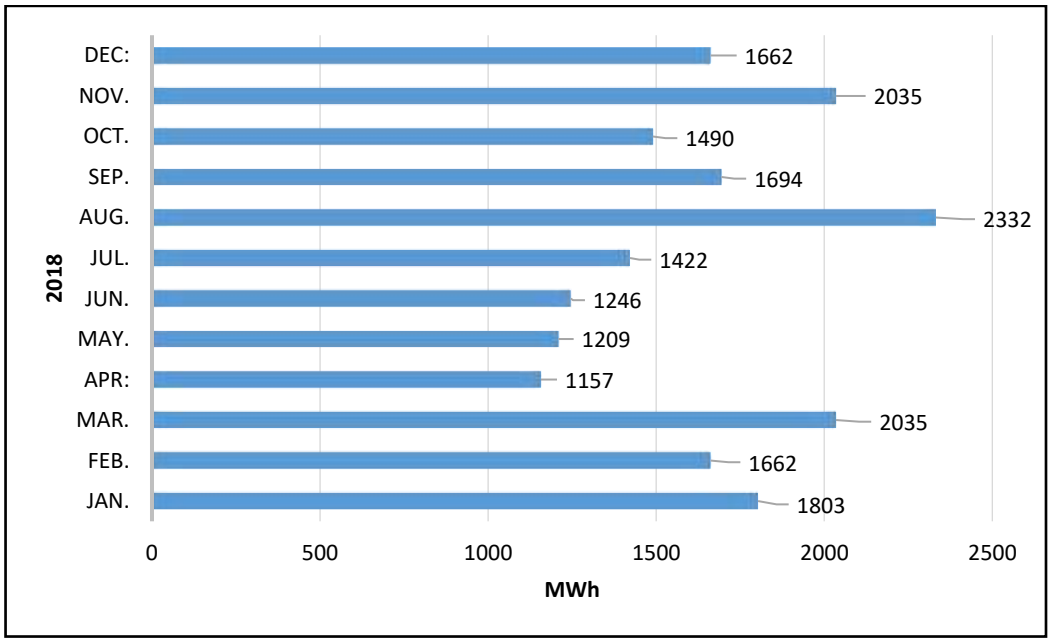


Figure 5.10 Electricity generation from the wind power per month in 2018 [59]

5.3 Hydroelectric Energy Capacity of Turkey

Hydroelectricity technologies are well known, environmentally friendly and carry low potential risk. Hydroelectricity power plants have a long lifespan, low operating costs, and are not dependent on imports. Therefore, they take the role of insurance in energy prices. While worldwide hydropower installed capacity in 2017 is 1,267 GW, electricity generated by hydropower in 2017 was 4,185 TWh [60].

Turkey is fortunate in hydroelectricty resources. It ranks nineth in the world for this type of energy among all countries. It has a theoretical hydroelectricity potential of 1% of the theoretical potential of the world and its economic potential is 16.6% of the economic potential of Europe [1].

Turkey’s hydroelecric potential is estimated as 433 billion kWh, while the technically usable potential is 216 kWh, and the economic hydroelectricity potential is 140 billion kWh/year [1]. With this capacity hydroelectric resources of Turkey takes a large share in renewable energy resources. Turkey’s total installed capacity in 2018 was 28,248 MW [70].

Turkey plans to increase the share of renewable sources in total installed power to 30% by 2023. Turkey's targets for 2023 reach 34,000 MW capacity of hydro power plants. Table 5.3 shows information about Turkey's some big installed capacity of hydroelectric power plants [61].

Table 5.3 Turkey's some big installed capacity of hydroelectric power plants [61]

Name	Location	Installed Capacity/MW
ATATÜRK	Şanlıurfa	2,405
KARAKAYA	Diyarbakır	1,800
KEBAN	Elazığ	1,330
ALTINKAYA	Samsun	703
BİRECİK-NİZİP	Şanlıurfa	672
DERİNER	Artvin	670
BERKE	Osmaniye	510
HASAN UĞURLU	Samsun	500
ERMENEK	Karaman	302
BORÇKA	Artvin	301
SIR	Kahramanmaraş	284

