LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
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Ceren Yazıcı

Sustainability Challenges for Solar Energy in Turkey

Examiners: Professor Risto Soukka
D.Sc. Sanni Väisänen

ABSTRACT

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Keywords: sustainability, Turkey, Turkish energy sector, solar energy, renewable energy, sustainable energy

In this thesis, sustainability challenges for energy sector in Turkey is discussed. The aim is to answer the question, "What is the role of solar energy for achieving sustainable energy sector in Turkey?". Before identifying the drivers, obstacles and instruments, basic background for popular solar energy technologies were provided. Following, current situation of Turkish energy sector is embraced and the current place of solar energy in Turkish energy sector is examined. The drivers for sustainable energy sector is defined and the role of solar energy is examined for a pathway to sustainability. The defined drivers are classified under environmental, economic and social aspects. The environmental drivers are global warming and climate change, greenhouse gas emissions from energy sector, environmental pollution and energy efficiency in power plants. The economic drivers are fossil fuel scarcity and dependency, security of energy supply, energy efficiency in power plants and fluctuating prices of fossil fuels. Social drivers are population growth and urban population, health problems caused by pollution, unemployment rate, work accidents in energy sector, fluctuating prices of fossil fuels and security of energy supply. Following, the obstacles for solar energy in Turkish energy sector are examined. The examined obstacles are again classified environmentally, economically and socially. The environmental obstacles for solar energy in Turkey are GHG emissions from and harmful materials used in production processes of solar system components, and disturbance of natural habitat. The economic obstacles are transition of current energy system, profitability of investments and willingness of investors, current energy targets and subsidies, technical requirements for solar energy and cyber safety. The social obstacles are geopolitical risks, land use, cyber safety and disturbance of natural habitats. While observing the drivers and obstacles, possible instruments for energy system transition to a more sustainable version are determined.

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In Lappeenranta 16 November 2017

Ceren Yazıcı

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ACRONYMS

BOS	The Balance of System
BP	British Petroleum
c-Si	Wafer-Based Crystalline Silicon PV
CSP	Concentrating Solar Thermal Power
DOE	U.S. Department of Energy
EECB	The Energy Efficiency Coordination Board
EMO	Chamber of Electrical Engineers
EMRA	The Energy Market Regulatory Authority
EU	European Union
EUR	Euro
EÜAŞ	Electricity Generation Company
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HCE	Heat-Collection Element
HFCs	Hydrofluorocarbons
IEA	International Energy Agency
ISE	Fraunhofer Institute for Solar Energy Systems
kr	kuruş
LCOE	The Levelized Cost of Electricity
mono-Si	Mono-Crystalline Silicon Wafer PV
multi-Si	Multi-Crystalline Silicon Wafer PV
NCCAP	The National Climate Change Action Plan of Turkey
OECD	The Organization for Economic Co-operation and Development
PM	Particulate Matters
PtX	Power-to-X
PV	Photo-Voltaic
REAP	The National Renewable Energy Action Plan
RPS	Renewable Portfolio Standards
R&D	Research and Development
STE	Solar Thermal Electricity
TANAP	Trans-Anatolian Natural Gas Pipeline

TEDAŞ	Turkish Electricity Distribution Company
TEİAŞ	Turkish Electricity Transmission Company
TETAŞ	Turkish Electricity Trade and Contracting Company
TF	Thin-Film PV
TPES	Total Primary Energy Supply
TS	Thermosyphon System
US	United States
WHO	The World Health Organization
YEKDEM	Renewable Energy Resources Support Mechanism

CHEMICAL COMPONENTS

CO_2	Carbon Dioxide
CH_4	Methane
N_2O	Nitrous Oxide
NO_x	Nitrogen Oxides
PM_{10}	Particulate Matter with 10µm diameter
$PM_{2,5}$	Particulate Matter with 2,5µm diameter
SO_2	Sulphur Dioxide

1 INTRODUCTION

The energy sector is one of the most important sectors in global level, with increasing population, urbanization and quality of living standards. Global population increases year by year, which leads to an increase of energy demand. Other facts leading to energy demand increase are urbanization and improvements of living standards. The total primary energy consumption of the world in 2015 was approximately 153.000TWh and 86% of this consumption was met by fossil fuels, which are oil, natural gas and coal (BP, 2016). The most critical issue about meeting the energy demand is the scarcity of current energy resources. Conventional energy resources are the most popular energy resource even though they are scarce, not easy to access and harmful to the environment. Renewable energy technologies can be a solution for this problem since they are sustainable and environmentally friendly.

In today's conditions, sustainability is the key aspect to the survival of all sectors. Since energy sector has a great presence in people's daily lives and has a problem of scarcity of resources, it is inevitable to disregard its sustainability to ensure its survival. Considering the energy demand of twenty first century's modern life, sustainable development in energy sector is becoming a necessity. The sustainability aspects lead to determine the challenges for sustainability of a specific system. Sustainability aspects can be classified under three types of indicators, which are environmental, economic and social indicators. Environmental indicators are mainly about negative environmental impacts of a system. One of the most important environmental impacts of a system is emissions of greenhouse gases (GHG) which cause global warming and climate change. Also, emissions of heavy metals and other particulate matters (PM) are very harmful to the environment and need to be considered for system sustainability. These negative effects also result with air and water quality degradation. Economic indicators are challenges of the economy of a system itself or the economy that a system is placed in. Social indicators are challenges related to the society which a system is placed in. Environmental, economic and social impacts of a system should be considered together for sustainability of a system.

For sustainable development of the energy sector, all sustainability challenges related with it should be considered. It is non-ignorable that the energy sector should be sustainable since there is a scarcity of energy resources and energy sector has the biggest damage share on the environment compared to other sectors. Without a sustainable energy system, it is impossible to meet future's energy demands. The necessary change is replacement of fossil fuels with renewable energy resources. Renewable energy resources are the solution for a sustainable energy system, since conventional energy resources are scarce and these energy resources are harmful to the environment. GHG emissions from fossil fuels cause global warming and climate change. Pollutants caused by fossil fuels are dangerous for human health. Emitted heavy metals and other PM by fossil fuel usage cause various diseases. Also, renewable energy technologies are more sustainable and cause lower GHG emissions. With renewable energy technologies, solutions provided for sustainability challenges are not just about GHG, heavy metal or PM emissions. It also leads to solve other sustainability challenges for energy sector, such as meeting energy demand, securing energy supply and improving energy efficiency.

With renewable energy technologies, a sustainable energy system is easier to be achieved. Among these technologies, solar energy has a great global technical potential as an energy resource. Solar energy has the biggest growth rate of power and heat generation between renewable energy resources. Between the years 2010 and 2015, the growth rate of solar photo-voltaic (PV) power was 42%, concentrating solar thermal power (CSP) was 35% and solar hot water heating was 12%. In addition, growth rate for these power and heating technologies for the year 2015 were 28%, 9,7% and 6% respectively. But still, estimated share of solar energy in global energy production of 2015 was less than 2%. (REN21, 2016, p. 29.) Solar energy is a renewable energy resource with greatest technical potential among renewables and needs to be considered as the main energy resource to create a sustainable energy system. In 2015, total primary energy consumption of the Organization for Economic Co-operation and Development (OECD) countries was 64.000TWh and 4,3% of this consumption is met by renewable energy resources. Solar share was only 192,4TWh which is equal to 0,3% of 2015's total energy consumption of OECD countries. (BP, 2016.) It is very necessary to understand the importance of renewable energy resources and upgrade the current energy systems accordingly.

Among OECD countries, Turkey has a theoretical solar energy potential of 15.120TWh. Located in a sunny belt, Turkey has various suitable locations for solar energy power systems. (Kick, 2011, p. 20.) However, only 0,04% of total primary energy consumption was met by solar energy in 2015. The important thing is that solar share in total primary energy consumption was increased by three times in one year, between 2014 and 2015. (BP, 2016.) This improvement assures that solar energy has a huge potential for the Turkish energy sector. Yet, it is not popular despite its potential. Turkey is a developing country with ever increasing population. Turkish population growth and modern technologies increase the demand of energy, which makes the Turkish energy sector one of the most dynamic ones in Europe. The situation of the Turkish energy sector is in a critical stage. Turkey has a fast-developing energy market with little emphasis on long term planning. According to Greenpeace, with today's trends and policies, the share of electricity generation from renewables will be 34% and share of solar energy between them will be 13% in 2050 (Greenpeace, 2015a). It shows that Turkey has a high potential for a sustainable energy system, but still it continues to rely on fossil fuels. Turkey is dependent on fossil fuels, which are mostly imported from other countries. This situation makes the Turkish energy sector reliant on other countries, harmful to the environment and unsustainable. Also, coal is considered as the domestic solution for this dependency. The Ministry of Energy and Natural Resources is planning to solve the energy supply problem with coal without considering the disastrous effects of coal combustion on the environment. Renewable energy technologies should be considered for a sustainable energy system, but still, it is not popular in Turkey.

The necessary action is to improve the energy system considering sustainability challenges. Turkey's energy sector is barely sufficient to meet the current energy demand and it is not sustainable. The thesis starts with providing information about current solar energy technologies. Its focus is on electricity and thermal energy technologies with active solar designs, which are solar photo-voltaic and solar thermal technology. Then, more information regarding the current energy sector in Turkey and solar technologies used in Turkey are given. Following, sustainability challenges for solar energy are discussed. Firstly, the drivers for a sustainable energy system in Turkey are presented. Following, the obstacles for solar energy in Turkey are examined. While observing the drivers and obstacles, they are classified under three aspects which are environmental, economic and social aspects. Finally, possible instruments for energy system transitions are examined. In this thesis, the aim is to assess renewable energy technologies to understand their compatibility with Turkish energy sector and to locate one technology that can ensure the sustainability of Turkish energy sector. The main goal is to assess a fully sustainable energy sector in Turkey with solar energy technologies. The thesis discusses only the electricity side of Turkish energy system and leave out heat and transport sub-sectors of Turkish energy system. Installed capacity is used for the discussion of energy potentials. Currently, the Turkish energy system is reliant on foreign fossil fuels and not sustainable. It is known that Turkey has targets for GHG emission reductions from and energy efficiency increase in energy sector. However, the country does not have any drastic actions to meet these targets. Besides, energy dependency creates a heavy economic burden on Turkey. Currently, it is impossible for Turkey to reach 100% renewable electricity system. However, with the help of solar energy technologies, the future for a sustainable energy system in Turkey is promising. The possibilities that solar energy can offer to achieve set targets should be considered by decision makers.

2 SOLAR ENERGY TECHNOLOGIES

Energy has become a basic need for human life. The primary energy demand continues to grow year by year and key drivers for this growth are population and gross domestic product (GDP) increase, which is basically used to measure overall economic activity of a nation. The most common energy technology used to meet the current energy demand is combustion technology using fossil fuels, which are not sustainable. Fossil fuels are harmful to the environment and cause global warming. Fossil fuels are the main reason of historic increase of atmospheric GHG concentration in the last decades. Yet, the share of fossil fuels in energy resources for primary energy consumption was 86% in 2015 (BP, 2016). Renewable energy resources are the solution for the fossil fuel domination on the global energy system. Unlike other energy resources, renewable energy resources are sources which are continuously renewed by itself. Renewable energy technologies are based on the conversion of energy from the natural environment. They do not cause emissions or pollution like conventional energy technologies and overall emission levels are lower than other technologies. (Greenpeace, 2015b.) Also, renewable energy may have a contribution to economic and social development, energy access and energy supply security. However, only 9,5% of total primary energy consumption in 2015 was met by renewables (BP, 2016).

Renewable energy is generally developed with government support policies and the development of renewable energy will continue to be shaped with new policies. Despite the challenges of policy changes, uncertainties and taxations, total number of countries which has renewable energy targets and supports for renewable energy with new policies increases year by year. Also, the countries who have renewable energy targets continue to upgrade their policies for more ambitious targets and started to aim for 100% renewable energy sectors. They also aim to support new innovative mechanisms to increase renewable shares in their energy mix. In addition, they focus on adjusting the existing policies for making the change rapidly, fluently and less costly. The most important tools for the energy mix change are feed-in tariffs and Renewable Portfolio Standards (RPS) policies. Feed-in tariffs are used by authorities at the national or provincial level and RPS policies are used at provincial level. (REN21, 2015, pp. 17-18.)

Renewable energy technologies can be listed as bioenergy, solar energy, geothermal energy, hydropower, ocean energy and wind energy. They can be used for electricity, thermal energy, mechanical energy supply as well as chemical fuel production. Energy conversion and storage technologies have a critical role for renewable energy. By using improved conversion technologies which are called Power-to-X (PtX) technologies, form of energy can be changed from power to other forms to meet electricity, heat, mobility and chemical demands, to make the system more adaptable and to store the energy efficiently. Between renewable energy technologies, solar energy is considered as the energy resource with highest technical potential. Solar energy technology is the conversion of radiant energy of sunlight and it is used for electricity or heat generation. Conversion technologies of solar radiation can be classified as active and passive designs. In Figure 1, an illustration of the direct solar energy is presented, in which flows represent the energy. It symbolizes the convergence of solar energy from source to services. Solar energy can be used to generate electricity or heat energy. Also, it is possible to generate synthetic fuels with improving conversion technologies. (IPCC, 2012.) In this thesis, active solar designs which are solar photo-voltaic and solar thermal technology are focused. The focus of the thesis is only on electricity generation. Solar PV is the conversion technology that uses solar radiation for electricity generation by photo-voltaic cells. Solar thermal is basically exploiting solar radiation for electricity generation by solar thermal electric plants (CSP) or hot water production by flat plate collectors (solar thermal energy). (Banos, et al., 2011, pp. 1758-1759; IEA, 2015a.)

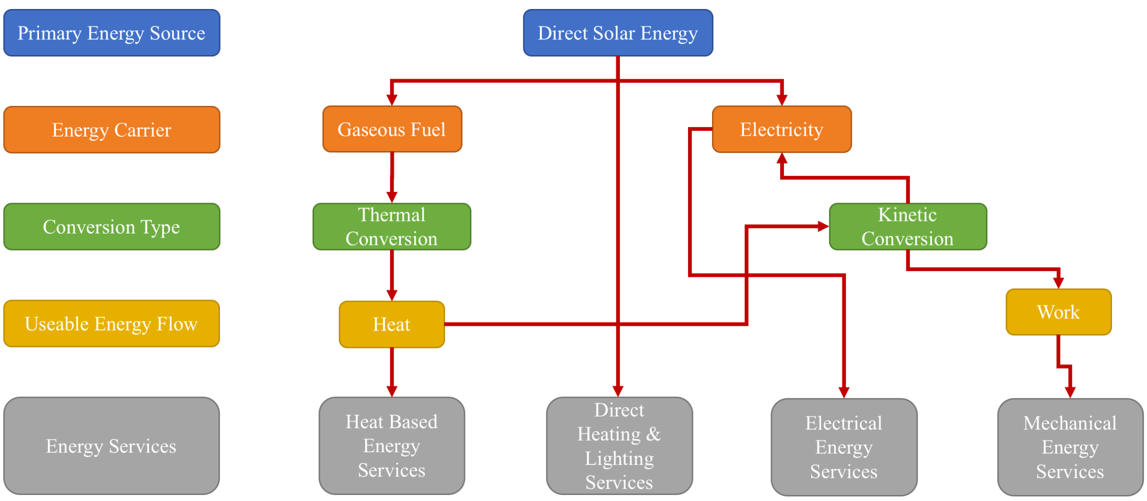


Figure 1: Path Illustration for Solar Energy from Source to Service (Modified from IPCC, 2012, p. 181)

Research and development (R&D) studies for solar energy has begun in the 1950s and gained acceleration with the 1970s' oil crisis. These R&D studies made solar energy technology one of renewable energy technologies with the fastest growth rate. As it has been mentioned before, the growth rate of solar photo-voltaic (PV) power was 42%, concentrating solar thermal power (CSP) was 35% and solar hot water heating was 12% between the years 2010 and 2015. Also, Figure 2, and Figure 3 show the capacity increase of solar technologies in ten years. From these figures, it can be said that solar energy technologies have started to be used more in each year. The share of solar energy on global electricity production increases every year. For instance, the share of solar energy on global electricity production in 2014 was 0,9%, but this share was increased to 1,2% in one year. The biggest effect for the popularity of solar energy technologies is technology improvements. With R&D studies and performance improvements, solar energy technologies become more energy efficient and less costly. The levelized cost of electricity (LCOE) of solar energy technologies are also decreased in the last few years. The LCOE basically measures lifetime costs divided by energy production which leads to calculate the present value of the total costs of a power plant (including building and operating costs) and to compare different technologies (DOE, 2015). The decrease of LCOE makes solar technologies preferable in some countries especially where the LCOE of solar energy technologies fell below the variable portion of retail electricity prices. For instance, Figure 4 shows the installed price of residential and non-residential PV systems in the United States between the years 2006 and 2014, and the median module efficiency of the systems installed in these years. The total price of the system started to decrease after 2009 with an average of 13% to 18% per year and the price decrease for the one year period between 2013 and 2014 was $0,4/W (9%) for residential systems, $0,4/W (10%) for non-residential systems ≤500 kW, and by $0,7/W (21%) for non-residential systems >500 kW. The overall cost decline is the result of a decrease in global PV module prices, which makes the solar PV technology more accessible. The figure also shows the increase of module efficiencies of PV systems installed in the United States, which also leads to cost decrease for PV systems. (Barbose & Darghouth, 2015, pp. 15-18; REN21, 2015; REN21, 2016.)

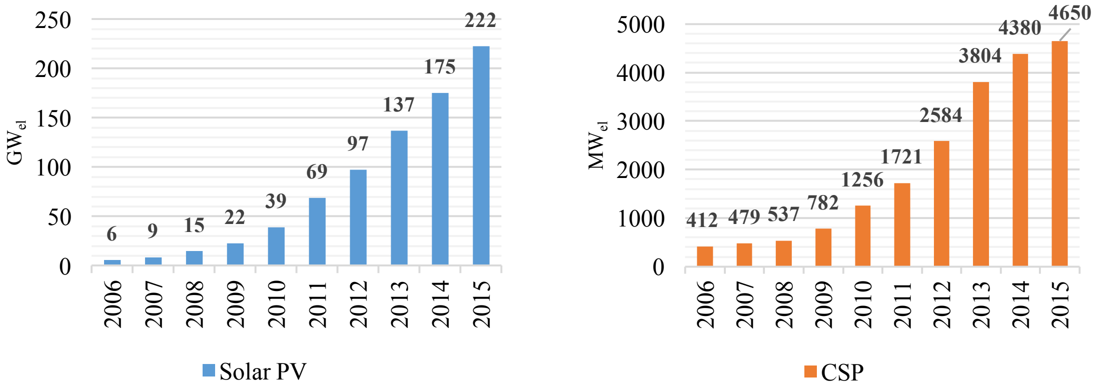


Figure 2: Global Solar PV and Concentrating Solar Power Capacities (IRENA, 2016, pp. 27-32)

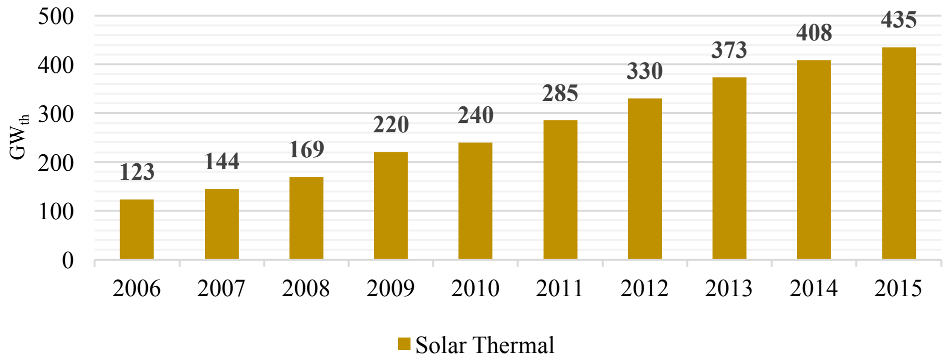


Figure 3: Global Solar Thermal Energy Capacity (Mauthner, et al., 2016)

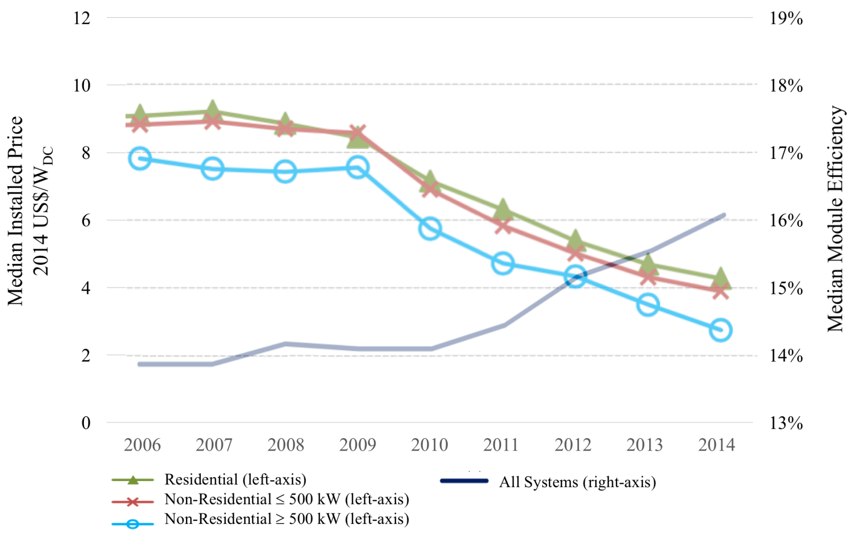


Figure 4: Installed Price of Residential and Non-Residential PV Systems in the United States, and the Median Module Efficiency of the Systems Installed (Modified from Barbose & Darghouth, 2015, pp. 15-18)

Solar energy technology has a very high theoretical potential with its plentiful energy resource. The resource is available in all regions of the world. However, it is more necessary to consider the technical potential for an efficient solar energy system installation. The theoretical potential represents the total amount of solar irradiance at the surface which is theoretically available for the solar energy system, but, technical potential represents the total amount of solar irradiance output which is obtained by the system installed. (IPCC, 2012., pp. 340-343) The type of technology and radiation data is very important for optimal design of a solar system. Figure 5 represents the average of direct normal irradiation annually on the world. Some regions have higher irradiation, but the irradiation levels are acceptable for a solar energy system all around the world. Moreover, solar energy was the renewable energy resource which had the highest investment share for the last 6 years (IRENA, 2017a). Figure 6 represents the global trend in investments on solar energy between the years 2006 and 2015. With the rising global trend of investments in solar energy technologies, solar energy has a promising future.