5.4 Geothermal Energy Capacity of Turkey

Geothermal energy is the heat (a form of energy) contained within the Earth and is often used to indicate the part of the Earth's heat that can be recovered. Geothermal sources can be used to generate energy either directly or indirectly. The sources with low temperature may be used for heating in houses or for production of chemicals in industry. The medium and high temperature sources (70-150 ^{o}C) on the other hand may be used to generate electricity. The international geothermal power market is growing with rate of 4% to 5%, approximately. There are about 700 geothermal projects under development in 76 countries [62]. China, USA, Sweden, Turkey and Japan are the top 5 countries in geothermal heat and hot springs applications. Turkey is enough rich in geothermal energy resources and using geothermal energy in many applications such as electricity generation, heating and cooling homes and greenhouses, thermal tourism, mineral extraction, drying and agricultural applications, etc. Geothermal sources map of Turkey is given in Figure 5.11. Turkey's geothermal sources are situated as 78% in Western Anatolia, with 8.5% in Central Anatolia, 7.5% in the Marmara Region, 4,5% in Eastern Anatolia and 0.5% in the other regions [63]. As Turkey's economy is growing and energy demand is raising, the interest in this type of energy is also rising like the other types of renewable. Turkey owns 12.5% share of the world total geothermal potential. Although most of this potential is not useful for electricity production, it can be used for direct heating applications. Turkey's geothermal potential is predicted as 38,000 GW, but almost 80% of this energy potential is appropriate for thermal applications rather than generating electricty. Geothermal electricity production potential of Turkey is predicted to be 2,000-4,500 MW or 35,000 GWh per year [6].

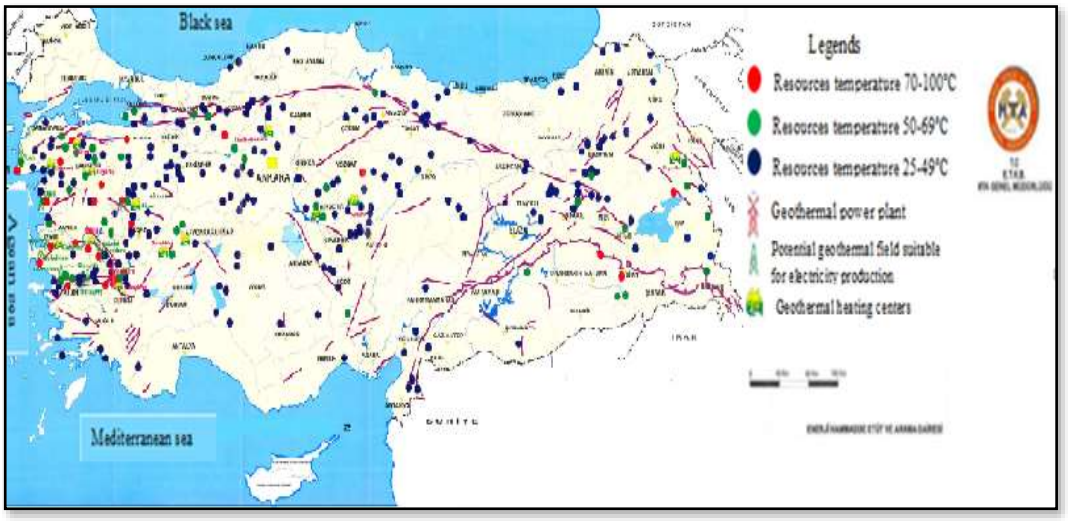


Figure 5.11 Geothermal energy potential map of Turkey [64]

Figure 5.12 shows power generation capacity additions by year. First geothermal electricity generation held in 1975 was initiated by Kızıldere, Denizli, power plant with 0.5 MWe power. Then, Turkey has increased its geothermal power capacity each following year. By the end of 2018, the total installed geothermal power capacity of Turkey is 1,347 MW and Turkey plans to increase its geothermal power generation capacity to 2,000 MW by 2020. At the end of 2018, in terms of installed capacity, Turkey is in fourth place worldwide with a total of 53 geothermal power plants in operation. According to the Turkish Geothermal Power Plant Investors Association, Turkey is able to build up additional geothermal capacity of 200 megawatts at least per year which requires about US $ 1 billion of annual investments [65].

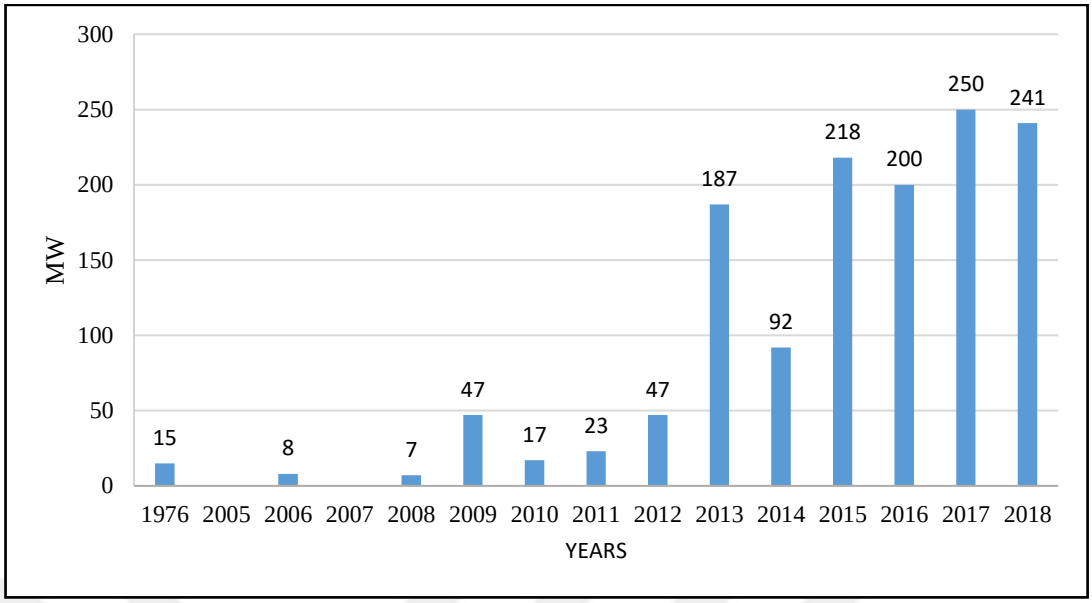


Figure 5.12 Turkey's geothermal power generation additions by years [65]

5.5 Biomass Energy Capacity of Turkey

Biomass is a renewable energy derived from animal and plant organic matter. Biomass is considered to be promising type of renewable and also green energy source which is found abundantly in nature (natural materials) or can be conveniently generated (derived materials). Turkey's basic biomass production is based on organic matter such as herbal resources. As shown in figure 5.13, the recoverable biomass energy potential of the country comes from forestry and wood processing residues, agricultural residues, animal wastes and municipal wastes. As it is seen from figure that the major biomass resource is the agricultural waste as being 90% of all biomass resources of Turkey. The ratios of other biomass resources in generating electricity lie between 2% and 5%. Total waste from forests is 4,800,000 Tons (1.5 MTOE-600 MW) and from agriculture is 15,000,000 Tons (300 PJ) [66].