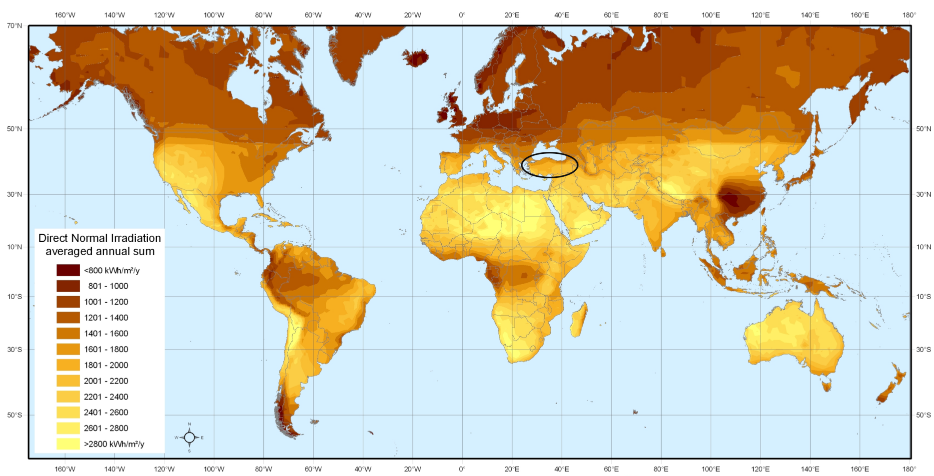


Figure 5: Direct Normal Irradiation Map (DLR, 2008)

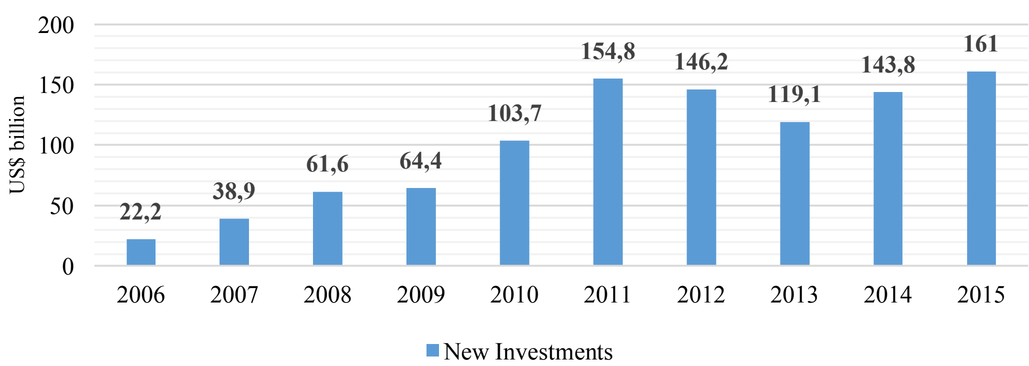


Figure 6: Global Trend in Investments on Solar Energy (IRENA, 2017a)

GHG emission levels of solar energy technologies are very low, especially compared with conventional energy technologies. Low emission levels make solar energy less costly in terms of external costs of emissions. Even if there are still environmental impacts from manufacturing and end-of-life phases of solar devices, solar energy is more desirable than non-renewable energy resources. Also, most of the materials used in manufacturing of solar energy harvesting device can be recycled. In addition, the operational phase of the technology has zero emission and does not cause noise pollution. Solar energy can be converted into electricity, thermal energy or fuel. Solar energy technology is suitable to be used as centralized and decentralized energy systems. It makes solar energy a favorable energy technology for power and heat resource both in rural areas and large energy networks. In addition, solar energy technologies with energy storage can be a very beneficial system combination, since energy storage allows the power flow to be continuous. (Banos, et al., 2011, pp. 1758-1759; IPCC, 2012, p. 343.)

The solar energy is one of the renewable energy technologies with the fastest growth rate. The technology is efficient since the energy conversion steps in the system are few. Solar energy technology has a very high theoretical potential with its plentiful energy resource. In addition, the resource is available in all regions of the world. Furthermore, its potential is the highest both theoretically and technically between renewable energy resources with the rising global trend of investments in solar energy technologies. The overall cost decline of solar PV systems makes the technology more accessible. Also, low emission levels of the solar energy technologies make the technology preferable. Between solar energy technologies, PV and CSP technologies are options for high level of electricity generation. These technologies become preferable to be installed and supported by governments. Moreover, PV is practical for rooftop installations. Also, solar thermal energy systems can be used in local areas and offers the least-cost option for heating in some areas of the world. These solar energy technologies, which are PV, CSP and solar thermal energy, will be explained further in the following chapter. (REN21, 2016; ISE, 2016.)

2.1 Photo-Voltaic (PV) Solar Power Technology

Solar PV technology is used to generate electricity with the photo-voltaic effect. Currently, it is the most popular technology among other solar power technologies. As it is mentioned before, it has the biggest growth rate between solar technologies, which is 42% from 2010 to 2015 (REN21, 2016, p. 29). Basically, PV system uses a thin sheet of semiconductor material. This sheet consists of two layers which are n-type layer and p-type layer. These two different types of layers are used to form a junction at the interface of the sheet. An internal electric field at the junction is created, and electron-hole pairs are generated by the solar photons in the electric field, which creates negative charges on one side and positive charges on the other side of the interface. This charge separation creates a voltage and current flows lead to generate electricity. The operation of an illuminated solar cell is described in Figure 7. Multiple cells are connected to increase the amount of electricity generated, which create solar modules. Solar modules are used to create solar panels, which is represented in Figure 8. The average lifespan of a solar module is between 20 to 30 years. (IPCC, 2012, pp. 351-355.)

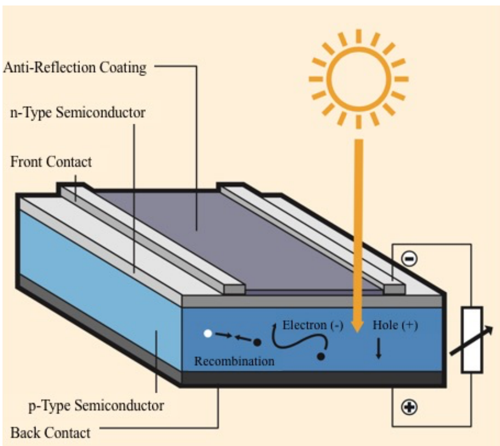


Figure 7: Operation of an Illuminated Solar Cell (IPCC, 2012, p. 351)

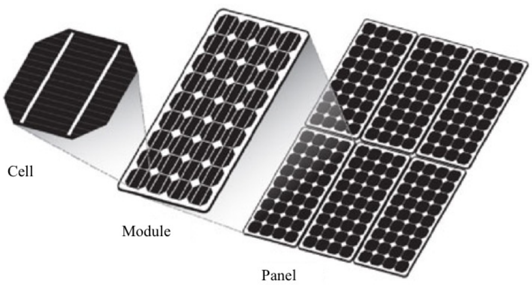


Figure 8: A Solar Panel's Infrastructure (Borthakur , 2017)

Efficiency of a solar system is related to the absorber material used in the thin sheet and the design of the device. There are various types of materials used in solar cells and each of them has a different collection capacity of photons. PV cells consist of organic or inorganic matter. Inorganic cells are more popular in PV market. Inorganic cells are based on silicon or non-silicon materials, which are classified as wafer-based crystalline silicon (c-Si) cells or thin-film (TF) cells. Wafer-based crystalline silicon cells are classified as mono- and multi-crystalline (also called poly-crystalline) silicon wafer PV and, they are the dominant cell technologies on the PV market since they are cheaper than other cell types. Figure 9 illustrates the most popular types of PV cell technologies. Peak cell efficiency for mono-crystalline silicon wafer PV (mono-Si) cells is around 25% and for multi-crystalline silicon wafer PV (multi-Si) cells is around 20,3%. (IPCC, 2012, pp. 351-355.) Among PV technologies, total peak electricity generation of mono-Si cells was 15,1GWp, of multi-Si cells was 43,9GWp and of TF cells was 4,2GWp in 2015 (ISE, 2016).

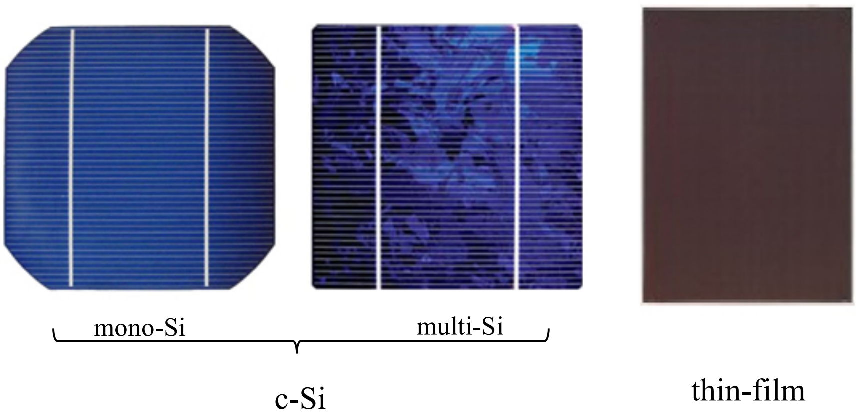


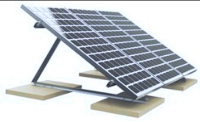
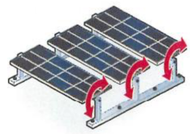
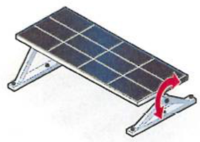
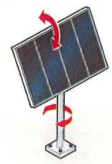
Figure 9: Types of PV Cell Technologies (Borthakur , 2017)

System design is also very important for system performance. PV panels should be installed without any shadowing effects. Also, a system should be designed with consideration of reliability, demand response, cost effectiveness and suitability to the electricity grid in the future. A PV system includes PV modules and balance of system (BOS) components, which contain an inverter, storage devices, charge controller, system structure and the energy network. Between BOS components, storage devices are very important for PV systems since sunlight is not accessible all day long. Storage technologies lead the PV solar power to be more practical to use and more flexible to access. As storage technologies are improved, large PV systems will be more beneficial for electricity demand and adaptable to the electricity grid. The system structure is another important component for PV systems. A PV system can be installed either as an off-grid application, or as a grid-connected application. Off-grid means that the system installed is not connected to a traditional power grid and grid-connected means vice versa. Off-grid applications lead PV systems to be preferable in the non-electrified areas, since the size of the system is adjustable. In addition, off-grid availability makes PV systems viable for individual consumer applications. In the grid-connected PV systems, electricity generated can be supplied to the electricity network. The grid-connected PV systems can be classified as distributed and centralized applications. The difference between grid-connected PV systems can be seen in Table 1. Besides, there are various installation types for solar PV systems. The most popular installation types for PV panels are roof-top and ground-mounted panels. Moreover, installation of panels with a tracking system can be effective for system efficiency. (IPCC, 2012, pp. 351-355.) The major tracking systems are 0-axis fixed optimally tilted, 1-axis (east-west or north-south) horizontal continuous tracking, 1-axis north-south optimally tilted tracking, 1-axis vertical optimally tilted tracking and 2-axes (non-concentrating or concentrating) tracking, which can be seen in Table 2. Between these tracking systems, 1-axis north-south horizontal continuous tracking PV system is considered as the best financially performing option. (Breyer & Schmid, 2010.)

Table 1: The Difference between Grid-connected PV Systems (IPCC, 2012, pp. 351-355)

Grid-connected PV types	Function	Installation
Distributed PV system	To provide power to: - a grid-connected customer - electricity network	- residential systems - rooftops on public and industrial buildings
Centralized PV system	To perform as a centralized power station with bulk of power supply (not associated with a particular electricity customer)	- ground mounted

Table 2: The Major Tracking PV Systems

The Major Tracking PV Systems	
0-axis fixed optimally tilted	
1-axis (east-west or north-south) horizontal continuous tracking	
1-axis north-south optimally tilted tracking	
1-axis vertical optimally tilted tracking	
2-axes (non-concentrating or concentrating) tracking	

The price of PV solar systems has declined throughout time and continue to decline. During the last 30 years, the prices for PV panels have decreased by more than a factor of 10. The price decrease is achieved not only by technology development, but also by the increase of PV utilization in newer markets. The price reduction has occurred for modules and other parts of the PV systems, with the help of attractive financing and good resources. The escalation in the PV market leads to stimulate more competitive applications between manufacturers. In Figure 10, typical solar PV system price changes for one year can be seen. In all leading countries in the PV market, system prices have declined. (IEA, 2015b, pp. 173-180.)

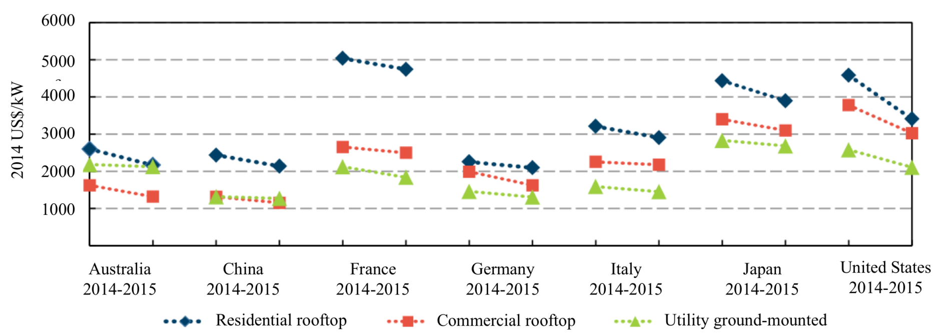


Figure 10: Typical solar PV system prices by segment (IEA, 2015b, p. 174)

2.2 Concentrating Solar Power (CSP) Technology

Concentrating solar thermal power (CSP) technologies, which is also known as solar thermal electricity (STE), lead to collect direct-beam solar irradiance and use it to heat a liquid, solid or gas material. The heat energy stored in the material is used in heat engine process to generate electricity. Since steam and gas turbine cycles are used for electricity generation like in current energy generation technologies, CSP technologies become attractive as a renewable energy technology. However, on contrary of conventional energy technologies, CSP technologies use renewable energy resource to heat the system fluid to be used in electricity generation. The excess heat from system can also be used to meet heat demand of the surrounding area. Since the system uses beams directly to generate heat energy, its performance is directly related with the site's geographical properties. For CSP plants, it is very important to be located on a site that is near-equatorial and cloud-free regions for better performance. CSP has the second highest growth rate from 2010 to 2015 between renewable energy resources and the growth rate for five years was 35%. Furthermore, the global capacity for CSP was 4,8GW in 2015 and the leaders in CSP installed capacity were Spain and United States. (REN21, 2016; IPCC, 2012, pp. 155-158.)

Commonly, sunlight is concentrated by reflection to a central receiver. Concentration method may differ according to the type of the system, as receivers differ from configuration to configuration. The CSP configurations can be classified as line-focus types and point-focus types. The line-focus types are parabolic trough and linear Fresnel reflector, which can be seen in Figure 11. Represented in Figure 12, the point-focus types are central receiver/power tower and dish concentrator. In parabolic trough, long parabolic reflectors are installed horizontally, to concentrate the solar irradiation to the absorber tube, which is located along the focal line of reflectors. The reflectors track the movement of the Sun. Inside the absorber tube there is a material called heat-collection element (HCE). Absorber tube consists of a blackened inner pipe which is located inside of a glass outer tube. In the linear Fresnel system, long parallel mirrors are used as concentrators to focus solar irradiation to a fixed linear receiver. In the central-receiver, which is also called power tower, an array of mirrors (called heliostats) are installed on the ground and track the Sun on two axes while reflecting the sunlight to the receiver located on the top of a tall tower. Heat transfer with system fluid occurs in the central receiver atop of the tower. In the dish concentrator, there is a single paraboloid reflector which tracks the Sun on two axes. The reflector is used to concentrate the sunlight to the receiver located about one dish diameter away from the dish. Point-focus type of configurations can reach higher temperatures than line-focus types, which leads the heat engine to convert more of the collected heat to electricity. (IPCC, 2012, pp. 155-158.) Throughout the development of CSP, the market was focused entirely on parabolic trough technology but this situation was changed and the CSP market is now balanced almost evenly between parabolic trough and tower technologies (REN21, 2016).

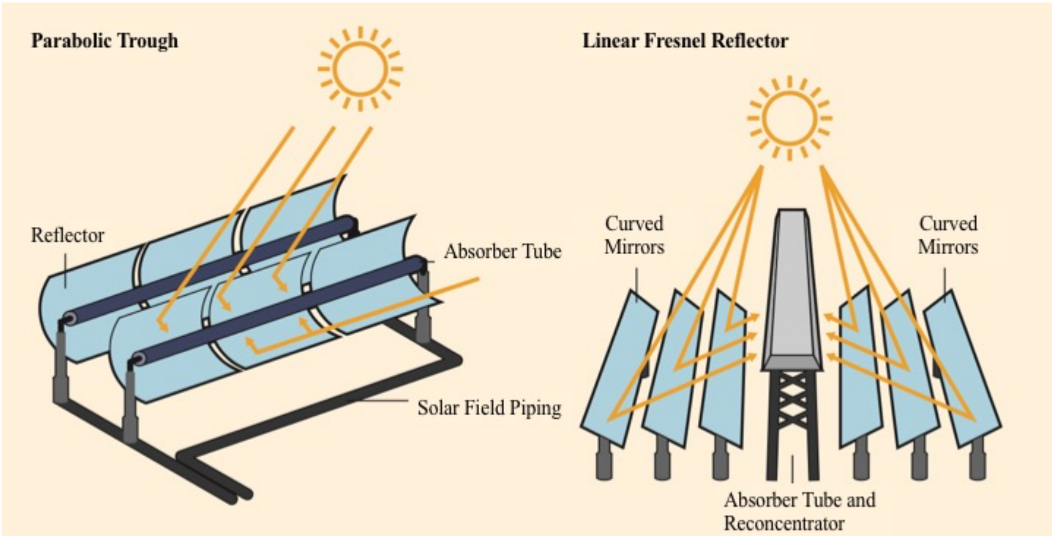


Figure 11: Line-focus Type Configurations of CSP Systems (IPCC, 2012, p. 156)

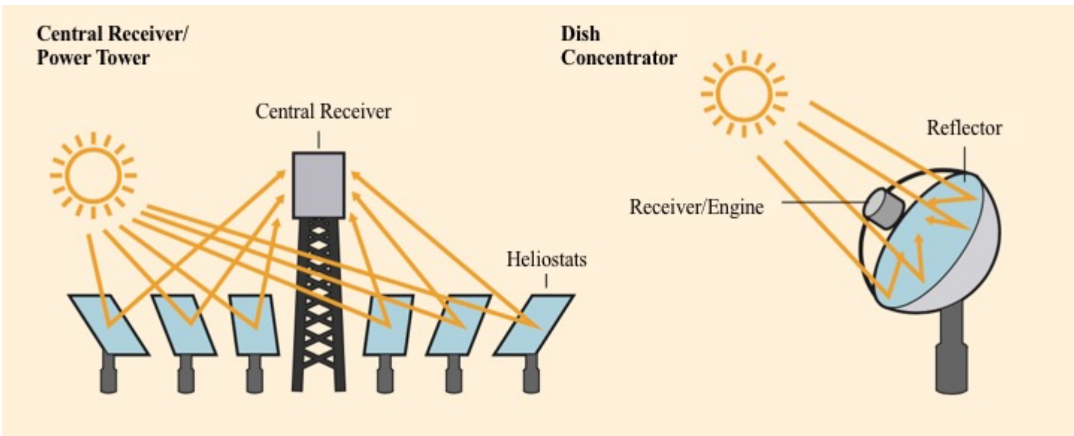


Figure 12: Point-focus Type Configurations of CSP Systems (IPCC, 2012, p. 156)

There are various advantages for CSP technologies. One of the main advantages of CSP is that the system capacity can have a wide range. CSP applications range from small distributed systems to large centralized power stations. The size of the site can be adjusted to the conditions and types of applications. Also, some of the components of CSP technology are modular and scalable. The materials required for this technology are common and accessible. In addition, thermal storage is possible in CSP technologies which is advantageous for peak loads (except for dishes). In thermal storage, the heat collected is stored before reaching the turbine. The heat in the storage unit can be used later to generate steam for electricity generation. The investment costs of CSP plants may differ because of the varying levels of thermal storage used in the system. As the size of the thermal storage increases, the installation costs increase. However, benefits of the CSP plants with high thermal storage capacity are more than CSP plants with low thermal storage capacity or without thermal storage. Furthermore, the CSP technologies are still improving and installation costs are expected to decrease. With the learning rate of the technology, almost 10% of decrease in investment costs is expected by 2050. There are options for new mirror materials, receiver designs, tower designs, size and number of heliostats, and new thermodynamic cycles. (IEA, 2014; IPCC, 2012, pp. 155-158.)

2.3 Solar Thermal Energy Technology

Solar thermal energy can be classified as active solar heating and cooling technologies, and thermal storage. In solar heating, solar irradiance is transformed into heat with solar collectors and the heat is transferred with a carrier fluid to a storage tank which is insulated to store heat. The carrier fluid stores the thermal energy to be used when it is needed. There are two important factors for the selection of solar collectors, which are type of service required for the collector and suitability of the temperature range of the carrier fluid for the system. This technology can be adjusted according to the climate of the area that the system will be installed. The collectors used for solar heating are flat-plate collectors and evacuated-tube collectors. Flat-plate collectors are mainly used for residential water- and space-heating systems. Generally, the parts of flat-plate collectors are an absorber, a header and riser tube arrangement or a single serpentine tube, a transparent cover, a frame, and insulation. A schematic diagram for a flat-plate collector is provided in Figure 13. The absorber can be installed as a single plate if required temperature for the application is low. Flat-plate collectors have a good price/performance ratio and a wide range of installation possibilities. The other type of collector, which is evacuated-tube collectors, is basically installed as parallel rows of glass tubes. The absorbers are enclosed in these transparent glass tubes and connected to a header pipe. Figure 14 illustrates an evacuated-tube collector. In this system, two heat transfers occur between liquid heated with solar energy in glass tubes and heat absorber pipes, and heat absorber pipes and liquid in the header pipe. Heated liquid in the header pipe is used for heat transfer for domestic hot water or space-heating system. The air in the collector tubes is pumped out to prevent heat loss and to allow system to achieve high temperatures, which makes the system useful for cooling or industrial applications. Solar water-heating is also a solar heating system, which is used for hot water production. Active and passive solar water heater are two types of this system. In passive solar water heaters, the water is heated with solar collector and stored inside the collector. It can also be stored in a separate storage tank located above the collector, which is called a thermosyphon (TS) system. For passive solar water heater, a schematic diagram for an indirect TS system is provided in Figure 15. This system is user-friendly and has low cost, however, it is not the best technology for climates with freezing temperatures. In active solar water heaters, carrier fluid circulation is controlled with electric pumps and controllers. An example for active solar water heater is shown in Figure 16. There are three types of configurations for this system, which are direct circulation system, antifreeze indirect circulation system and drain-back indirect circulation system. (IPCC, 2012, pp 346-349.)

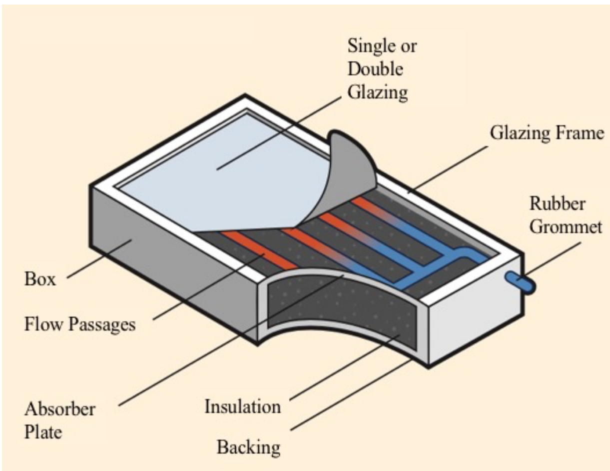


Figure 13: Schematic diagram for a flat-plate collector (glazed flat-plate collector) (IPCC, 2012, p. 347)

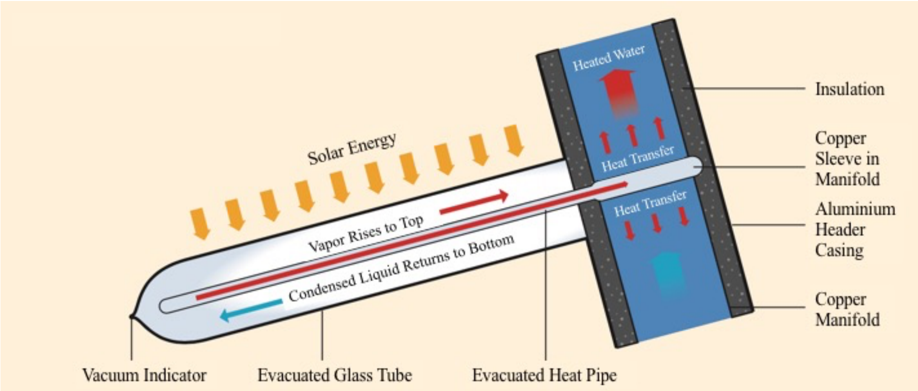


Figure 14: Schematic diagram for an evacuated-tube collector (IPCC, 2012, p. 347)

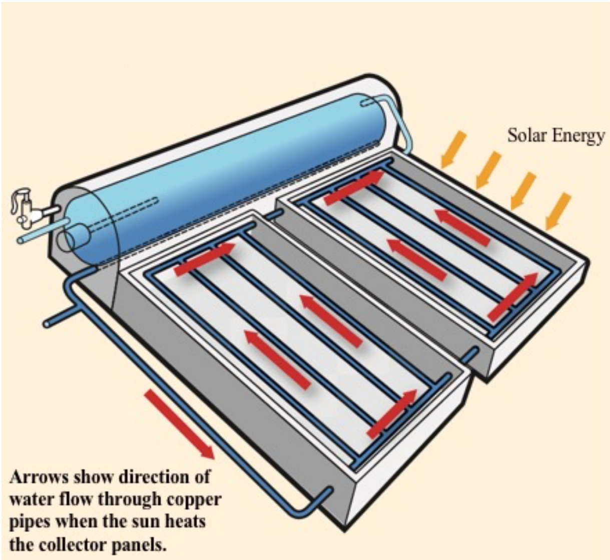


Figure 15: Schematic diagram for passive solar water heater (indirect TS system) (IPCC, 2012, p. 348)

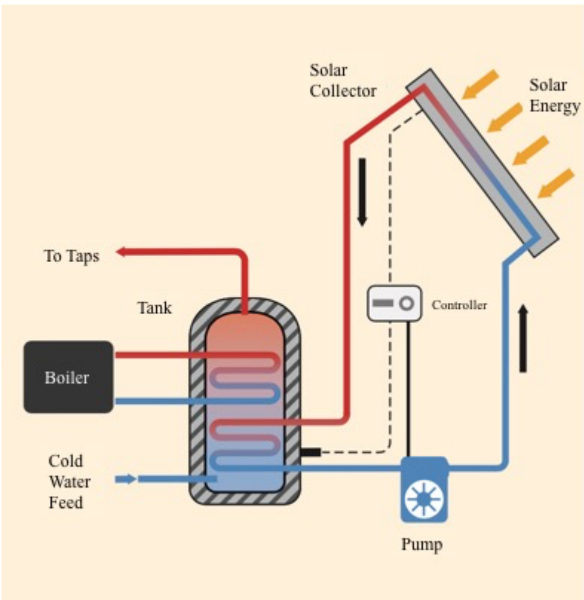


Figure 16: Schematic diagram for active solar water heater (antifreeze indirect circulation system) (IPCC, 2012, p. 348)

Solar cooling technologies can be classified under three categories, which are solar electric refrigeration, solar thermal refrigeration and solar thermal air conditioning. In the solar electric compression refrigeration system, PV panels are used for the power need of conventional refrigeration machines. In the solar thermal refrigeration system, solar thermal energy is used to produce refrigeration effect with solar mechanical compression, solar absorption or solar adsorption refrigeration. Finally, solar thermal air conditioning is the system for dehumidification of the air in air-conditioning units, by using solar thermal energy. (IPCC, 2012, p. 349.)

The other type of technology for solar thermal energy is thermal storage which leads to reliability and efficiency in solar thermal systems. Thermal storage technologies can be classified as sensible, latent, sorption and thermochemical. In sensible heat storage system, a material with a heat capacity is used. Generally, water is used for heat storage in the market. Latent heat storage stores the energy generated from a phase change of a material. This storage technology is more compact than sensible heat storage with water. In sorption heat storage, a sorption material is used either for absorption or adsorption to store heat transferred from water vapour. This technology has higher heat storage capacity than sensible heat storage with water. Thermochemical heat storage uses endothermic chemical reaction to store heat. Typically, chemicals used in this technology have 8 to 10 times higher storage capacity than water. Beside these storage technologies, underground thermal energy storage is also used for seasonal storage of heat or cold, generally by using a natural underground layer. (IPCC, 2012, pp. 349-350.)

3 ENERGY SECTOR IN TURKEY

Turkey is a developing OECD country which is located between 36-42 north latitude and 26-45 east longitude with a surface area of 785.350 km^2 (Kick, 2011, p. 20; The World Bank, 2016). In Figure 5, the location of Turkey is marked with a circle on the map. Agricultural and forest land represent 49,7% and 14,9% of total land respectively. The rest of the land is used for other purposes. The total population was 78,67 million in 2016 and the population growth rate 1,05% per year for last fifteen years. In 2015, 73,39% of the total population represented the people living in urban areas. The country has the 18th largest economy in the world. The GDP was 856 billion USD in 2016, which was equal to 10.807USD/capita. In 2016, the percentage of value added from agriculture, industry and other services to the GDP were 6,1%, 28,5% and 65,5% respectively. (CIA, 2016; The World Bank, 2017.)

From 2002 to 2012, urbanization in Turkey increased drastically which opened the country to foreign economic and financial interactions. This situation leaded to an upgrade of various Turkish laws and regulations with European Union (EU) standards. However, the improvements have lost acceleration after 2012. Between 2015 and 2016, the growth rate of Turkish economy has decreased from 6,1% to 2,9%. Furthermore, the unemployment rate has increased in these years. The estimated unemployment rate was 10,9% in 2016. In addition, the influx of 3 million Syrian refugees in 2015-2016 created new social, economic, and political demands. Also, political challenges and terror attacks made Turkey's financial situation more complicated. In this challenging environment, energy sector is one of the most negatively affected sectors in Turkey. Turkey is mainly dependent on fossil fuels imported from other countries. Furthermore, gasoline and diesel pump prices increased due to global oil prices and the depreciation of Turkish lira. Besides, Turkey is party to international agreements on the environment, such as air pollution, Antarctic treaty, biodiversity, climate change, desertification, endangered species, hazardous wastes, ozone layer protection, ship pollution, and wetlands. Also, Turkey has environmental issues about water pollution, air pollution in urban areas and deforestation within its boundaries. Energy technologies play an important role on these issues that Turkish government should emphasize on. (CIA, 2016; The World Bank, 2017.)

Turkey should aim to raise the share of solar, wind, biomass and geothermal energy between energy resources to increase security and self-dependency in energy sector. Between primary energy resources, the share of renewable energy installed capacity has increased from 32,5% to 43,4% from 2006 to 2016 (TEİAŞ, 2017). However, there is lack of renewable energy policies to support and increase renewable energy usage in energy sector. In addition, the country continues to be dependent on energy resources imported from other countries, while global oil prices continue to rise. Beyond these problems, it is still considered that the stability of the energy sector can be assured by increasing gas storage and deploying three new nuclear power plants, instead of investing on renewable energy resources. (The World Bank, 2017.)

3.1 Energy in Turkey

The main drivers for energy sector in Turkey are the need of new capacity to meet the energy demand, supply security and the increase of renewable energy share. The biggest challenges for these improvements are costs and availability of finance. Despite these challenges, Turkish energy sector showed a noticeable progress in last ten years. Policy updates were made and the electricity sector was started to be liberalized and privatized. With significant reforms, private investments on electricity generation and distribution increased in last ten years, which secured energy supply to the consumers. However, Turkish energy sector is still dependent on imports of energy resources. The deployment of three nuclear power plants are planned to decrease the country's energy dependency. (IEA, 2016, pp. 9-17.)

In 2015, total primary energy consumption was 1.527,25TWh. Only 14,4% of total primary energy consumption was met by renewable energy resources. On the other hand, the total primary energy consumption was 1.427,7TWh in 2014 and 75% of it was met by imported fuels: 24,7% of the total supply of energy was met by oil products, 33,4% by natural gas and 32,1% by coal. In 2014, the share of renewables in total energy supply was only 9,8%. (World Energy Council, 2016, p. 14.) In one year, between 2014 and 2015, the share of renewable energy consumed increased by 47,3%. But still, 85,6% of the total energy consumption was met by fossil fuels in 2015. Figure 17 represents the distribution of energy consumption by energy resource in 2015. (BP, 2016.) According to the latest data, the final energy consumption percentages between sectors are represented for the year 2014 in Figure

18. Between the sectors, industry had the highest level of energy consumption. The sector which used renewable energy most was residential. In 2014, the 60% of the renewable energy was consumed by residential, 22% consumed by industry, 11% consumed by commercial, 2% consumed by transport and 5% consumed by other sectors. Final renewable energy consumption by technology in 2015 is represented in Figure 19. This figure shows that solar PV has the lowest share between other technologies. (IEA, 2017; IRENA, 2017b; EMO, 2017.)

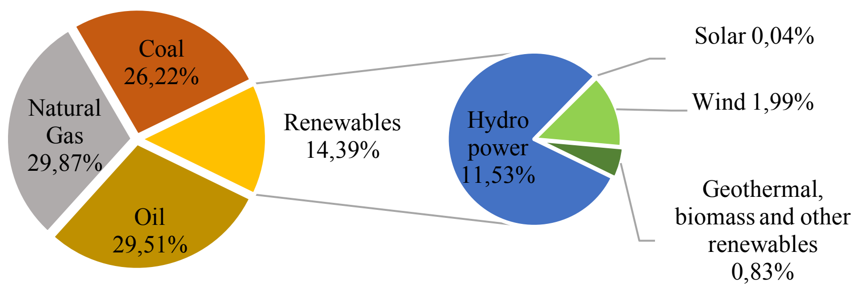


Figure 17: The Distribution of Energy Consumption by Energy Resource in 2015 (BP, 2016)

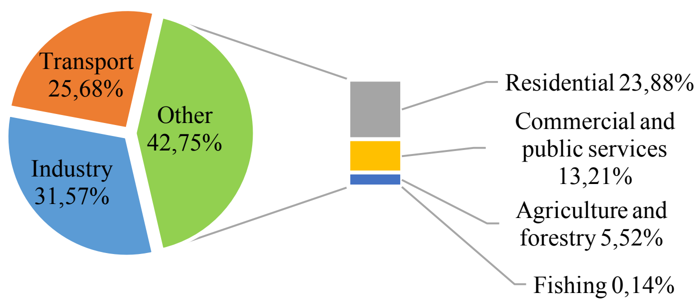


Figure 18: Final Energy Consumption by Sector in 2014 (IEA, 2017)

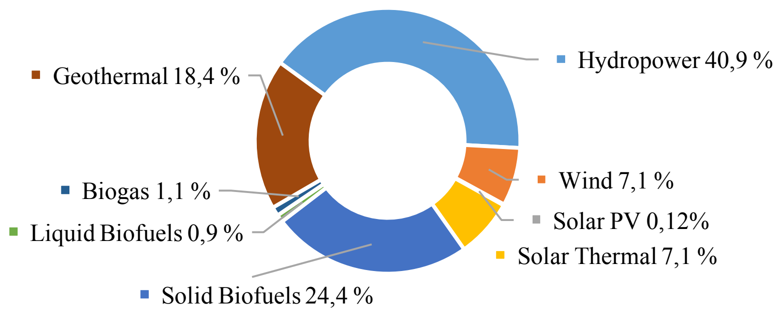


Figure 19: Final Renewable Energy Consumption by Renewable Energy Technologies in 2015 (IRENA, 2017b)

The primary energy supply can be found by summing up energy production and energy imports, subtracting energy exports and international bunkers, and adding or subtracting the stock changes (OECD, 2016). As mentioned before, the primary energy supply of Turkey is formed by oil, natural gas, coal and renewable energy. The distribution of total primary energy supply (TPES) between energy resources for the year 2014 was presented in Figure 20, while showing the distribution of TPES between sectors. This figure shows that 43,8% of TPES was used to generate electrical energy. In addition, 41% of electrical energy was generated by natural gas, 41% by coal and 6% by oil. Only 12% of the electrical energy was generated by using renewable energy. Turkey is highly dependent on imported fossil fuels. This situation makes energy generation in Turkey very expensive. (World Energy Council, 2016, p. 14.)

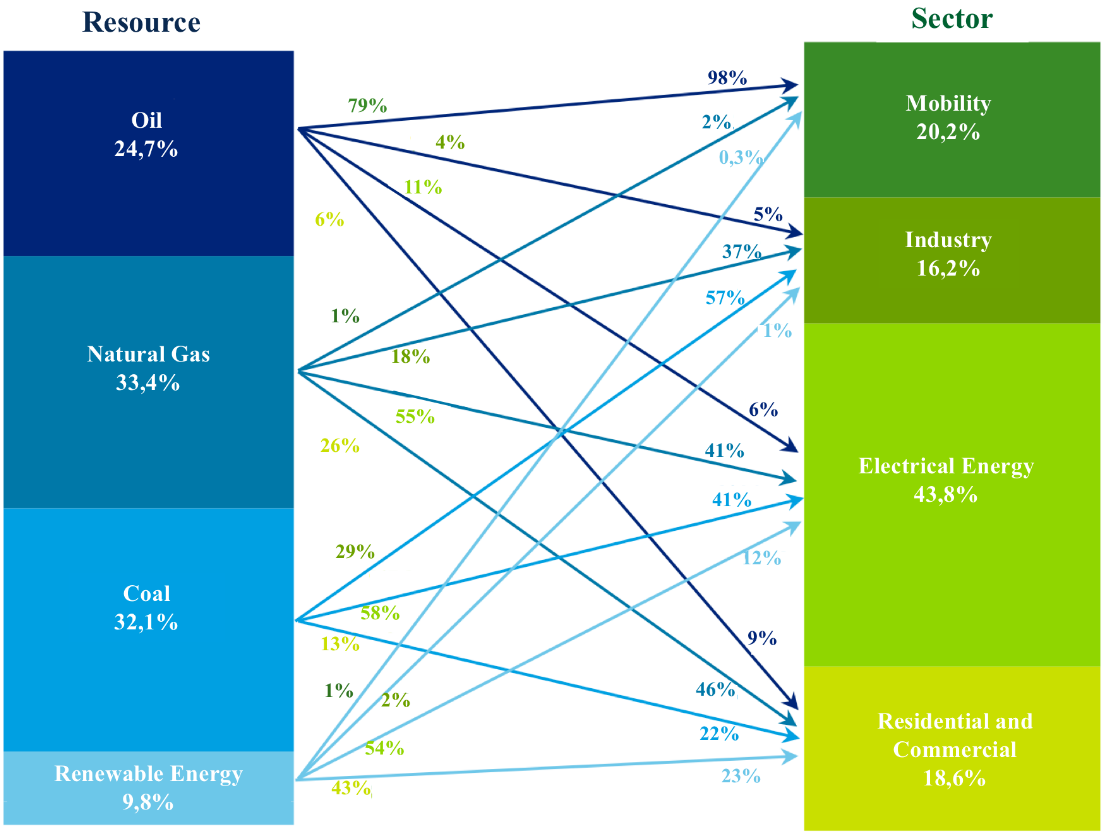


Figure 20: TPES of Turkey in terms of Resource and Sector in 2014 (Modified from World Energy Council, 2016, p. 14)

The energy sector in Turkey has been privatized since 2010, which leads to a significant progress. The liberalization and privatization of electricity generation and distribution increased the amount of private investments and results with increase of generation capacity and energy access security. (IEA, 2016 pp. 9-17.) For the Turkish energy sector, the total energy demand has increased and the total installed capacity has improved as well as the total electricity generation. The improvement of total installed capacity and total electricity generation can be seen in Figure 21. This graph represents the total installed capacity of renewable energy resources for the years 2006-2016 and total electricity generation from renewable energy resources for the years 2006-2015. Between the years 2010 and 2016, the total installed capacity increased from 49,52GW to 78,5GW. Even if the share of renewable energy resources has increased in the last decade, it only represents 43,4% of the total installed capacity, which is 34,08GW in 2016. The share of renewable energy in installed capacity is high. However, the TPES for electricity is still met by fossil fuel energy technologies. The reason of this difference is that renewable energy is not preferred because of its intermittent nature. In addition, Turkey mostly uses fossil fuels for meeting heat demand. Between renewable energy technologies, hydropower has the highest rate of investments and the reason of renewable share increase in installed capacity is hydropower investments. However, other renewable energy resources did not increase as noticeable as hydropower. In 2015, gross electricity demand was 265.724,4GWh. 261.783,3GWh was generated nationally, 7.135,5GWh was imported and 3.194,5GWh was exported. The renewable energy generation only represents 32,15% of the total electricity generation in 2015. As mentioned before, Turkey has an energy sector highly dependent on fossil fuels. The distribution of Turkey's installed capacity by primary energy resources in 2016 can be seen in Figure 22. In this distribution, waste energy is excluded from renewable energy capacity. 56% of total installed capacity represents the fossil fuels. As it can be seen in Table 3, the amount of fossil fuels used still increases year by year, even if the share of fossil fuels has decreased. In addition, the high amount of fossil fuels for this capacity is imported from other countries. (TEİAŞ, 2017.)