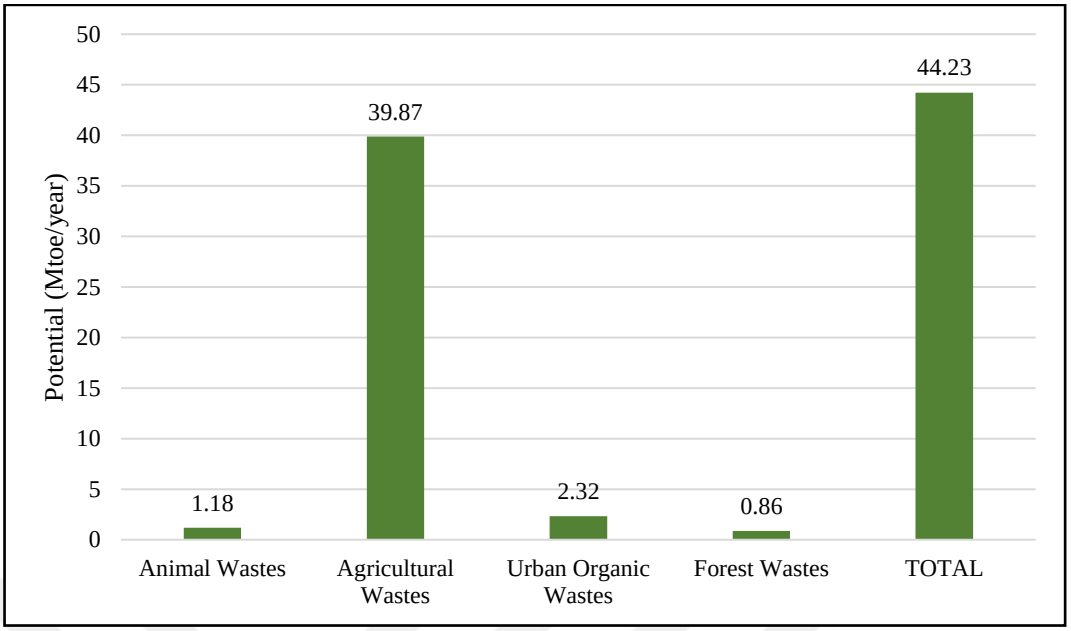


Figure 5.13 Turkey's biomass potential in resource based [67]

The ratio of biomass energy generation in Turkey is quite low as compared to the other renewable energy types. Despite Turkey is importing approximately 70% of its total energy needs which is expected to increase as energy demand increases, the share of bioenergy must also be increased. The contribution of biomass has considerably reduced in the total energy consumption from 20% to 8% for last three decades. Also, most of biomass products are used in the form of animal wastes and fuelwood for heating and cooking in rural areas [68].

On the other hand, the electricity production from biomass is considered to be very encouraging. Biomass integrated gas turbine technologies are thought as future of biomass-based electricity production. The country biomass energy potential is predicted as 32 Mtoe or 372,000 GWh/per year and recyclable part of this potential is nearly 16.9 Mtoe or 197,000 GWh/per year [6]. Turkey's biomass waste potential is equal to 8.6 million tonnes oil. The total potential of biogas quantities that can be produced from biomass is 1.5-2 MTEP [54]. In 2018, the installed biomass capacity of Turkey was 811 MW and 3,216 GWh electricity was generated by the biomass power plants [66].

5.6 Renewable Energy: 2023 Targets of Turkey

According to IEA Global Energy and Status report, global energy demand grew 2.1% in 2017 provisional estimation. Recent years, a considerable increase has occurred in global energy demand. Global energy demand is increased by nearly 4 million tons of equivalent (Mtoe) between the years of 2000-2017 [69]. Fossil-fuel corresponds to over 70% of this increase in energy demand around the world. Natural gas reaching a share of 22% of that energy demand. Renewable also grew powerfully about a quarter of global energy demand growth [69].

According to World Bank Statistics, Turkey is 6th largest economy in Europe and the 17th in the world. Turkey's economy is growing and its population is rising. Energy supply is the most important parameter in the development of country. In Turkey, unfortunately substantial amount of electricity is generated from fossil fuels, especially from coal, natural gas, and oil. However, Turkey does not have indigenous natural gas, oil, and good quality coal reserves. Therefore, in order to solve its energy needs, the country imports these resources with an increasing trend and this leads to an increasing trade deficit and also increasing greenhouse gas emissions [12].

In order to reduce the dependency on imported energy sources, and also to reduce greenhouse gas emissions causing global warming and climate changes, Turkey should concentrate on renewable energy sources and technologies. As a part of Vision 2023, Turkish has very ambitious targets to shape the country's energy market on renewable sources up to year 2023. Despite all challenges, country pays a large effort to generate energy from nuclear and renewable energy sources.

Turkey's energy policy is mainly based on alternative energy resources, energy supply security, diversity of energy resources, utilization of domestic energy resources to create additional value to economy, and energy efficiency. From this perspective, special effort has been made to maximum the utilization of local and renewable energy resources [10].

In order to fulfil Vision 2023 energy targets, It has been estimated that Turkey needs to spend between 31.4 and 90.5 billion US$ or 61.0 billion US$ on average which is almost equal to the investments done so far [14].