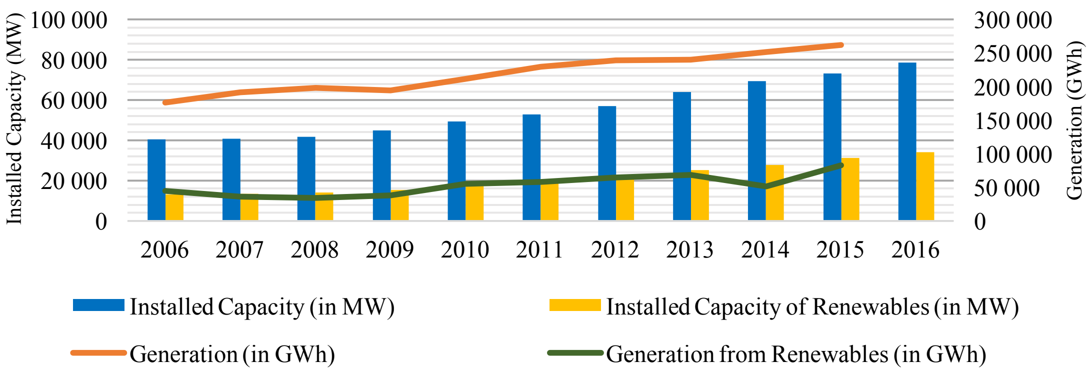


Figure 21: Annual Development of Turkey’s Installed Capacity and Generation (TEİAŞ, 2017)

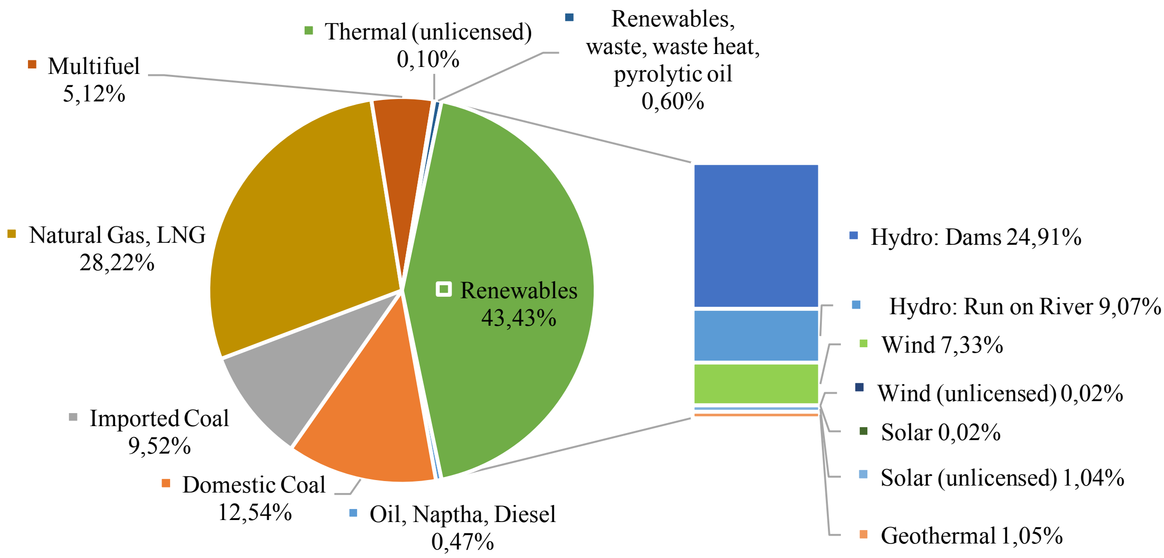


Figure 22: The Distribution of Turkey's Installed Capacity by Prımary Energy Resources in 2016 (TEİAŞ, 2017)

Table 3: Turkey's Installed Capacity by Primary Energy Resources for the Years 2005 - 2016 (TEİAŞ, 2017)

	2005 (in MW)	**% in total**	**2016 (in MW)**	**% in total**
Coal	9.116,8	23,47 %	17.316,3	22,06 %
Liquid Fuels	2.505,7	6,45 %	368,7	0,47 %
Natural Gas	10.976,2	28,26 %	22.156,1	28,23 %
Renewable + Waste + Waste Heat	35,3	0,09 %	467,4	0,6 %
Multi Fuel	3.268,3	8,41 %	4.021,1	5,12 %
Hydro	12.906,1	33,23 %	26.681,1	33,99 %
Geothermal	15,0	0,04 %	820,9	1,05 %
Wind	20,1	0,05 %	5751,3	7,33 %
Solar	0,0	0,00 %	832,5	1,06 %
TOTAL	38.843,5	100 %	78.497,4	100 %

As it is mentioned before, fossil fuels represent 56% of Turkey's total installed capacity in 2016. Oil consumption in Turkey was 450,7TWh in 2015, which was 12,6% higher than the oil consumption in 2014. According to the latest data, 65,4% of the oil products was consumed by transportation sector in 2014. The equivalent of 456,24TWh of natural gas was consumed in 2015 and this value was 2,4% lower than the previous year's natural gas consumption. The biggest consumers for natural gas in 2014 were industry and residential sectors, with a share of 43,4% and 39,5% respectively. There are no proved reserves for oil and natural gas in Turkish territory. Thus, all the oil and natural gas consumption was met by imports from other countries. The natural gas can be imported either by pipeline or as liquefied natural gas. In 2015, the total amount of natural gas imported by pipeline was 39,69 billion cubic meters and 67% of imported natural gas was from Russian Federation, 19,7% was from Iran and 13,3% was from Azerbaijan. The total import of liquefied natural gas in 2015 was 7,49 billion cubic meters and the biggest sources for these imports are Algeria, Qatar and Nigeria. Turkey exports some part of the imported natural gas. Table 4 represents the gas trade in Turkey in years 2014 and 2015. Moreover, the project called Trans-Anatolian Natural Gas Pipeline (TANAP) will lead Turkey and EU to gain access to new natural gas sources from Azerbaijan, the Eastern Mediterranean and Middle East regions in future. The project will be completed by 2018-2019 and will give Turkey an important role in gas trade by pipelines. Between fossil fuels, Turkey has a significant reserve only for coal. In 2015, 46,17 million tonnes of coal have been produced in Turkey and the production in 2015 was 29,2% lower than the production in 2014. At the end of 2015, total proved reserves for coal were 8702 million tonnes, of which 3,7% was anthracite and bituminous, 96,3% was sub-bituminous and lignite. With this level of coal reserves, the remaining reserves will last 191,96 years, if the production continues at the level of 2015. On the other hand, total coal consumption was 400,42TWh in 2015, which was 4,7% lower than the consumption in 2014. In 2014, coal was consumed mostly by industry sector with a share of 52%. Commercial and public services had a share of 30%. Turkey is also planning to install three nuclear power plants in the next decade but currently, there is no active nuclear power plant in Turkey. (BP, 2016; IEA, 2016, pp. 71-129; IEA, 2017.)

Table 4: Gas Trade in Turkey in 2014 and 2015 (in billion cubic meters) (BP, 2016)

2014				**2015**			
Pipeline imports	**LNG imports**	**Pipeline exports**	**LNG exports**	**Pipeline imports**	**LNG imports**	**Pipeline exports**	**LNG exports**
41,09	7,26	0,58	0	39,69	7,49	0,57	0

Renewable energy resources gained importance in Turkish energy sector in the middle of 1980s. Between renewable energy resources, hydropower has been the highest share as installed capacity through years. Year by year, the share of other renewable energy resources also increased. Figure 23 represents the development of installed renewable energy capacity of Turkey between the years 2006 and 2016. The share of renewable energy resources other than hydropower started to exist in Turkish energy mix in 1984. But still, hydropower has the highest share as installed renewable energy capacity. In 2015, 176TWh of energy consumption was met by hydropower and this amount was 64,6% higher than the previous year's hydropower consumption. Hydropower installed capacity was 34% of the total installed capacity in 2016. Consumption of wind energy has also increased by 35,6% between the years 2014 and 2015. In 2015, wind energy consumption was 30,4TWh. Besides, wind energy installed capacity was 7,33% of the total installed capacity in 2016. For solar energy, only 0,65TWh of total energy consumption was met by solar technologies in 2015. The amount of solar energy consumed in 2015 was 3,29 times higher than 2014 solar energy consumption levels. The total installed capacity share of solar energy was 1,06% in 2016. Lastly, geothermal, biomass and other renewable energy resources were used to meet 12,7TWh of the total energy consumption in 2015. Besides, the total installed capacity of other renewable energy resources share was 1,64% in 2016. (BP, 2016; TEİAŞ, 2017.)

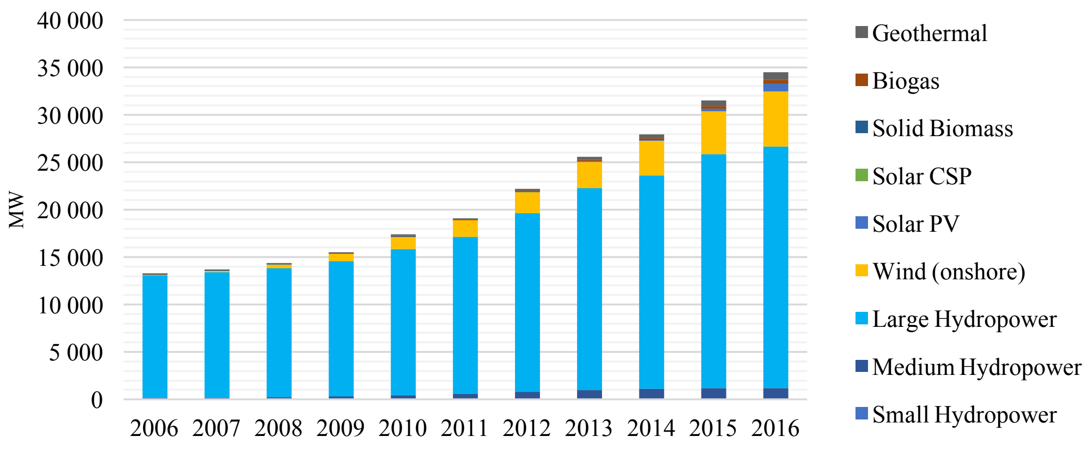


Figure 23: Installed Renewable Energy Capacity between the years 2006-2016 (IRENA, 2017c)

Dependency on fossil fuels makes energy generation in Turkey very expensive. High percentage of energy consumption is met by fossil fuels and Turkey only has coal reserves as fossil fuel. Before the implementation of cost-based energy pricing mechanism in 2008, increasing demand and imported gas prices with constant retail electricity prices leaded Turkish energy sector to face with financial challenges. The energy sector has faced risk of blackouts, limits on funding for new investments and discouragement of private investors. After the adjustments on tariffs, financial recovery has been achieved with cost-based energy pricing mechanism. However, increasing fossil fuel prices in global level leaded to increase of Turkish energy prices, as the sector is highly dependent on fossil fuels. In addition, gasoline and diesel retail prices are one of the highest between OECD countries due to high tax levels. In Figure 24, tariffs for residential, industrial, commercial and wholesale consumers between the years 2006 and 2014 are represented in terms of kuruş (kr) per kWh, which is Turkish lira subdivided into 100. The tariff is constituted by energy costs, distribution and transmission costs, cost of loss and thefts, funds and taxes. For example, tariff for residential consumers is composed of 59% of energy costs, 12% of distribution and transmission costs, 9% of loss and theft costs, and 20% of funds and taxes. Compared to other countries located in Eastern Europe and Central Asia, Turkish electricity price is very high. (The World Bank, 2015, pp. 121-127.)

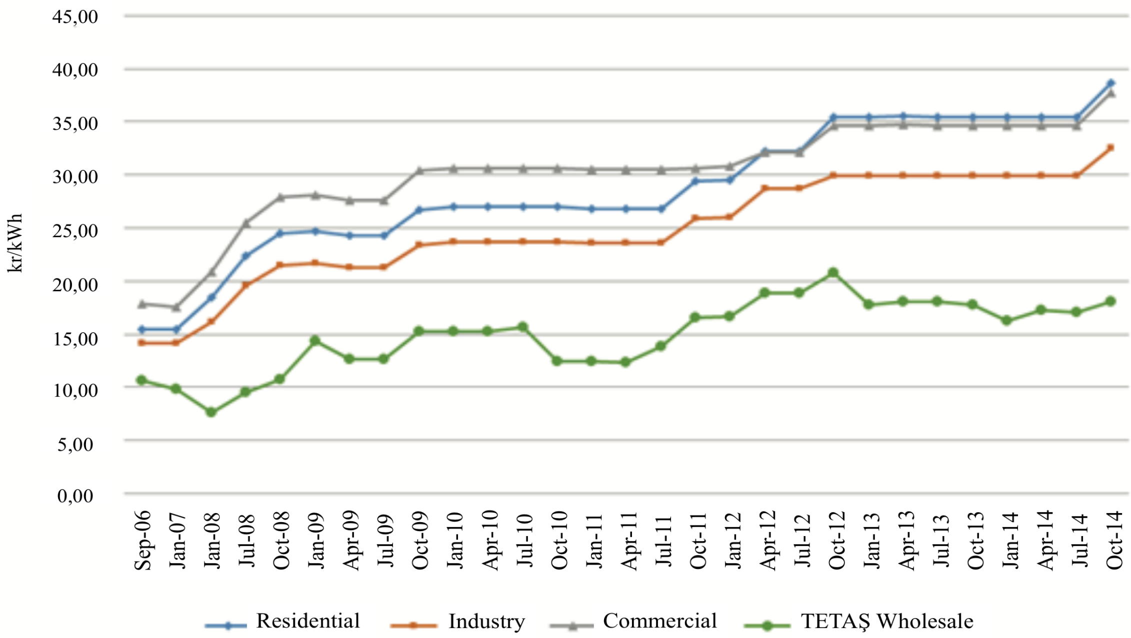


Figure 24: Residential, Industry, Commercial and Wholesale Consumer Tariffs between 2006 and 2014 (The World Bank, 2015, p. 74)

Economy growth in Turkey leads to increase in energy usage. However, inefficient energy technologies cause high level of energy intensity. The definition of energy intensity is the ratio of TPES divided by unit of GDP adjusted for the purchasing power parity. Between European countries that are International Energy Agency (IEA) members, Turkey's energy intensity is the 12th lowest. However, calculated energy intensity of Turkey has been increased by 7,1% between the years 2005 and 2015, while the energy intensity of other European IEA countries was decreased by 16,3% in the same period. Energy efficiency is directly related with energy intensity and Turkey has a great potential for energy efficiency improvements in various ways. According to the analysis made by the World Bank, there is a potential for energy savings in industry, transport and household sectors. In 2015, the potential of total savings for these sectors were calculated as 191,89TWh relative to 2009. This amount of energy can be represented as EUR13,2 billion, in terms of economic value. Energy efficiency is one issue that Turkish Ministry of Energy and Natural Resources emphasizes on. The Energy Efficiency Coordination Board (EECB) is the institution which is responsible of preparation, revision, approval and coordination of strategies and plans related with the national energy efficiency. Responsibilities of EECB also includes the support for R&D projects and the control of their implementation. The most important target set by EECB is reduction of Turkey's energy intensity by 20% from 2011 levels, until 2023. This target aims the reduction of energy consumed per GDP by increasing energy efficiency. The aim is to increase efficiency in energy generation technologies, especially in production, transmission and distribution of electricity. Efficiency increase also helps to decrease energy losses and harmful emissions from energy generation processes. (The World Bank, 2015; IEA, 2016, pp. 47-50.) The improvement of energy efficiency may also lead to an increase in private investments on electricity market, and ensure cost effectiveness and supply security for the consumers (Bloomberg, 2014).

Turkish electricity market used to be a monopoly. After a reform on the market in 2001, liberalization occurred and private companies could present themselves in the market. After various regulation reforms about electricity market, an independent entity named the Energy Market Regulatory Authority (EMRA) was established in 2001. The main tasks of this authority can be listed as preparation and implementation of secondary legislations on electricity sector, authorization and control of market participants, formation of tariffs, audit for legal and financial issues of market, and improve of performance standards. However, the electricity pricing is still controlled by the government partially. Presently, there are four main companies in the market. They are partially owned by the state. In generation sector, EÜAŞ (Electricity Generation Company) is the operating company. TEİAŞ (Turkish Electricity Transmission Company) is the leading company in transmission sector. In distribution sector, TEDAŞ (Turkish Electricity Distribution Company) operates. Finally, TETAŞ (Turkish Electricity Trade and Contracting Company) is the active company who operates in wholesale trading sector. In Figure 25, the shift of installed capacity from public sector to private sector can be seen. However, even if the market is privatized, the Turkish state still has a noticeable role in the electricity sector, especially on generation and transmission. On the other hand, prior agreements are present between government and specific private power suppliers. This situation harms the prioritization of lower cost power generators in the market (Bloomberg, 2014). If the market liberalization can be increased, it may create a beneficial environment for renewable energy projects. The pricing of electricity in Turkish electricity market is made according to the costs of electricity generation, transmission and distribution. The pricing does not change from region to region. However, some regions have higher transmission and distribution losses. Besides, 15,7% of the total electricity is assumed as loss or stolen approximately in 2014. 2,5% of losses were transmission related and 12,6% of losses were distribution related. Furthermore, the electricity theft is high in specific regions. However, thefts and losses are reflected to the overall pricing of Turkish electricity, which makes the pricing mechanism imbalanced between consumers. (Bavbek, 2015, TEİAŞ, 2017.)

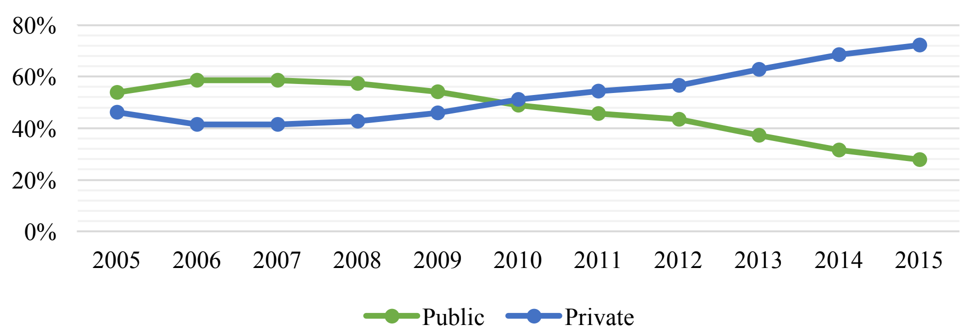


Figure 25: The Distribution of Turkey's installed Capacity by the Public and Private Sectors (TEİAŞ, 2017)

In Turkish electricity industry, there are twenty-one distribution companies with their own region. These companies are responsible of electricity distribution and connection services, without discrimination between system users. Also, it is their responsibility to read users' meters and prepare regional demand projections. These companies are obliged to buy the electricity from TETAŞ to compensate loss or theft of electricity. On the other hand, TEİAŞ is the responsible company for transmission operation. The duties of TEİAŞ are operating the transmission of electricity through the country, and maintaining and developing transmission facilities. Energy transferred over the transmission system developed over years. At the end of 2015, total length of transmission network was almost 57,000km and 100% of the population has access to electricity. In 2015, 96,6% of the investments in electricity sector is spend for transmission facilities. Long power interruptions were rare in this sector until 2015. Turkey experienced a power interruption in March 2015, which lasted 10 hours. The reason of this blackout was the tripping of a 400kV transmission line which caused disconnection of the Turkish grid from the Continental European grid. (IEA, 2016, pp. 26-27; TEİAŞ, 2017.)

Turkey's emission levels are in a critical level. Fuel combustion represents high share of Turkey's installed capacity and emits high amount of GHGs. Between sectors, energy sector has the greatest role of 72,5% in Turkey's GHG emissions in 2014. Transport and power generation sectors are mainly responsible for this amount of emissions. It is possible to reduce emission levels by using more efficient energy technologies. Thus, increasing the energy system efficiency and increasing the share of renewable energy resources may solve the GHG emission problem. Unfortunately, Turkey still has an electricity sector reliant on coal-fired power plants. Turkey has low quality coal reserves with high amount of air pollutants. In addition, most of the coal is imported from other countries. Coal-fired power plants also cause local air pollution which creates concerns for air pollution in the large cities. In 2014, 81,4 of total emitted GHG was Carbon Dioxide (CO_2), 12,1% was methane (CH_4), 5% was Nitrous Oxide (N_2O) and 1,1% was hydrofluorocarbons (HFCs). Between the years 2005 and 2015, CO_2 emissions were increased drastically. CO_2 emissions increased from 4,12 to 4,24 metric tonnes per capita between the years 2010 and 2015. Furthermore, the emitted CO_2 amount increased by 1,1% from 2014 to 2015. Escalation of CO_2 emission levels in ten years can be seen in Figure 26. Since the greatest emitter of CO_2 is power sector, emission levels are expected to increase with the usage of current technologies. Turkey aims to reduce its GHG emissions by 21% until 2030. In 2012, the National Climate Change Action Plan of Turkey (NCCAP) was published for the period of 2011 and 2023. NCCAP was published and declared 541 actions for combatting climate change. However, the plan consists of only monitoring reports and it does not contain any assessment about progress of these actions. NCCAP defined the reduction of harmful emissions and air pollutants as a goal and measure. In NCCAP, emissions to be reduced include Nitrogen Oxides (NO_x), Sulphur Dioxide (SO_2) and PM from road transport usage, coal-fired power plants and industrial facilities. Various coal-fired power plants have been upgraded to supercritical technology, meaning that they can reach supercritical steam pressures. However, there are still coal-fired power plants which operate under critical pressure levels and these plants continue to emit air pollutants such as dioxins and heavy metals. Figure 27 represents the map of thermal power plants in Turkey. The map shows the type of energy resource used in and the installed capacity of each plant. Figure 28 and Figure 29 show particulate matter with 10µm (PM_{10}) and particulate matter with 2,5µm ($PM_{2,5}$) emission maps of Turkey. The relation between these three figures shows the effects of coal-fired power plants on the air pollution in Turkey. As it can be seen from the maps, both PM_{10} and $PM_{2,5}$ emissions are higher in provinces that contain coal-fired power plant. (IEA, 2016, pp. 33-36; BP, 2016; The World Bank, 2017.)

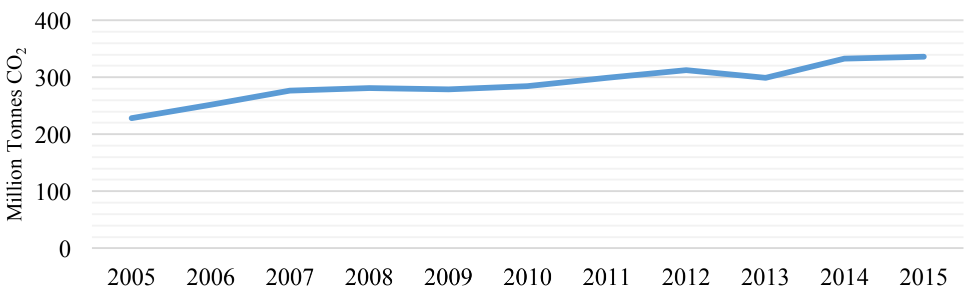


Figure 26: CO_2 emission levels between 2005 and 2015 in Turkey (BP, 2016)

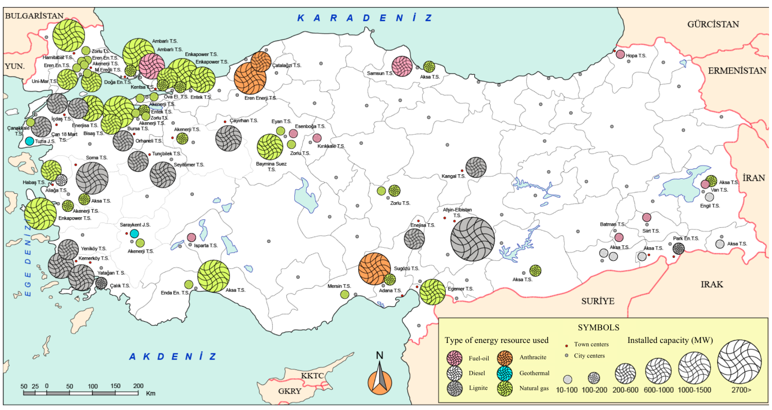


Figure 27: The Map of Thermal Power Plants in Turkey (Saygılı, 2014)

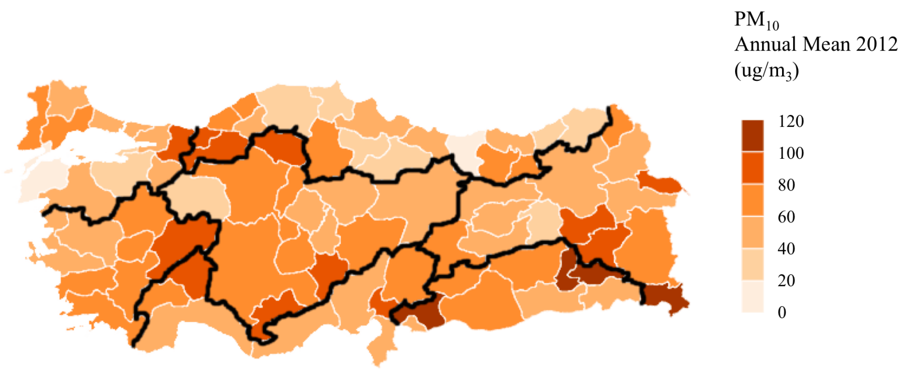


Figure 28: PM_{10} emissions in Turkey by province in 2012 (WHO, 2013)

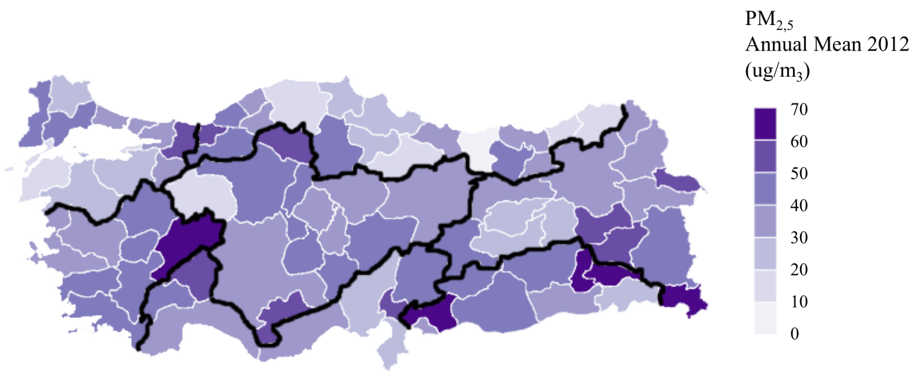


Figure 29: $PM_{2,5}$ emissions in Turkey by province in 2012 (WHO, 2013)

3.2 Targets and Strategies of Turkish Energy Sector

The Turkish government adopted energy targets for 2023 and 2030 with some strategies and action plans about energy efficiency, renewable energy and climate change. With these targets, Turkey aims for a more sustainable energy system. Even though Turkey has a strong potential for renewable energy technologies, Turkey is planning to complete the construction of its first nuclear power plant in 2019. Turkey is trying to decrease fossil fuel usage by focusing on nuclear power, despite its potential for renewable energy. Besides, current integration rules and network upgrades are not sufficient for the distributed generation from renewable energy technologies. On the other hand, there are targets and support policies for renewable electricity. As a support, renewable energy law exists, as well as some targets and feed-in tariffs. However, the energy sector lacks adequate quotas, capital grants, subsidies, soft loans, tax relief, tradable green certificates, and carbon pricing or auction schemes. (IEA, 2015b; Bavbek, 2015.)

It is forecasted that Turkey will have high economic growth rates for next several years. As economic growth is directly related with energy demand increase, security for demand response is very important for Turkey. In Figure 30, forecast done by TEİAŞ shows the expected electricity consumption increase between the years 2017 and 2023. It is critical for Turkey to meet the expected demand without any interruption. Turkish energy policies have been defined according to principles of transparency, reliability, cooperation, efficiency, coherency, innovation and pioneering. With the light of these values, The National Renewable Energy Action Plan (REAP) for Turkey has been created. REAP is based on main strategic energy guidelines provided by different Ministries of the Turkish Government. These guidelines are Electricity Energy Market and Security of Supply Strategy Paper, Climate Change Action Plan 2011-2023, Energy Efficiency Strategy Paper 2012-2023, and The Republic of Turkey Ministry of Energy and Natural Resources Strategic Plan 2010-2014. The objective of REAP is to promote the development of renewable energy in Turkey with some strategies. One of the strategies is to increase the share of renewable energy capacity by 30% until 2023. Other strategies are increasing the usage of renewable energy in transportation sector, supporting the development of renewable energy based on higher installed capacities by 2023, usage of renewable energy as a solution for sustainability and climate change, development of a framework to increase the usage of distributed generation technologies, and avoiding any obstacles that can hinder renewable energy sector's progress. One of the most important mechanisms created to support renewable energy sector is Renewable Energy Resources Support Mechanism (YEKDEM). This mechanism introduces a "renewable pool" that renewable energy producers participate by supplying their energy generation into the pool. The suppliers are compensated by distributing the total cost of electricity supply to the pool. By introducing the "renewable pool" system instead of direct purchase from generators, renewable energy producers are supported with increased competition by rewarding them according to their efficiency. However, since electricity generators that use fossil fuels are not included into the same pool and are directly contracted by the government, the renewable energy generators cannot compete these generators on an even field. Thus, this mechanism is an excellent first step to a renewable based energy sector in Turkey, but it has still more room to improve. (IEA, 2016; Deloitte, 2014; The World Bank, 2015.)

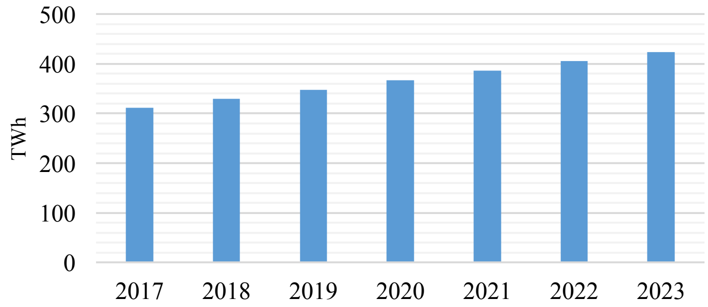


Figure 30: Forecasted Electricity Consumption in Turkey (TEİAŞ, 2017)

As it is mentioned before, Turkey has an emerging economy, which obligates the government to focus on energy savings from energy intensity. It is necessary for Turkey to reduce the final or primary energy consumption by increasing the efficiency in energy sector or using non-conventional energy resources. The main target of Turkish government is to reduce energy intensity at least 20% between the years 2011 and 2023. In the National Energy Efficiency Action Plan (NEEAP), various targets were mentioned under energy efficiency strategy. The targets include:

- Reduction of energy intensity and energy losses,
- Decrease of energy demand and GHG emissions of buildings,
- Promotion of sustainable buildings using renewable energy resources,
- Provision for market transformation of energy efficient products,
- Reduction of fossil fuel consumption in transportation sector by increasing public transportation usage,
- Increase of efficiency in many sectors related to energy such as production, transmission and distribution. (IEA, 2016.)

Turkey adopted some energy targets for 2023 under the Vision 2023, as an achievement for the centennial of the Republic of Turkey. Energy targets for 2023 include the endorsement of local energy resources and the increase of the renewable energy share in Turkish electricity mix. The energy intensity reduction with efficiency improvement by 20% below 2010 levels is aimed. It is aimed that the share of renewable energy in installed capacity will be 30% in 2023. In addition, a reduction of at least 20% is targeted for energy consumed per GDP until 2023. In Turkey, energy sector need to be evolved with consideration of energy demand increase and security. The sector improvements with new policies and targets may lead to sustainable economy growth. The government has been created targets, support policies and strategies for energy efficiency (EE), renewable energy (RE) and climate change. In 2016, the share of renewable energy in installed capacity was 43,4%, which is higher than the set target of 30% for the share in 2023. (IEA, 2016; Bavbek, 2015.)

The aims of the energy strategy of Turkish government are to satisfy the energy demand and decrease the dependency to the import of energy resources. The defined targets show that the dependency of imported energy resources is very important for Turkish energy sector. The targets set for the years 2023 and 2030 estimates that total installed capacity will be increased by 54,1% between 2016 and 2023, and 36,4% between 2023 and 2030. The targets also involve the capacity increase of both renewable energy resources and nuclear energy. National coal reserves are also considered as an alternative energy resource for imported fuels. As can be seen in Table 5, natural gas is the fossil fuel whose usage is tried to be minimized most between the years 2016 and 2023. The installed capacity of natural gas was decreased by 11,9% from 2015 to 2016 and the usage of natural gas for installed capacity is targeted to be stabilized until 2030. On the other hand, coal still has a high share in installed capacity until 2030. However, the coal reserves in Turkey are not sufficient to meet the target capacity. According to a research, to fully utilize its coal-fired power plants' capacity, Turkey will rely on imported coal (Bloomberg, 2014). This situation contradicts with the main purpose of the coal utilization, which was to decrease dependency on foreign energy resources. Coal usage also contradicts with the climate change targets, with its negative effects on the environment. Increasing the share of renewable energy resources in installed capacity play a larger role in addressing the climate change targets. Between renewable energy resources, wind and solar have the most significant increase until 2030. If these targets are set, more than 50% of the total installed capacity will be met by renewable energy resources. (Bavbek, 2015.)

Table 5: The capacity targets set out by the government for years 2023 and 2030 (in GW) (Bavbek, 2015; TEİAŞ, 2017)

	2015 (GW)	**Change of 2016 over 2015 (%)**	**2016 (GW)**	**Change of 2023 over 2016 (%)**	**2023 (GW)**	**Change of 2030 over 2023 (%)**	**2030 (GW)**
Total	73,15	→ 7,3% →	78,5	→ 54,1% →	121	→ 36,4% →	165
Coal	15,67	→ 10,5% →	17,32	→ 44,4% →	25	→ 40,0% →	35
Natural Gas	25,15	→ -11,9% →	22,16	→ 12,8% →	25	→ 0,0% →	25
Hydro	25,87	→ 3,1% →	26,68	→ 27,4% →	34	→ 0,0% →	34
Wind	4,50	→ 27,7% →	5,75	→247,8%→	20	→ 90,0% →	38
Solar	0,26	→234,4%→	0,83	→501,0%→	5	→220,0%→	16
Nuclear	0		0		9,6	→ 25,0% →	12
Other	1,72	→235,7%→	5,76	→ -56,6% →	2,5	→100,0%→	5

3.3 Solar Energy Technologies in Turkey

The deployment of renewable energy in Turkish energy sector was doubled between the years 2009 and 2014. However, after that period the share of renewable energy resources in energy mix stabilized. Electricity demand accelerated continuously and demand increase was met mainly by conventional energy resources. The government has specified a lot of targets for years 2023 and 2030, especially for renewable energy technologies. Besides, large potential for hydro, wind and solar power attracts the attention of investors. Especially, solar technology has a very fast growth rate for last years. In 2015, solar energy consumption was 0,65TWh and this amount was 329% higher than 2014 consumption levels. Moreover, a scenario of Greenpeace expects that the share of electricity generation from renewable energy resources will be 90% by 2050 and 47% of this will be from solar energy (Greenpeace, 2015). All things considered, the solar market in Turkey is still emerging and needs to be considered for a sustainable energy sector. (IEA, 2016; BP, 2016.)

Turkey is in the Mediterranean region which enables the country to have very high solar energy potential. Turkey has seven regions which are Marmara, Aegean, Black Sea, Central

Anatolia, Mediterranean, Eastern Anatolia and Southeast Anatolia Regions. Between these regions, Southeast Anatolia and Mediterranean are the regions who receives the highest level of solar irradiation throughout a year. The solar irradiation map with regions can be found in Figure 31. The average solar irradiation is calculated as 3,6kWh/m^2 per day yearly. Also, the total yearly radiation period is 2640 hours, which is equal to 7,2 hours per day on average. Figure 32 shows that the country receives the highest level of solar irradiation on July and the lowest level of solar irradiation on December. The figure also shows the average duration of sunlight for each month. The solar irradiation level in Turkey is more advantageous than most of European countries. The average solar irradiation level of Turkey is the fifth between European countries. In a research, Turkey's average solar irradiation was measured as 1527kWh/m^2. But still, Turkey only has PV system performance of 1420kWh/kW. Even the performance is very low compared to other countries, Turkey still has a potential for higher system performance for PV systems. (World Energy Council Turkish National Committee, 2009; Bavbek, 2015.)