Turkey has specified many actions to increase the renewable energy share in electricity generation. In the 2009 Electricity Market and Security of Supply Strategy and in Electricity Energy Market Law (No. 6446), Turkey underlined the main role of renewable energy in achieving its targets of reducing foreign resource dependence, diversifying the electricity mix and meeting increasing energy demand with local and renewable energy resources. Turkey's 2009 Strategy aims to reach 30% of renewable energy resources in electricity production by 2023, 100th anniversary of establishment of the Republic of Turkey [41]. Due to the new regulations and reforms made recently by Turkish Government, Turkey's energy sector has become one of the most attractive investment destinations in the world. The regulations made by the government encourages the investors to put invests in renewable energy sector. One of the most important regulations on this strategy is purchasing guarantee from a defined price given to electricity generated from renewables. According to this support mechanism, both licensed and unlicensed facilities generating electricity from renewables can benefit from this tariff for 10 years from their operation date. Real and legal entities generating electricity from renewable energy resources with maximum installed capacity of 1 MW can also benefit from feed-in prices described above in case they inject the remaining electricity to distribution system after reducing their self-consumption.

According to National Renewable Energy Action Plan for the period 2013-23, in line with the methodology and requirements of the EU Directive 2009/28/EC. The action plan evaluates the renewable energy policies and potential of Turkey, and contains a number of indicative targets to reach a total capacity of 61 gigawatts (GW) for different renewable energy sources by 2023. Some of these targets are [41]:

- using all economically feasible hydropower potential for generating electricity to reach 34 GW
- increasing the installed wind power generation capacity to 20 GW

- expanding the use of solar power in electricity generation to utilize Turkey potential and reach to 5 GW at least.
- increasing installed geothermal power generation capacity to 1GW (already reached)
- increasing installed biomass power generation capacity to 1 GW.

Figure 5.14 presents the renewable energy potential, installed capacity and the Turkish government 2023 Vision targets. According to this figure, Turkey has been using a large amount of its hydropower potential. There is still 8.7 GW of the hydoropower that can be eveluated. Turkey's target is to reach 34 GW of installed capacity in hydropower. Therefore, the hydropower development is considered to be very important in Turkey's Vision 2023 energy agenda. On the other hand, there is a huge potantial in wind and solar that can be evaluated in future [16, 50].

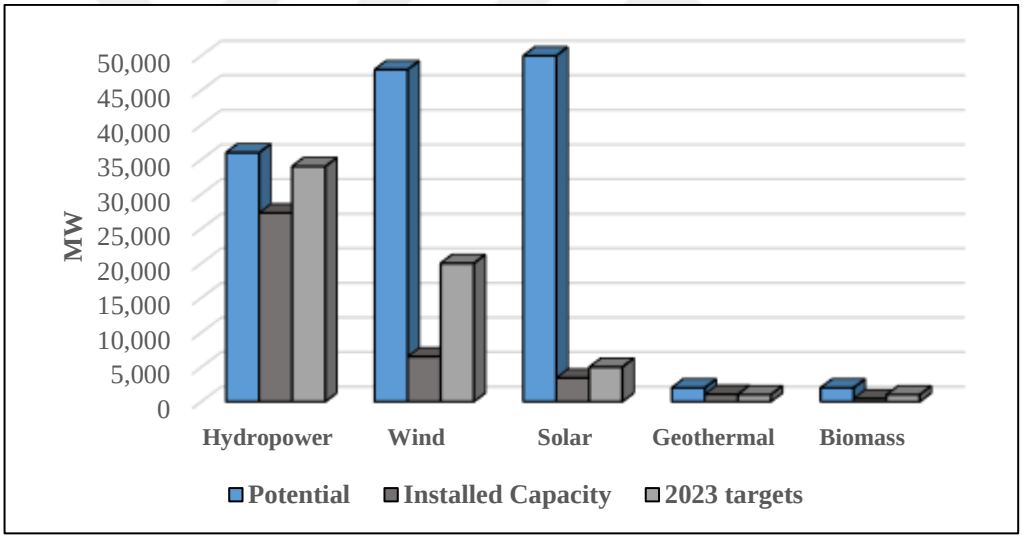


Figure 5.14 Relationship between renewable energy potential, installed capacity and 2023 targets [16, 50]