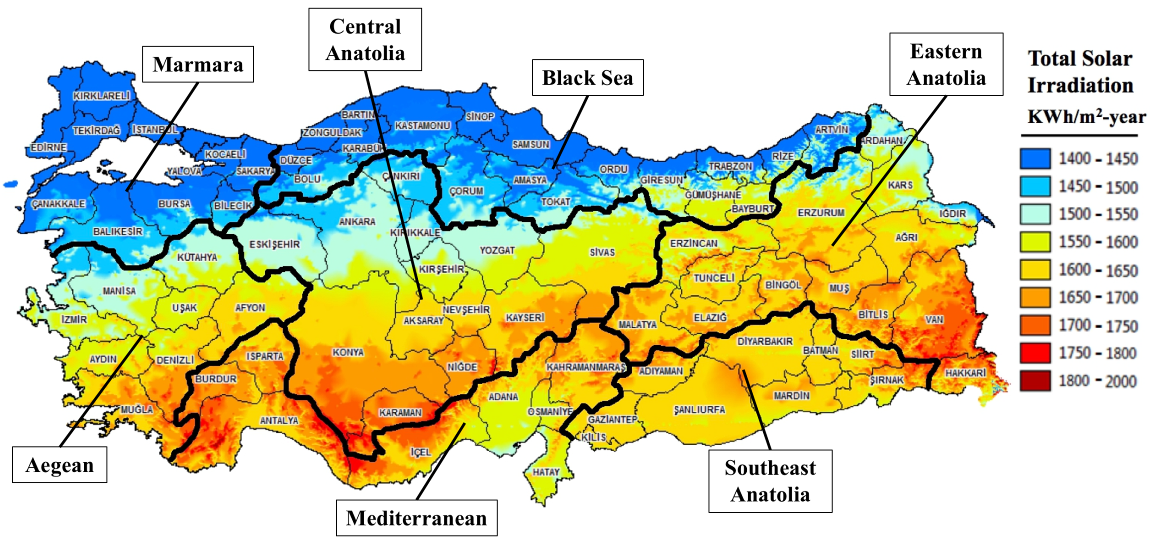


Figure 31: Total Solar Irradiation Map of Turkey (Yenilenebilir Enerji Genel Müdürlüğü, 2016)

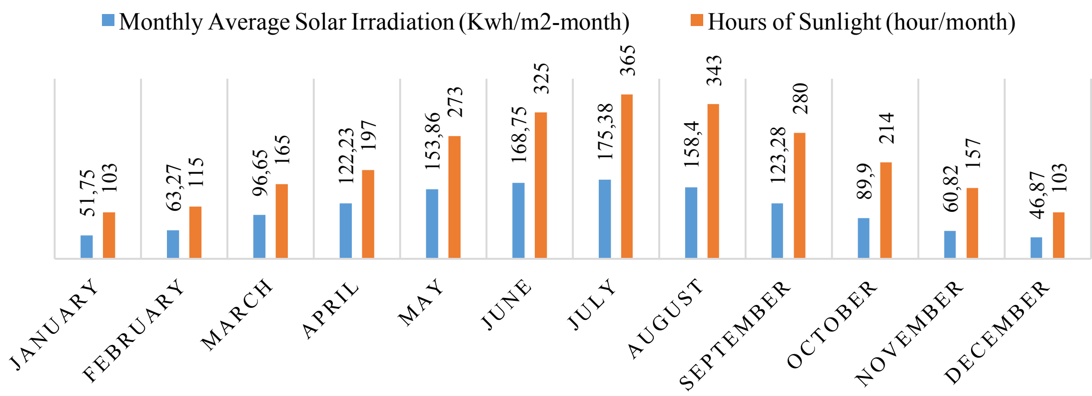


Figure 32: Monthly average Solar Energy Potential of Turkey (World Energy Council Turkish National Committee, 2009)

Solar energy consumption was 0,65TWh in 2015, which represented only 0,04% of total primary energy consumption. Despite the solar energy potential in Turkey, the share of solar energy in total installed capacity is still very low. The technologies used in Turkish solar market are PV solar power, CSP and solar water heating. At the end of 2016, total installed capacity for PV power and CSP were 832,5MW and 1MW respectively. Figure 33 represents the installed capacity of solar PV technology between the years 2006 and 2016. It also shows the total generation from this technology between 2006 and 2015. In 2015, total generation from solar PV in Turkey was 194,1GWh, which was 0,07% of Turkey's gross electricity generation in that year. Figure 34 shows the monthly distribution of Turkey's total electricity generation from PV technology in 2015. Turkey has only one CSP plant located in Mediterranean region, which started energy production in 2013. The configuration type of the plant is power tower and the plant has a thermal storage capacity of 4MW/h (National Renewable Energy Laboratory, 2017). In 2015, total generation from this plant was 3,07GWh. Even if Turkey is in a suitable climate for CSP, the technology seemed to be stabilized at current level. Solar water heating is the most popular solar technology used in Turkey. With a total area of collectors bigger than 10 million m^2, Turkey has the second highest solar water heating capacity in 2015 in global level. The most commonly used type is flat-plate collectors for domestic hot water usage. The thermal collectors are generally used in the Aegean and Mediterranean regions. 8,93TWh_{th} of solar thermal energy was generated by solar thermal collectors and this represented 0,6% of Turkey's TPES in 2014. At the end of 2014, the total capacity of solar thermal collectors was 12.730MW_{th}. Solar water heaters are an economic alternative for domestic hot water usage and suitable to use all around Turkey. (BP, 2016; IRENA, 2017c; TEİAŞ, 2017; REN21, 2016; Mauthner, et al., 2016.)

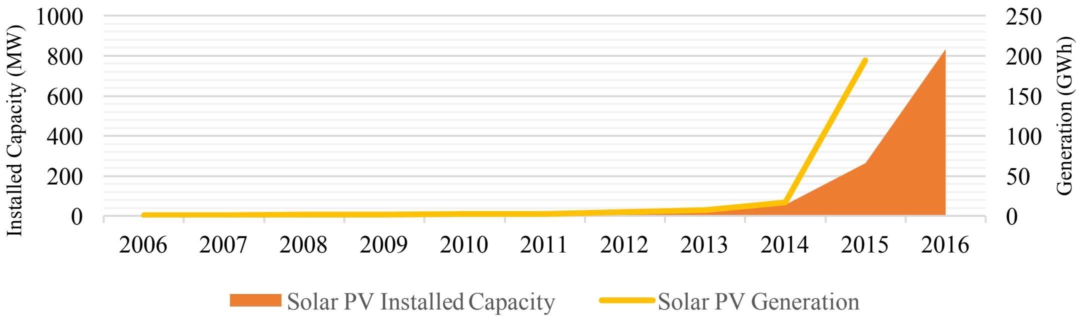


Figure 33: Solar PV Installed Capacity and Generation (IRENA, 2017c)

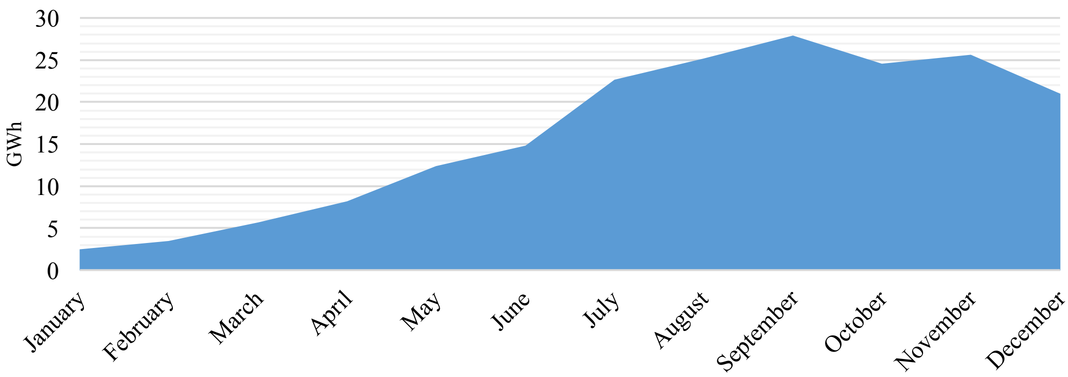


Figure 34: Monthly Distribution of Turkey's Total Electricity Generation from PV in 2015 (TEİAŞ, 2017)

The renewable energy targets of Turkey aim to increase the share of solar energy in energy mix. In 2016, the solar energy installed capacity was 832,5MW, which represents 1,06% of the total installed capacity. The renewable energy targets aim to increase solar energy installed capacity to 5GW by 2023 and 16GW by 2030. Furthermore, it was resulted in a Greenpeace scenario that the share of solar energy in electricity generation can be 42,3% with the country's solar potential (Greenpeace, 2015a). Under YEKDEM, a supporting mechanism has been introduced with a which a tariff for purchase guarantee of renewable energy technologies. Supporting mechanisms for solar PV includes a purchase guarantee of 0,133US$/kWh for solar electrical energy production, 0,013US$/kWh for PV module capacity, 0,035US$/kWh for PV cells, 0,006US$/kWh for inverters and 0,005US$/kWh for materials that focus solar energy on PV modules. CSP technology also has a purchase guarantee which can be seen in Figure 35. In this figure, solar energy technologies have the highest purchase power incentives from the government. Furthermore, the investment costs of solar facilities show a decline in last years, which may support the development of solar market. The solar market has been started to grow in last years. Today, there are 100 solar thermal companies and 15 PV module and system manufacturers. Furthermore, the bid of the biggest solar project in Turkey with 1000MW installed capacity has been finalized as 6,99US cent/kWh in March 2017 (Yıldırım, 2017). This project shows the potential of solar energy in Turkey and that the government is planning to depend more on renewable energy. Compared to solar thermal market, the PV market in Turkey is still emerging. To support local production for solar system components, there are incentives, which aims to boost the solar energy sector for new job and improvement of current businesses. (BP, 2016; IRENA, 2017c; Bavbek, 2015; IEA, 2015c; World Energy Council, 2016.)

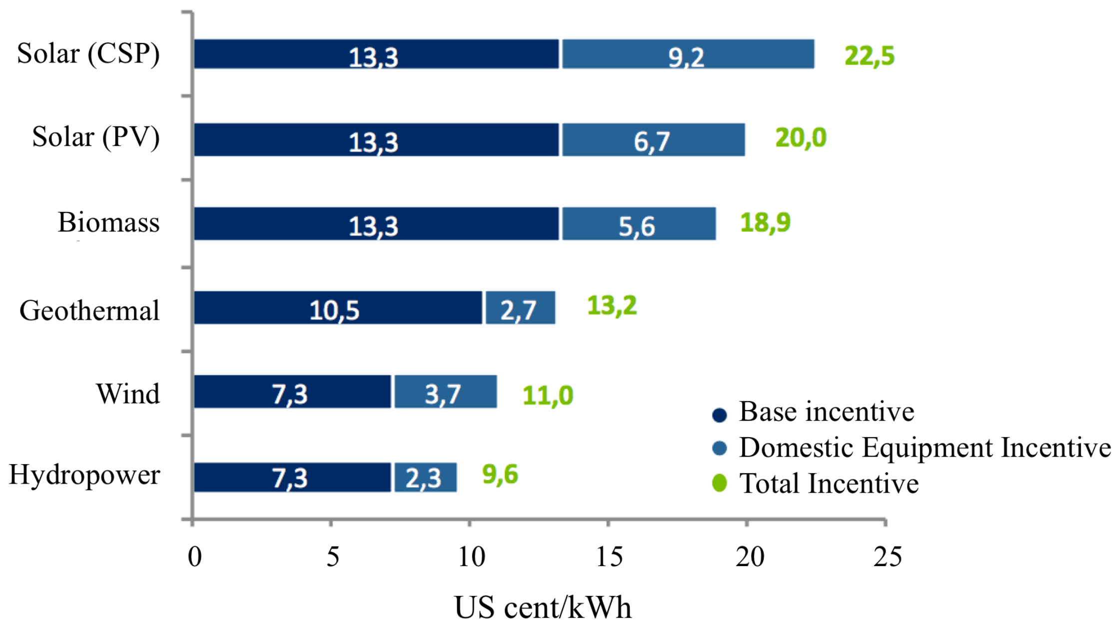


Figure 35: Purchase Guarantee Tariff introduced by YEKDEM (World Energy Council, 2016)

4 SUSTAINABLE ENERGY FOR TURKEY

The definition of sustainable development as defined by the Brundtland Report is: “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987). Energy sector has a critical role in sustainable development. Scarcity of energy resources, negative environmental impacts, ecological footprint, greenhouse gas emissions, global warming, fresh water levels, land use and increasing energy demand with growing population are all examples for the sustainability challenges related with energy sector. That’s why; sustainability is very important especially for energy sector. The average annual growth rate for the global energy demand was estimated as 1,2% for the last decades and conventional energy resources are neither sufficient to meet this demand, nor environmentally friendly (Esen, et al., 2015). For a sustainable energy system, renewable energy resources should be considered. Renewable energy technologies are the solution for most of the challenges for a sustainable energy system. However, the total share of renewable energy for global energy demand is still very low. In 2014, only 13,8% of world TPES was from renewable energy technologies. (IEA, 2016.)

Among renewable energy resources, solar energy is a massive energy resource which can fulfill the increasing energy demand. However, total share of solar energy technologies in global energy mix is very low. In the data provided by International Energy Agency (IEA) for year 2015, TPES in OECD countries was distributed as 2,2% for hydropower, 5,3% for biofuels and waste, 2,1% for other renewables, which includes geothermal, wind, solar and tide. (IEA, 2016.) Even if the solar energy technologies are improved day by day, the technology has a very low level of share in most of the countries’ energy mix and classified as other renewables in many energy mix studies because of the low level of share.

Between OECD countries, Turkey is one of the countries which has very low share of solar energy in its energy mix. Even if the country has a promising technical potential for solar energy, only 1,06% of the total installed capacity was represented by solar energy in 2016. On the other hand, demand response and foreign energy resource dependency are two important problems which Turkey should concentrate on for a sustainable energy sector. The solution for these problems are renewable energy resources and solar energy is one of the renewable energy technologies which can be very favorable with its potential in Turkish territories. The vision of the Turkish government for energy sector should be focusing to become more sustainable and the solution for a sustainable energy sector lies in solar energy technologies. For the transition of Turkish energy sector, there are some drivers and obstacles specified under environmental, economic and social aspects. After examination of the drivers for sustainable Turkish energy sector, the obstacles for solar energy technologies in Turkey were analyzed. Finally, instruments for solar energy transition in Turkey were observed to achieve more sustainable energy sector in Turkey. A hierarchical illustration was created to explain the flow of this chapter, which can be seen in Figure 36.

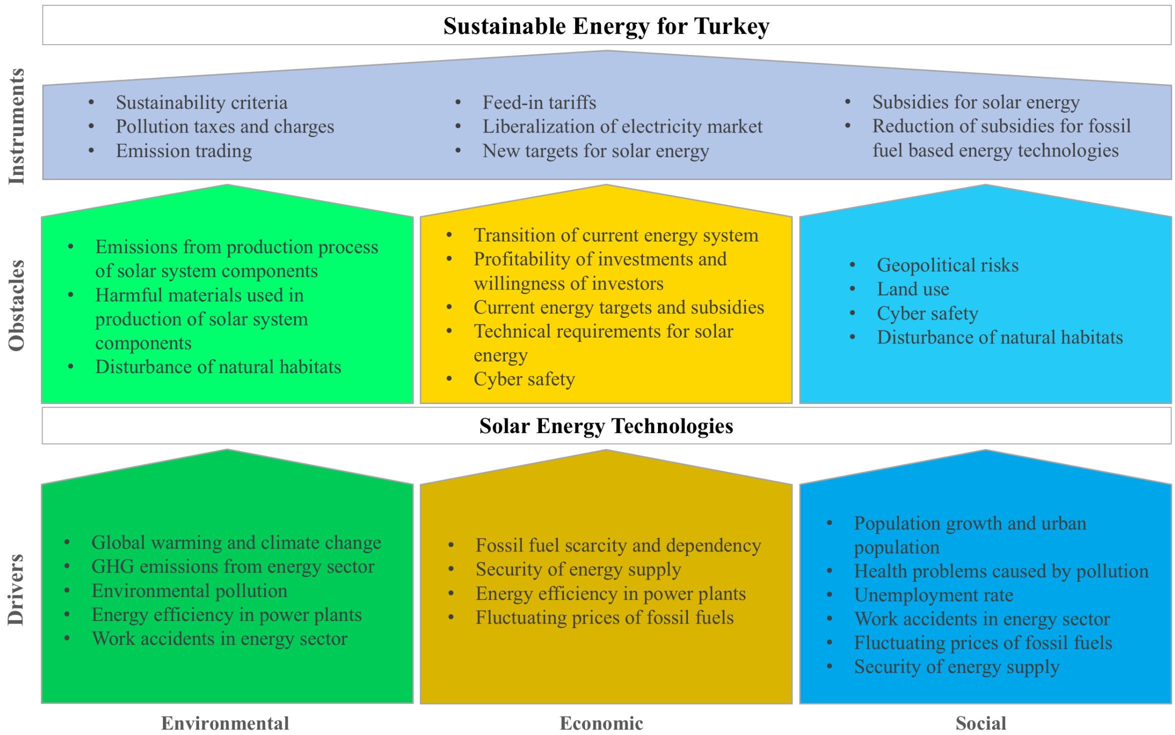


Figure 36: Drivers, Obstacles and Instruments for Sustainable Solar Energy in Turkey

4.1 Drivers

For sustainable development, energy sector should be self-sufficient and environmentally friendly. However, today's energy sector is neither self-sufficient, nor environmentally friendly with high level of fossil fuel usage. The answer is in renewable energy technologies and solar energy is the one which has the highest theoretical potential between renewable energy resources in the world. Some of drivers for a sustainable energy sector can be listed as climate change, GHG emissions, air and water pollution, ozone depletion, security of energy supply, scarcity of energy resources, fossil fuel dependency, increasing energy demand leading by population growth, and health problems caused by pollution. These drivers can be grouped under three aspects which are environmental, economic and social aspects. This classification leads to examine the drivers with the most related and important aspect for them.

Turkish energy sector is far from being sustainable. 85,6% of the total energy consumption in 2015 was from fossil fuels. More than 40% of installed capacity was met by imported fuels in 2016. In the same year, 56% of total installed capacity was formed by fossil fuels. On the other hand, 1,06% of total installed capacity was from solar energy in the same distribution. Solar energy is one of the renewable energy resources with high potential in Turkey. But still, the share of solar energy in installed capacity is very low. In the current situation, drivers for a sustainable Turkish energy sector can be listed under environmental, economic and social aspects. The specified drivers emphasize the most important issues related with current energy system in Turkey. (TEİAŞ, 2017.)

4.1.1 Environmental Drivers

The negative effects of conventional energy resources on the environment are non-negotiable. As Turkish energy sector is dependent on fossil fuels and fossil fuels are scarce in global level, energy system transition is a necessity due to climate change and security of energy supply. Climate change is the most important driver for a sustainable energy system and it is possible to achieve sustainability only with renewable energy technologies. The main reason of climate change is the usage of fossil fuels in energy sector and their GHG emission levels. Two-thirds of the GHG emissions are emitted by the energy sector, especially by the conventional energy technologies. The ecosystem has a fragile balance and affected negatively by emissions. As the density of the GHGs in the atmosphere increases, absorbed radiation from the Sun cannot be reflected enough to space because of the block by these gases and this causes global warming. The disturbed balance of ecosystem results in various environmental, economic and social consequences. Water scarcities, agricultural failures, tropical disasters and other natural catastrophes are just one side of the bigger problem. With the increase of GHG concentration in the atmosphere, these events will continue to occur more frequently. According to an estimation from the World Health Organization(WHO), the climate change causes more than 150.000 deaths in a year. In addition, the adaptation to the climate change will have higher costs than the energy system transition. The global warming should be kept below 1,5°C and it is only possible with non-conventional energy resources, to decrease the GHG emission levels. In this critical situation, renewable energy resources have a very important place in the energy sector. Between renewable energy technologies, solar energy technologies have much lower emission levels compared to conventional energy technologies. Besides, Turkey has a very high potential for solar energy technologies and it is possible to upgrade the current energy system to a more sustainable version by focusing on solar energy. Turkey is highly reliant on coal and coal is the fossil fuel which is the largest source of GHG emissions between conventional energy resources. Apart from being a party of international agreements on the environment, Turkey also has local environmental issues such as water pollution, air pollution and deforestation. Climate change has disastrous effects for Turkey's rich ecosystem and need to be focused on immediately. (WWF, 2011.)

Energy sector is the biggest emitter of GHGs in the world. In Turkey, 72,5% of GHGs were emitted by energy sector in 2014. In GHG emission levels from energy sector, energy resources and technology efficiency plays the main role. Turkey's one of the targets on energy sector is increasing energy efficiency. However, aimed efficiency improvements are on current power plants, especially on coal-fired power plants. Even if efficiency improvements in coal-fired power plants may decrease the GHG emission levels, it still is not sufficient to meet GHG emission reduction targets. As mentioned before, Turkey aims to reduce its GHG emissions by 21% until 2030. However, it is possible only with more efficient energy technologies. Increasing the share of renewable energy technologies in energy sector is the solution to reduce the GHG emissions. Between renewable energy technologies, solar energy technologies have very low GHG emission levels. The emissions are only from the production process of the system components. In addition, it is possible to decrease GHG emissions more from production processes by using renewable energy in production. Nonetheless, Turkey is still focusing on coal as an energy resource, which is the biggest resource of GHG emissions. Coal-fired power plants are also the reason of local air pollution, especially in large cities. Air pollution in large cities is another environmental issue that Turkey should take care of. Between GHGs, the highest amount of emitted GHG is CO_2. In 2015, 336,33 million tonnes of CO_2 was emitted in Turkey. On the other hand, NCCAP was declared 541 actions for combatting climate change and a part of these actions were related with GHG emission reduction. However, the plan did not consist any excessive actions for GHG emission reduction from energy sector. At the end of 2013, atmospheric CO_2 had reached 400ppm and expected to reach 450ppm until 2030s. It has been predicted that atmospheric CO_2 concentration should be stabilized until 2030s to achieve the limit of 2°C climate temperature increase. This situation is directly related with future global economic activities and emission rates. Turkey is a part of global emission levels and should act accordingly. To decrease emission levels in energy sector, fossil fuels should be replaced by non-carbon energy sources and renewable energy technologies are a necessity for this replacement. Between them solar energy is very promising for Turkish energy sector and need to be considered for sustainable energy sector. (BP, 2016; IEA, 2016; WWF, 2011.)