Turkey's 2023 Vision targets related to renewable energy installed power capacity by sources is given in Table 5.4. As it is seen from the table that the overall target which Turkey wants to reach is 61 GW of renewable energy capacity by 2023 [16]. The results show that Turkey has already exceeded its Geothermal capacity targets, and conducted 69.1% of the overall targets**.** On the other hand, the performances in wind and biomass installed capacity are below the average. Therefore, Turkish government has to either revise these targets or pays more effort in order to conduct

wind and biomass targets. Although, Turkey has already reached to its 2023 target in solar energy, the installed solar capacity is still very low as compared to the potential. The installed solar capacity so far is based on inlicensed systems with small scales.

Table 5.4 Renewable energy resources installed power 2023 target of Turkey [16,51,59,65,66,70]

Renewable Energy Resources	Installed capacity (MW) /2018	Installed power (MW) /2023 target	Realization percentage (%)
Hydropower	28,248	34,000	83.2%
Wind	7,369	20,000	36.8%
Solar	5,063	5,000	101 %
Geothermal (revised)	1,347	2,000	67.3%
Biomass*	811	1,000	44.7%
Total	**42,838**	**62,000**	**69.1%**

*Includes industrial waste

CHAPTER 6

CONCLUSION

It is certain that energy has a vital role in the country's economic, social and cultural development indicator. Demand to energy resources has recently increased depending on many factors, such as rising population, urbanization rate, industrialization, technological development, economic growth, and improving living standards. The electricity as a secondary form of energy is indispensable for our modern life. It is used in many areas ranging from heating, cooling to illumination and also many other areas. Until last two decades, fossil fuels were used to meet energy needs. However, majority of the countries have insufficient fossil resources to meet their energy needs. Furthermore, importing fossil resources causes budget deficit for these countries. On the other hand, in order to meet their energy demand, some countries have started using renewable energy resources.

Turkey, with about $1 trillion of gross domestic product (GDP), is a member of G-20 countries. In addition, our country aims to be among the top ten advanced economies with $2 trillion of GDP as a target for 2023. In order to achive its goals, the demand for energy and natural resources has been recently increasing. Our country has recorded the fastest growth in electricity demand among OECD countries, with an annual growth rate of 5.5% since 2002. As a developing country, our country’s energy demand is also increasing. Our country has been generating 70% of its energy, on average, from fossil resources. However, the country has insufficient fossil resources and importing fossil resources causes a high budget deficit. Therefore, our country country aims to reduce dependence on imported fossil fuels and trade deficit. In order to achive its purpose, our country wants to increase the ratio of renewable energy in energy generation.

The fossil fuel energy sources are rapidly depleting in the world. Coal, oil and gas reserves are estimated to end in 134, 50 and 52 years, respectively. Our country does not have indigenous natural gas, oil, and good quality coal reserves. While our country has only 1.1% of the global coal reserves, most of the owned reserves are not

in good quality. Coal production in our country is 0.6% of the global and consumption is 1.2% of the world total coal consumption. Our country has in short supply both oil reserve and production with 1.0% share in the world oil consumption. Our country has very limited domestic gas reserves. The natural gas production with owned reserves is very low being less than 1% of the domestic gas demand. On the other hand, our country has been extensively using natural gas both for electricity generation and also for cooking and heating facilities with 1.4% share in the world natural gas consumption. Furthermore, despite all efforts done in recent years Turkey has not yet been able to produce electricity from nuclear. However, the first nuclear power plant is being build in Akkuyu, Mersin, by a Russian company according to build operate transfer aggrement.

The share of fossil fuels in electricity generation is expected to drop from 65% in 2016 to 50% in 2040. On the other hand the share of renewable sources in electricity production is expected to increase from 24% to 40% in the same time interval.

As regarding to the renawable energy production, Turkey efforts to increase the share of renewable energy sources in energy mix in order to reduce its energy import dependency. For the same reason, it aims also to add the nuclear power to its energy mix to maximize the use of domestic resources and combat climate change.