Turkey's energy sector is dependent on fossil fuels. Especially, coal has a great place in the sector. However, using coal as an energy resource causes massive pollution to the environment. Particularly, coal-power plants located near large cities cause air pollution and air quality depreciation. In Turkey, approximately 97% of the citizens live in large cities exposed to PM and this PM emission levels are the highest in Europe. Considering that air pollution in large cities is an important problem in Turkey, renewable energy technologies should be increased in Turkish energy mix. One of the problems about Turkey is urban area population which results with energy demand increase in large cities. More power plants were located around large cities to meet excessive energy demand. As coal-fired power plants are popular in Turkey's energy sector, density of these plants increases around large cities. As discussed before, coal combustion results with high amount of PM emissions. For instance, Figure 28 and Figure 29 represented in previous section shows the PM emission levels around Turkey in 2012. When the thermal power plant map represented in Figure 27 is analyzed, the relation between PM emissions and type of energy resource used in thermal power plants can be seen clearly. In addition, NCCAP aimed to reduce harmful emissions and pollutants, especially from coal-fired power plants. However, coal-fired power plants seem to exist in Turkish energy sector, as the efficiency improvements for current coal plants are planned and coal-based energy targets are still strived to be achieved. Another problem about this situation is Turkey's obsession about coal as fuel, which is due to domestic abundance of coal reserves. However, the reserves present in Turkey are not sufficient to meet expected energy demand and to solve fuel dependency to other countries. In addition, the most popular coal type present in Turkey is lignite, which is low on calorific value and high on pollutants. Turkey should change its focus from coal to renewable energy resources. Especially, solar energy has huge potential in Turkey and is an answer to solve air pollution. In addition, solar energy technologies can be used all around the country, especially in large cities. Some technologies such as distributed PV systems installed on rooftops on buildings enable solar energy to be used even inside of a city. This may lead to improve air quality and to secure the energy supply in large cities. Apart from air pollution, water pollution is also an environmental problem. As water pollution is another specified environmental problem, Turkey should decrease the share of coal in total primary energy consumption, since coal usage also causes water pollution.

Main environmental drivers for sustainable Turkish energy system were defined as global warming and climate change, GHG emissions from energy sector, and environmental pollution. These drivers are related with each other and a solution for one of them may also be a solution for others. There are also other environmental drivers such as energy efficiency in power plants and accidents in working sites in energy sector. However, these drivers are explained further under economic and social aspects.

4.1.2 Economic Drivers

Conventional energy resources represent high share of energy consumption in Turkey. High percentage of total energy consumption of Turkey was met by fossil energy resources (BP, 2016). One of the main drivers of Turkish energy sector is supply security. Unfortunately, the investments that have been made to secure energy supply is mostly on non-renewable energy resources, such as conventional energy resources and nuclear energy. Considering that fossil fuel reserves are finite in global level, are depleted very quickly and that Turkey does not have valuable fossil fuel reserves, renewable energy resources should be considered for a sustainable energy sector in Turkey. Scarcity of fossil fuels leads to price increase in global level and fossil fuel imports lead massive cash flow from Turkey to other countries. In 2014, 75% of total primary energy consumption was met by imported fossil fuels, which shows that Turkish energy sector is highly dependent on fossil fuel imports. Turkey lacks fossil fuel sources. There are no proved reserves for oil and natural gas in Turkish territory and the domestic coal reserves are low in calorific value. But still, Turkey is planning to solve energy dependency on foreign resources by counting on domestic fuel reserves. 43,8% of TPES is used for electricity generation and only 12% of electrical energy is generated by renewable energy resources. The share of renewable energy resources in total installed capacity is low compared to fossil fuels but total renewable energy installed capacity and generation increases year by year. From 2015 to 2016, total installed capacity of renewable energy resources increased from 31,24GW to 34,08GW. However, Turkish energy sector still depends on fossil fuels. It is vital that Turkey start to be focused to upgrade the energy system in a more sustainable way. (TEİAŞ, 2017.)

Another critical issue in energy sector is the security of energy supply. Security of energy supply is important for both economic and social aspects of sustainability. It is expected that Turkey will have high economic growth rate for near future which will lead to energy demand increase. Growing population also leads to energy demand increase year by year. Turkey has a population with a growth rate of 1,6% per year. This situation makes energy demand increase and energy supply more challenging. In addition, it is expected that energy demand will continue to increase in future. Figure 30 represents the electricity consumption forecasts for the years between 2017 and 2023. Therefore, the security of energy supply is a priority for Turkish government. Supply security of electricity has improved with the support of coal-fired power plants. It is debatable that it is an improvement, as the increase is provided by fossil fuel resources. Moreover, meeting the electricity demand increase with low-quality lignite coal is challenging. The second support for the demand increase is expected from hydropower. However, Turkey's installed power capacity of hydropower is pushing the limits. Also, lower contribution from hydropower at peak of demand may occur because of droughts. Diversifying the energy mix with renewable energy resources is a necessity for Turkish energy sector for energy supply security. Instead of focusing on its renewable energy potential, Turkey is planning to deploy three new power plants. It is planned that the construction of the first nuclear power plant will be finished in 2019. Nuclear energy capacity targets for years 2023 and 2030 were set as 9,6GW and 12GW respectively. Even if Turkey has a huge potential for renewable energy resources, like solar energy, they still focus on non-renewable energy technologies. In addition, it is very critical for Turkey to secure the plant area from possible terror attacks or natural disasters. Turkey has faced with terror attacks in last few years and the damage from a nuclear catastrophe can be irreparable. (IEA, 2016.)

Energy efficiency is directly related with the amount of energy resource usage. Inefficient energy technologies cause more energy resource usage and more losses in energy conversion steps. Especially, conventional energy technologies have high energy losses and GHG emissions. Thus, energy efficiency is important for both economic and environmental aspects of sustainability. By improving energy system efficiency or changing the used technology to more efficient one, it is possible to decrease energy resource demand. Efficiency increase leads to reduce energy loss both in conversion, distribution and transmission steps. Besides, it is possible to reduce the energy need by improving the building insulations. For instance, upgrading the housing methods with passive solar designs would lead to less energy consumption for heating and cooling of houses. Renewable energy technologies have higher efficiency compared to conventional energy technologies. Especially, PV power between solar technologies has very high efficiency rates as there are few conversion steps. Turkey is planning to increase efficiency in existing coal-fired power plants, instead of focusing on more efficient renewable energy technologies. Turkey has a potential of EUR13,2 billion worth of energy saving, by increasing efficiency in energy sector. It is also targeted that Turkey’s energy intensity will be reduced by 20% until 2023. Turkey should focus on its solar energy potential, because increasing the efficiency in coal-fired power plants may not be sufficient to reach the target. The best efficient way to generate and use energy is renewable energy technologies. The Turkish energy sector should be upgraded for more efficient energy systems.

The economic drivers for Turkey’s energy system are mainly related with energy resource dependency of the country. Turkey is dependent on fossil fuel resources in its energy sector. This situation affects Turkey’s economy negatively and risks the security of energy supply. For a sustainable energy sector, securing energy supply is very important as an economic and social driver. Furthermore, conventional energy resources using fossil fuels are not efficient, which causes energy losses and GHG emissions. It makes efficiency in energy sector important economically and environmentally. On the other hand, importing and using fossil fuels is far away from being economically and technically efficient. Fossil fuel dependency also leads to energy price fluctuations and this situation is further discussed under social drivers part of this section. Turkey can solve these problems by implementing renewable energy technologies to its energy sector. Especially, solar energy has a remarkable potential for Turkey and should be considered for an economically sustainable energy system.

4.1.3 Social Drivers

The population of Turkey has an increasing trend. Population growth is one of the drivers of energy demand increase and population growth rate of 1,6% per year makes energy demand supply for Turkish energy sector more challenging every year. Furthermore, 73,39% of the total population represents the urban population, which takes the challenge one step ahead. With high level of population in urban areas, energy demand is higher in large cities. To secure the energy supply to large cities, fossil fuel based power plants became more frequent around them. However, this situation causes air and water pollution in large cities, which are two of environmental concerns of Turkey. Besides, air and water pollution cause various diseases. Once again, the solution lies under renewable energy technologies. Especially, solar energy is one of the clean energy technologies, which can be replaced with current fossil fuel based power plants to secure the energy supply. Some technologies such as distributed PV systems installed on rooftops of buildings enable solar energy to be used even inside of a city. This availability may lead both to supply the energy security and improve the air quality in large cities. Although solar energy technologies are improving day by day, current level of technologies is enough to secure the energy supply.

100% of the population has access to electricity in Turkey. However, security of energy supply is ensured by fossil fuel based energy technologies, which cause environmental pollution and leads to various health problems to citizens. Especially, coal-fired power plants located around large cities cause air and water quality deterioration. Unfortunately, there are various harmful effects of air pollution on human health. PM emissions from these plants cause health problems, such as lungs diseases, hearth diseases, cancer or asthma. Furthermore, Turkey is one of the European countries which has the highest rate of premature deaths. PM and ozone emissions caused approximately 28.924 premature deaths in 2010. (Health and Environment Alliance, 2015.) Air quality in Turkey can be ameliorated by decreasing number of coal-fired power plants and increasing the share of renewable energy technologies. Especially, solar energy is one of the clean energy technologies, which emits very low of GHGs and PM. It is possible to increase air quality and decrease the health problems caused by air pollution by installing solar power plants, especially in large cities.

Another social driver for sustainable energy sector is the increase of unemployment rates in Turkey. Along with decrease in growth rate in last years, unemployment rate increased. In 2016, the estimated unemployment rate was 10,9%. Increasing population also affects the unemployment rate negatively. Energy sector has an important role on employment rates of a country. Especially, direct and indirect jobs from renewable energy sector is very high. Between renewable energy industries, solar PV industry has the highest number of job opportunities provided to the society in global level. Apart from PV plants, there are also PV module manufacturing in Turkey. The amount of job opportunities from solar PV sector can be boosted by supporting the technology on energy sector. In addition, solar thermal technologies are popular in Turkey which makes Turkey one of the major employers in solar heating and cooling. All solar energy technologies have huge potential both for energy generation and job opportunities in Turkey. (REN21, 2016.)

Fossil fuels are not only harmful to the environment due to their emissions. They are also harmful with their extraction processes. The accident that recently happened in the Gulf of Mexico is a good example for this. Controlled by BP, the extraction site caused a major oil spill into the Atlantic Ocean. This spill has left irreparable damage on the environment. (WWF, 2011.) Similar accidents happened in Turkey. Mine accidents happened in Turkey caused 361 deaths and 80 severe injuries in 2014. The reasons of this damage were because of landslides, firedamp explosions, blazes and flooding. Between the years 2012 and 2014, around 100 coal mines had been closed due to not following the safety standards. In 2014, a disaster happened in a coal mining site located in Soma, in Aegean region. The Soma disaster caused deaths of 301 workers. Turkish mining sector is one of the biggest employers among other sectors. However, the sector has the highest rate of worker deaths between sectors that are under Turkish energy sector. (Jamasmie, 2015.) Accidents at working sites in energy sector is a critical issue as a social driver for sustainable energy system and the job opportunities from coal sector should be replaced with renewable energy jobs.

In Turkey, dependency on fossil fuel imports has huge impact on energy supply security. It also affects energy prices negatively. High prices of fossil fuels imported from other countries results with expensive energy in Turkey. In addition, high taxation rates make Turkish gasoline and diesel retail prices one of the highest between OECD countries. Furthermore, Turkish electricity price is very high compared to average electricity price in other Eastern European and Central Asian countries. For instance, 20% of electricity tariff is for funds and taxes. Apart from having high taxes, energy is expensive in Turkey because the energy sector is highly dependent on fossil fuels. It is possible to avoid energy price fluctuations by changing the focus of sector to the local renewable energy resources. LCOE of solar technologies decreases day by day. Figure 37 shows the total build-up costs of electricity generation from coal and solar energy in 2013 and 2030. This figure shows that LCOE costs of coal was and will be lower than LCOE of solar. However, other costs of coal energy related with health issues and CO_2 emissions are higher than solar energy. Besides, costs like LCOE and subsidies are forecasted to decrease until 2030 for solar energy. The decrease of LCOE makes solar technologies preferable in countries which has high potential for solar energy potential. Besides, it is possible to solve dependency and price fluctuation problem by implementing renewable energy technologies to the energy sector.

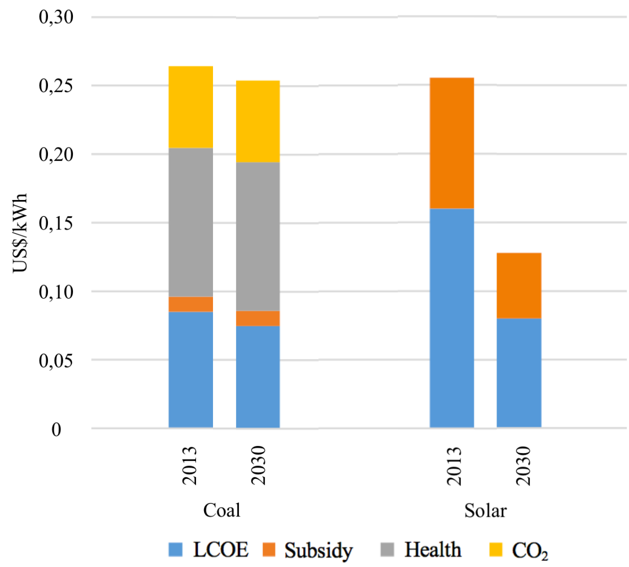


Figure 37: Total Build-up Costs of Electricity from Coal and Solar Technology for Years 2013 and 2030 (Acar, et al., 2015)

Social drivers for sustainable energy sector are defined as population growth and urban population, health problems caused by pollution, growing unemployment rate in Turkey, accidents in working sites in energy sector and fluctuating prices of fossil fuels. Fluctuating prices of energy can also be considered as an economic driver. In addition, security of energy supply, which is considered as an economic driver, also has social effects. Once again, these drivers for sustainable energy sector in Turkey leads to one solution, which is renewable energy.

4.2 Obstacles

In the previous section, environmental, economic and social drivers were determined for sustainable energy sector in Turkey. These drivers lead for sustainability in energy sector to one solution, which is renewable energy. Between renewable energy technologies, it was mainly focused on solar energy technologies as Turkey has a huge potential for solar energy. Despite the benefits of solar energy technologies for Turkish energy sector, there are various obstacles for energy system transition from current system to solar energy based system, such as emissions from production process of solar energy system components, harmful materials used in production of technology, habitat disturbance, current energy subsidies, unstable policies, technical requirements of the technology, transition of the current energy technologies and cyber safety. Again, these obstacles are classified under three aspects which are environmental, economic and social aspects. These obstacles are examined to determine possible instruments to overcome these obstacles for the sustainability of Turkish energy sector.

4.2.1 Environmental Obstacles

Energy system transition is a very challenging task for Turkey. However, there will be more serious problems if the system will not be upgraded with renewable energy technologies. One of the results will be unrepairable effects of GHG and PM emissions on the environment. Between renewable energy technologies, solar energy has very low levels of GHG and PM emissions. Only emissions are from manufacturing and end-of-life phases of system components. Emissions from these phases are avoidable, as the energy used in production phase can be supplied by renewable energy resources and the materials used in system components can be recycled to reduce negative impacts of life cycle of system components. In addition, energy consumption in production phase of system components may be reduced by using recycled materials. Instead of material extraction, recovered material usage decreases total energy usage by more than two thirds. Materials used in production consumes lots of energy in extraction. In addition, materials like steel and aluminum are very popular in every sector. This situation makes recycling and reusing of these materials more practical and beneficial.

Another obstacle for solar energy technologies is habitat disturbance. With PV technology, size of the plant is directly related with installed capacity. However, PV power plants which uses ground-mounted panels as an installation type may cause disturbance in plant's surrounding habitat. For CSP technology, habitat disturbance is also a problem. Concentrated light beams can also be a risk for avian animals. But mostly, since CSP plants are built in dessert-like areas, their effects on natural habitats are negligible with most cases.

Environmental obstacles for solar energy in Turkey can be listed as emissions from production phase of solar system components, materials used in production phase and possible habitat disturbance from installed solar plants. Disturbance of the plants can also be considered as a social obstacle, as the local community may be disturbed from the plant. However, when these obstacles are compared with the drivers for solar energy, it can be said that the results of the drivers may be costlier than not changing anything.

4.2.2 Economic Obstacles

Transition of current energy system is one of the obstacles for sustainable energy system in Turkey. Turkey has a fossil fuel based energy sector. Apart from technical challenges, technology upgrades are challenging in a financial way. Upgrading the current system to a renewable energy based system requires financial support. Turkey has the 18th largest economy in the world but its economy's growth rate decreased in last years. Despite the fact that Turkish energy sector is dependent on fossil fuels, the energy demand increases year by year. Furthermore, the population increase in urban areas leads to increase of energy demand in urban areas, which makes energy transmission more challenging. On the other hand, government has been focused on non-renewable technologies to meet excessive energy demand, which are nuclear power and improvement of currently used technologies, such as coal-fired power plants. In addition, current strategies are more focused on non-renewable energy resources. Unfortunately, there is lack of renewable energy policies to support and increase renewable energy usage in energy sector. Despite all, the biggest challenges for meeting energy demand, supplying security and increasing the renewable energy technologies in Turkey is costs and availability of finance.

Transition of energy sector to a more sustainable version is directly related with the availability of finance. The biggest issue about this is profitability of the possible investments and number of investors willing to invest on more sustainable energy projects in Turkey. Between the years 2005 and 2010, investments on renewable energy technologies remained limited because of low feed-in tariffs and lacking secondary legislations for renewable energy. After introduction of higher feed-in tariffs in 2010, investments on renewable energy technologies have increased by both local and international investors. Introduced by YEKDEM, a supporting mechanism has been generated with a tariff for purchase guarantee of renewable energy technologies. In addition, liberalization and privatization of electricity generation and distribution increased private investments on electricity generation and distribution. However, electricity market is not fully liberalized as the power suppliers are determined according to the prior agreements. This situation blocks the prioritization of lower cost power generators in the market and affects new investments on renewable energy technologies negatively. If the market liberalization can be increased, it may create a beneficial environment for renewable energy projects, which may lead to investment increases in renewable energy sector. On the other hand, the investment costs of solar facilities, as a renewable energy technology, show a decline in last years, which may support the development of solar market in Turkey as well. However, it is still a challenge to find investors for renewable energy projects, which Turkey should focus on for sustainable energy achievement.

Turkey has energy targets for years 2023 and 2030. Turkey's energy sector is dependent on fossil fuels and targets show that Turkey will continue to be dependent on foreign fossil fuel resources in future. The share of installed capacity targets for fossil fuels are 41,3% in 2023 and 37% in 2030. The usage of natural gas for installed capacity is targeted to be stabilized until 2030. On the other hand, it is also targeted that the share of coal in installed capacity will grow by 44,4% from 2016 to 2023 and by 40% from 2023 to 2030. The reason of these targets is that Turkey don't have domestic natural gas resources but have domestic coal reserves. However, the coal reserves in Turkey are not sufficient to meet the target capacity and will depend on coal imports eventually, if they don't change their targets. On the other hand, Turkey planned to install three nuclear power plants to solve energy dependency and security of energy supply problems. The targets are determined as Turkey will have 9,6GW of installed capacity in 2023 and 12GW of installed capacity in 2030 from nuclear, which represents 7,9% and 7,3% of the total installed capacity respectively. Unfortunately, Turkey has faced with terror attacks in last years which leads to question the security of these nuclear plants. On the other hand, EECB targeted to reduce energy intensity by 20% until 2023. However, the sector still relies on less-efficient energy technologies. In addition, there are still some subsidies for fossil-based energy technologies. This situation is incoherent, as Turkey adopted energy targets for 2023 with some strategies and action plans about energy efficiency, renewable energy and climate change. In addition, Turkey has published NCCAP which consists of 541 actions for combatting climate change. However, it consists of only monitoring reports without any assessment about progress of these actions. The country still considers coal as an installed capacity with a share of 21,2% in their targets for 2030. This situation makes implantation of solar energy to the Turkish energy market more challenging. More subsidies should be created for renewable energy technologies and energy efficiency, which will be beneficial in long-term.

Another obstacle for solar energy in Turkey is related with technical requirements. The solar energy supply may vary according to the time of the day or weather conditions. The technology functions only in daytime and requires energy storage technologies. Besides, the weather conditions directly affect energy generation. If the weather is cloudy, the technology is less effective to generate energy. As discussed before, the solar irradiation level in Turkey is more advantageous than most of European countries and the average solar irradiation level of Turkey is the fifth between European countries. Despite the potential of solar energy in Turkey, the energy storage technologies are required to avoid energy supply variation. Fortunately, the energy storage technologies are also improving day by day. Besides, CSP and solar thermal energy technologies store energy in the form of heat, which is an easier form of energy to store and Turkey has a suitable climate for CSP. But still, sustainability of energy sector can be achieved only if various renewable energy resources are implemented to the sector.

In this section, economic obstacles for solar energy in Turkey were discussed. The main economic obstacles were determined as transition of the current energy system, profitability of the investments on solar technologies and possible investors, current energy targets and energy subsidies focused on non-renewable energy technologies, and technical requirements for solar energy. Also, cyber safety can be classified as an economic and social obstacle for solar energy but it is discussed in the following section, under social obstacles.

4.2.3 Social Obstacles

Turkey is in a very critical political location between Europe and Asia. Turkey is neighbor to Syria, which is a country that suffers internal struggles and conflicts within its borders. Due to this conflict, three million Syrian refugees have fled to Turkey. This sudden spike in population might undermine long term energy capacity investments due to increased immediate upgrades. In addition, the forecasts show that energy demand will continue to increase near future. This situation highlights the importance of energy supply security. With current targets, it seems like solar energy is not the first option for installed capacity increase.

Solar energy requires placement of solar panels over large areas. Turkey is a country with high agricultural activities. Agricultural lands compose 49,7% of total land area of Turkey. This means that it is highly probable that a new solar farm can be built on an agricultural area. Furthermore, Turkey is combatting with deforestation and currently, 14,9% of total area is represented by forests. Deforestation for solar energy is out of question for Turkey. All in all, agricultural and forest lands can pose difficulties for solar farm permits. The usage of agricultural and forest lands for solar farms may create negative impacts on local citizens' opinions.

Solar energy networks are highly digitalized. A risk generally associated with digitalized energy networks is that its cyber safety. Computer hackers can potentially stop energy production and transmission from solar farms. They might also steal generated energy without notice. Digital network security is an issue that is rising in importance. Turkey, just like any country that aims to digitalize their energy system, should invest in security measures along with renewable energy technologies.

Social obstacles are listed as geopolitical risks of Turkey, land use of solar energy technologies and cyber safety. Cyber safety can also be considered as an economical obstacle, as successful cyber-attacks may result with financial problems and possible cyber-attacks may decrease the number of potential investors on Turkish energy sector. In addition to these obstacles, disturbance of natural habitats can also be considered as a social obstacle, as it may have negative effects on the citizens. All things considered, it can be said that social obstacles are mainly related with the technology itself. However, the obstacles that social drivers may create are more challenging than the social obstacles for solar energy.

4.3 Instruments

In the previous section, drivers for sustainable energy sector in Turkey has been determined. The drivers are the environmental, economic and social problems related with energy sector in Turkey. In this thesis, the aim is to answer the question, “What is the role of solar energy for achieving sustainable energy sector in Turkey?”. However, there are some obstacles for solar energy related with technical structure of solar energy systems or problems related with Turkish energy sector infrastructure. In this section, various instruments are presented to meet with their corresponding driver counterparts and to avoid obstacles as much as possible. Instruments were suggested for transition to sustainable Turkish energy sector.

One of the instruments that can be used for sustainable energy system transition for Turkey is the introduction of sustainability criteria for energy sector. Sustainability criteria would enable a sustainable energy sector. Implementing renewable energy certificates to the energy sector can be used as a support mechanism for sustainability criteria. By its definition, a sustainable energy sector will ensure adequate energy supply while protecting the environment and the economy. These criteria will be required for Turkey in the event of joining EU. Otherwise, it will still be required from Turkey to create a clean energy system, since the current system is far away from being sustainable, destroys the environment and increases the national debt.

Currently, there is no taxation policy for air pollution in Turkey. As air pollution is one of the environmental concerns in Turkey, especially in large cities, Turkey should consider instating air pollution taxes to control air pollution and reduce emissions. With these taxes, polluting energy technologies such as coal combustion would lose competitiveness and more cleaner energy technologies would be preferred. However, Turkey relies on its coal reserves which undermines the preference of renewable energy technologies. Due to this problem, introduction of air pollution tax has a potential to be an instrument for sustainable energy sector that Turkey should consider.

In EU, emission trading is one of the instruments to control GHG emissions. Emission trading market leads to make companies responsible for their environmental performance. With GHG emission limitation, companies can exchange their limits so that one company, which spends GHG emission rights lower than the limit, may have a profit by selling its GHG emission rights to another company, which exceeds its GHG emission limits. Also, the company that exceeds its GHG emission limits may pay less for additional emissions from its surplus GHG emissions. In Turkey, there is no system to control GHG emission levels. On the other hand, GHG emissions increased fast in last few years because of population and economy growth. The highest level of emissions was from energy sector, which is possible to reduce the GHG emission levels by changing energy technologies to renewable energy based ones. Implementing carbon market application may support the usage of clean energy technologies. Currently, there is only a voluntary carbon market in Turkey. As its name suggests, this market is completely voluntary and does not have legal consequences. By upgrading the current voluntary carbon emission market, it is possible to introduce the emission trading system to Turkey. With carbon market, is it possible to slow down the speed of GHG emission increase in Turkey.

Feed-in tariffs are an effective instrument to support renewable energy technologies in energy mix. Turkey has some feed-in tariffs on renewable energy technologies. It is possible to improve current feed-in tariffs on renewable energy technologies to improve renewables sector in Turkey. As mentioned before, increase of feed-in tariffs in 2010 led to increase the investments on renewable energy technologies. The increase of feed-in tariffs in 2010 led to boost investments to renewable energy technologies by both local and international investors. Feed-in tariffs are effective way to support a renewable energy technology to increase its popularity in an energy sector. As Turkey has huge potential for solar energy, improvements of feed-in tariffs for solar energy technologies may have a significant effect to achieve more sustainable energy technology.

Electricity market in Turkey has started to be liberalized in 2001. Liberalization and privatization led to significant progress in energy sector. However, the sector is not 100% liberalized. The government still controls the electricity market partially and has an influence on generation and transmission steps. The prior agreements still exist between government and specific private power suppliers. Liberalized market may increase the investments on electricity market and create a beneficial environment for renewable energy technologies to be popularized. With a fully liberalized electricity market, the share of renewable energy technologies in installed capacity may increase and the average price of electricity may decrease. The technologies with lower generation costs may automatically be boosted in market and renewable energy technologies may gain importance as an investment option.

Turkey has energy targets for years 2023 and 2030. Despite that these targets are determined for more sustainable energy sector, Turkey planned to install three nuclear power plants near future. Even though Turkey has a strong potential for renewable energy technologies, its energy sector will be still reliant on non-renewable energy technologies in its targets for future. As discussed before, Turkey has a huge potential for solar energy between renewable energy technologies. The country also has a target to increase renewable energy shares in installed capacity. However, satisfying the energy demand and securing the energy supply is more important, as the sector is more focused on energy technologies with faster results. As such, the targets for 2023 includes the share rates of fossil fuels as 41,3% in 2023 and 36,4% in 2030. Furthermore, solar energy only has a share target of 4,1% in 2023 and 9,7% in 2030, despite its potential. On the other hand, one of the strategies was to increase the share of renewable energy capacity by 30% until 2023. Turkey’s installed capacity from renewable energy technologies was 43,4% in 2016, which is higher than the target for 2023.

The targets should be upgraded to achieve a more sustainable energy sector. The share targets of renewable energy technologies with high potentials in Turkey should be revised and introduced with higher levels.

Turkish energy sector has subsidies for renewable energy technologies. However, these subsidies don't support renewable energy technologies enough to compete non-renewable energy technologies. Furthermore, there are also subsidies for fossil fuels which makes the energy sector less competitive for renewable energy. Subsidies should be focused on renewable energy to form a fair energy sector for renewable energy technologies. Subsidies should be used as an instrument to support renewable energy progress in sector. Between renewable energy technologies, the subsidies for solar energy technologies are the highest. With increased subsidies, Turkey can gain a momentum for solar energy development instead of relying on fossil fuels. Also, smaller scale projects can be realized and solar capacity can be further increased in Turkey.

The instruments for achieving a more sustainable solar energy sector in Turkey were specified as introduction of sustainability criteria, pollution taxes and charges, emission trading market, improvement of feed-in tariffs, liberalization of electricity market, upgrading current energy targets for solar energy, improvement of solar energy subsidies and decrease of fossil fuel based energy subsidies. These instruments may enable to overcome the obstacles for solar energy in Turkish energy sector. In addition, it is possible to answer the drivers for solar energy with these instruments. As Turkey is currently using some of these instruments, it is necessary to upgrade the current ones to achieve a more sustainable energy sector.

5 CONCLUSIONS

Today, energy sector is very challenging because of population growth, energy demand increase, energy supply security, scarcity of energy resources, financial relations between nations and environmental impacts of common energy technologies. Sustainability in energy sector is a necessity to overcome these challenging issues. Energy sector has an important place in today's modern life and it is necessary to find a solution for these challenges without compromising future's abilities. Transition of energy sector to more sustainable phase is vital for this issue. Renewable energy technologies enable pathways to attain a sustainable energy sector. Renewable energy technologies may lead to meet increasing energy demand, secure energy supply and improve overall efficiency of the energy systems. Renewables also emit less GHG, heavy metal and PM emissions compared to non-renewable energy resources. Unfortunately, Turkey's energy sector is far from being sustainable with a low share of renewable energy in its installed capacity. Despite its potential for a sustainable energy system, renewable energy represents only 43,4% of installed capacity in 2016. The country continues to rely on fossil fuel imports from other countries. Furthermore, Turkey is party to international agreements related with air pollution, Antarctic treaty, biodiversity, climate change, desertification, endangered species, hazardous wastes, ozone layer protection, ship pollution, and wetlands. Turkish government should focus on being more sustainable in energy sector to comply with these agreements. In this thesis, between other renewable energy technologies, solar energy is focused to upgrade the current Turkish energy sector to a more sustainable version. Turkey has a very high potential of solar energy among other renewable energy resources. Solar energy may have a vital role to achieve sustainable energy sector in Turkey.

The share of solar energy in Turkish energy mix is very low. Even though the country has a promising technical potential for solar energy, only 1,06% of the total installed capacity was represented by solar energy in 2016. With solar energy technologies, it is possible to achieve more sustainable energy sector in Turkey. There are some apparent drivers for sustainable energy in Turkey. These environmental, economic and social drivers highlight the importance of sustainable energy sector in Turkey. The environmental drivers are global warming and climate change, GHG emissions from energy sector, environmental pollution and energy efficiency in energy sector. These environmental drivers are directly related with the international agreements that Turkey is a party of and with the environmental issues that Turkey need to deal with. There are also economic drivers which highlight the necessity of sustainable energy sector in Turkey. These drivers are fossil fuel scarcity and dependency, security of energy supply and energy efficiency. There are also social drivers for sustainable energy sector which are population growth and urban population, health problems caused by pollution, growing unemployment rate, work accidents in energy sector and fluctuating prices of fossil fuels. These drivers are related with each other and all have the same answer as a solution which are renewable energy technologies. In this thesis, solar energy is focused on between renewables, as the sustainable energy solution for the Turkish energy sector. Unfortunately, there are some obstacles for solar energy in Turkish energy market. The environmental obstacles for solar energy in Turkey can be listed as GHG emissions from and harmful materials used in production process of solar system components. There are also economic obstacles such as transition of current energy system, profitability of investments and willingness of investors, current energy targets and subsidies, and technical requirements of solar energy. Finally, the social obstacles for solar energy are geopolitical risks, land use and cyber safety. Various instruments have been determined to ensure the transition to sustainable energy sector in Turkey, in consideration of drivers and obstacles presented.

The instruments presented in the previous section aim to achieve sustainable energy sector in Turkey. The most important instrument that can be used for transition to sustainable energy sector is sustainability criteria. The introduction of sustainability criteria leads to limit harmful emissions from energy sector, increase the system efficiency of energy technologies used, decrease the pollution caused by energy sector, and most importantly, decrease the climate change impacts of energy sector. The sustainability criteria can lead the energy sector to use renewable energy technologies, which can automatically resolve the problems such as fossil fuel scarcity and dependency, security of energy supply, health problems caused by pollution from fossil fuel energy and fluctuating prices of fossil fuels. Sustainability criteria that are defined by EU, can be the most effective instrument for the achievement of sustainability in Turkish energy system. As such, most of the following instruments can be classified under sustainability criteria. For instance, sustainability criteria that are currently used in Europe to promote biofuel usage (Pavlovskaia, 2014). Another instrument that can be used for achieving sustainable energy sector is environmental pollution taxes and charges.

One of the environmental concerns that Turkey is dealing with is air pollution, especially in large cities. Pollution taxes are instruments used in EU and other European countries such as Norway. Environmental taxation is also promoted by OECD with a guide for policy makers (OECD, 2011). It is possible to implement this instrument to Turkish energy sector to control and reduce environmental pollution. That way each participant of Turkish energy sector may be responsible of their emissions and may avoid the costs by decreasing their emission levels. Another instrument that can be used for emission control is emission trading mechanism. Carbon market in Europe can be a good example to emphasize the benefits of this system. It is possible for Turkey to reduce emissions by applying this mechanism in energy sector. Unfortunately, there is a carbon market in Turkey functioning only with voluntary participants. Participation in carbon market should be forced so that it can be an effective instrument for sustainable energy sector. Feed-in tariffs for renewable energy technologies are currently used as an instrument in Turkey. However, the support for renewables provided by feed-in tariffs should be enhanced. In that way, it is possible to increase the share of renewables in Turkish energy mix and make the energy sector more sustainable. In EU countries, more advanced feed-in tariffs are used in energy sector. It is important for Turkey to increase and diversify the current feed-in tariffs to support renewable energy. Liberalization of electricity markets has a crucial role on sustainable energy sector, as it leads increase the usage of renewable energy technologies. In Europe, energy generation step is not controlled by governments generally and generation should be fully liberalized in Turkey too. With prior agreements, power suppliers were automatically selected beforehand and this situation affects renewable power suppliers negatively. Liberal electricity markets may create a fair market for renewable energy technologies to compete with non-renewable energy resources. Between renewables, solar energy can be the most competitive with its high potential. However, solar energy should also be supported and implemented to the Turkish energy sector. Primarily, new targets for solar energy should be defined to bring it into the forefront between other energy technologies. Despite its potential, solar energy has a very low targeted share in installed capacity for years 2023 and 2030. When comparing the leading EU countries with Turkey in terms of solar energy installed capacity, the countries which have lower average direct normal irradiation annually have higher installed capacity of solar energy than Turkey. Subsidies for fossil fuels should be replaced with subsidies for renewable energy resources and solar energy should be supported using this instrument. By using these suggested instruments, it is possible to upgrade current energy sector in Turkey to a more sustainable version. Also, these instruments may lead sector participants to act within sustainability measures. Between the technologies that may increase the sustainability in energy sector, solar energy may be the most popular renewable energy technology with its potential in Turkey.

All in all, solar energy has a great potential in Turkey. Turkey should focus on renewable energy resources to make their energy sector sustainable. However, with the current policy stances that disfavors renewables, it is challenging to effectively utilize this potential. It is very important that decision makers should change their point of view and focus more on renewable energy resources to secure the energy supply and make the energy sector self-sufficient. Turkey should aim to reduce its energy costs to stay competitive in all sectors that require energy. Otherwise, economic and environmental burdens of fossil fuels will lead to the collapse of Turkish economy and environment. Unfortunately, there are some obstacles for the upgrade of current energy system. The economic limitations are the most important obstacle for transition of Turkish energy sector. Investors prefer other sectors rather than investing on energy sector. The renewable energy sector should be supported and taken to forefront. Government should support the investments in renewable energy sector and direct the possible investors to the renewable energy technologies, especially to solar energy technologies. In addition, renewable energy technologies should be supported with various supporting mechanisms such as feed-in tariffs, tax credits and subsidies. Implementing renewable energy to Turkish energy sectors has various benefits. Above the environmental benefits, economic and social benefits are non-negligible. First, solar energy technologies lead to decrease GHG emissions and environmental pollution from energy sector. In addition, sustainable energy sector may ensure the economic independence of the country. Cash flow from the country can be decreased by decreasing fossil fuel imports from other countries. Independency and self-sufficiency is very important for a country like Turkey, which is located on a very political location. On the other hand, solar energy is the one which creates the highest number of job opportunities between renewable energy technologies. The new positions from solar energy sector may benefit the economy in Turkey. Solar energy, with its low cost, high efficiency and relatively easy to use technology, should be taken advantage of for a sustainable energy sector in Turkey. With its high potential, it is very likely that solar energy may become a major part of Turkish energy system. If the necessary changes are made to the policy surrounding solar energy, this transition can be much quicker.

6 SUMMARY

In this thesis, the aim is to assess renewable energy technologies to understand their compatibility with Turkish energy sector and to locate one technology that can ensure the sustainability of Turkish energy sector. The main goal is to assess a fully sustainable energy sector in Turkey with solar energy technologies.

In the introduction section, the place of energy sector in today's modern lives, increasing energy demand and popularity of conventional energy resources in global level was emphasized. The importance of sustainability concept in energy sector is explained and the role of solar energy in a sustainable energy system is clarified. Following, an introductory information of Turkish energy sector and the place of solar energy in it is provided. This section lead to understand that sustainability in energy sector is a necessity and solar energy between renewable energy technologies may be very beneficial for a sustainable energy sector. In addition, Turkey relies on fossil fuels in its energy sector and usefulness of solar energy is non-negligible for Turkish energy sector.

In the solar technologies section, information about the most popular solar energy technologies was delivered. To begin with, the benefits of renewable energy technologies and current renewable policies are mentioned. The place of solar energy between renewables, types of solar energy technologies, R&D studies and technology improvements of solar energy are explained. The potential of solar energy and its beneficial environmental impacts are mentioned. Following, the most popular solar energy technologies are explained, which are PV power, CSP and solar thermal energy technologies. First, system components, efficiency and material types, performance and system design, and pricing of PV power technology are explained. Following, information about system functioning and types, advantages and disadvantages of CSP technologies are provided. Finally, solar thermal energy types, which are solar heating, solar cooing and thermal storage technologies, are explained in this section. At the end of this section, it is concluded that solar energy has a very promising future for sustainable energy sectors around the world, since the solar energy technology is efficient, new solar technologies are improving and installation costs are decreasing. Solar energy has a very high theoretical and technical potential and can be a solution for sustainability in energy sector.

Next section is provided to explain energy sector in Turkey. First, general information about Turkey is delivered, such as surface area, land usage, population, GDP, regulation upgrades, economy growth, unemployment rate, political challenges, environmental issues and fossil fuel dependency in Turkey. The place of renewable energy in Turkey's energy mix is also discussed. In the first sub-section, the overview of Turkish energy sector is introduced. Statistics and further information about consumption by resource and by sector, energy imports, primary energy supply, installed capacity and electricity generation, the place of fossil fuels and renewables, pricing mechanism, energy intensity and efficiency of the sector are delivered. Also, electricity markets and emissions from energy sector are discussed. In the second sub-section, current targets and strategies for energy sector of Turkey are examined, while mentioning demand expectations, action plans and used mechanisms. In the third sub-section, the focus is on solar energy in Turkey. Information about solar energy consumption in Turkey, solar potential of the country and irradiation levels by region, generation from and installed capacity of each solar technology, targets, incentives and current situation of solar market in Turkey are delivered in this part of the thesis. The aim of this section was to provide background information about Turkish energy sector and its infrastructure, future of the sector and the place of solar energy technologies in the sector. Turkey still relies on fossil fuels and depends on foreign energy resources. The increase of renewable energy shares in installed capacity of Turkey is a necessity and solar energy technologies are one of the beneficial solutions for sustainable Turkish energy sector.

Sustainable energy for Turkey is the section where the drivers of sustainability in Turkish energy sector, the obstacles for solar energy technologies in Turkey and the instruments for upgrading current Turkish energy sector to a more sustainable version are discussed. For a sustainable development of energy sector, all renewable energy technologies are important. But, this thesis focus only on solar energy technologies, as solar energy has the highest potential between renewables energy technologies in Turkey. In this section, drivers and obstacles were determined to specify the most beneficial instruments to apply for more sustainable energy sector in Turkey. With the specified instruments, it is possible to promote solar energy technologies in Turkish energy sector and lead the sector to a more sustainable way. By promoting renewable energy technologies, Turkey can secure the energy supply and decrease the energy dependency from other countries.

The drivers for a sustainable energy sector are determined according to the most important issues faced in Turkey. These drivers are classified under environmental, economic and social aspects. The obstacles are also classified under the same aspects. The obstacles are determined according to possible challenges that can be faced with in usage of solar energy. Finally, possible instruments that can be applied in energy sector are discussed. The aim of these instruments is to support sustainability aspects and upgrade the current energy sector to a more sustainable version. Some of the instruments are focused on energy sector and some are focused on specific technologies, which are solar energy technologies in this thesis.

Finally, conclusion on the research done is presented in the last section. The instruments suggested are compared with instruments used in EU and possible improvements with suggested instruments are predicted. In this section, it is concluded that solar energy in Turkey has a promising future with its high potential. However, it is necessary to upgrade current policies and subsidies to benefit the potential of solar energy in Turkey. The solar technologies may play a great role for transmission of Turkish energy sector to a more sustainable phase.

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