Among the renewable energy reources, the biggest share in electricity generation is based on hydroelectric power. Turkey's feasible hydropower potential for generating electricity is 34 GW. By the end of 2018 the total installed hydroelectric capacity of Turkey was 28,248 GW. That is, Turkey has already been using about 83% of its hydroelectric power capacity. As a target in 2023, it also aims to use all of its hydroelectric power capacity. On the other hand, a noticeable progress has recently been done on wind, solar and geothermal powers.

In geothermal, our country has fourth highest installed capacity in the world. Geothermal electricity production potential of Turkey is predicted to be 2,000-4,500 MW. The country has already been using 1,347 MW of this potential and want to reach 2,000 MW by 2023. Even if this traget is achieved until 2023, it is still half of the total feasible potential. Therefore, more investment is needed in this area.

Two of the most promising renewable energy resources for Turkey are the solar and wind. Turkey's wind potential has been estimated as to be 48,000 MW. In 2018, total installed wind power capacity in operation was 7,005 MW and 19.882 billion kWh electricity was generated. Although, the wind power technology is well known and domestic technologies are also in progress. Turkey's installed capacity is still far below the total capacity. Thefore, Turkey has to increase its installed potential and develop domestic technologies related.

By the end of 2018, total number of solar power plants was 5,863 with installed capacity of 5,063 MW. The electricity production from these installed solar power plants was 7,477.3 GWh which takes 2.5% share in the total electricity production [51]. However, the installed capacity and also the electricity production from the solar resources is very low as compared to the potential of the country. It is suggested that Turkey must put more invests in developing and installation of solar systems in order to reduce import based energy production.

When examining the indigenous rate at electricity energy installed capacity from 2000 to 2017, Turkey's native capacity rate fall from 66% to 57%, however, an import-based installed capacity rate increase from 34% to 43% at the same time. A similar situation can be seen on the side of electricity production from 2000 to 2017. Turkey's domestic production rate falls from 55% to 45.2%. On the other hand, the import-based production rate increased from 45% to 54.8% during the same period. Furthermore, Turkey's electricity production and consumption consistently increase excluding a few years around 2009. A similar situation can also be seen in Turkey's primary energy supply. Although domestic production has increased, the total primary energy supply of Turkey has increased more than indigenous production. Turkey's domestic production rate was 31% at total primary energy supply in 2002. However, in 2017, the domestic production rate falls from 31% to 24%. While total primary energy supply increased approximately 68,000 toe from 2002 to 2017, the indigenous production increased only 11,000 toe during the same period [43].

The primary energy demand of Turkey was forecasted that about extra 100,000 toe energy is need in 2023, 100th anniversary of establishment of the Republic of Turkey. Similarly, 30% of the Turkey's electricity consumption is considered to meet by

means of renewable energy resources in 2023. At current time, only 60,000 GWh of production is based on renewable energy. In other words, Turkey needs extra 100,000 GWh production from the renewable resources. Turkey has enough potential to meet this energy demand, but evaluation phase of that potential was found some deficiency, such as research and development, the absence of technology, technical infrastructure and qualified labor force. Using renewable energy will provide advantages to Turkey's economy in many points, such as reduction of import dependency, growing energy demand with sustainable way and diversity of energy resources.Although Turkey is a poor country in terms of fossil fuels, it is geographically located between the countries of its region with 75% of the world's proven oil and gas reserves and European energy consumer markets. This geostrategic location provides Turkey to take the advantage of being an energy corridor with opportunities and responsibilities in terms of energy security. The oil and gas produced in east and south neighboring countries of Turkey is trasported to Europe through many pipe lines crossing over Turkey. In this regard, as a part of its energy strategy, Turkey aims to strengthen its position between East-West and South-North Energy Corridors.

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CURRICULUM VITAE

PERSONAL INFORMATION

Name Surname: Mustafa VURAL

E-mail **:** mvural24.25@gmail.com

EDUCATION

Bachelor **:** Selçuk University / Faculty of Engineering and Architecture / Department of Electrical and Electronic Engineering

(2007-2011)

Master Degree: Ankara Yıldırım Beyazıt University / Graduate School of Natural Sciences / Department of Energy Systems Engineering

(2016-2019)

WORK EXPERIENCE

Engineer: Directorate General of Natural Lottery Administration (2012)

Energy and Natural Resources Expert: Ministry of Energy and Natural Resources (2013-continued)