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Economic Analysis of Wind and Solar Energy Sources of Turkey

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Economic Analysis of Wind and Solar Energy Sources of Turkey

by

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Abstract

Economic Analysis of Wind and Solar Energy Sources of Turkey

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Renewable energy sources have become very popular in the last years in electricity generation thanks to the technological developments, the increase in the price of fossil fuels and the environmental concerns. These factors have also prompted Turkey to utilize her very rich renewable energy sources to meet the demand increasing around 7% annually. In this study, solar and wind energy potential of Turkey is analyzed in terms of its economics to find out whether these sources are real alternatives to fossil fuels in electricity generation. Before this analysis, wind and solar energy technologies and costs and wind and solar energy potential of Turkey are discussed. Then, models are set up for five technologies which are onshore wind, offshore wind, solar PV, solar trough and solar tower technologies models to calculate cash flows which are used to calculate payback, NPV, IRR, LCE and shut-down price to conduct economic analysis. In addition to base case scenario, uncertainty analysis is done for the most promising technologies which are onshore wind and solar tower technologies by evaluating NPV and LCE under uncertain environment. The main finding of these analyses is that only onshore wind projects are attractive in Turkey; none of other technologies is attractive. However, with a minor increase in the regulated price for solar thermal electricity, tower plant projects will also be attractive.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Renewable energy has become very popular in the last years due to the environmental concerns and the increase of fossil fuels price. In addition to these developments outside of the sector, the dynamics in the sector has played an important role in this period. The most important development in the sector is the decrease of the electricity generation cost from renewable sources in the last two decades. For example, the unit cost of wind-generated electricity decreased from ₵35/kWh in 1980s to ₵4/kWh in 2001 (Herbert et al., 2007). As a result, wind energy has become the world's fastest growing energy source (Ilkilic and Turkbay, 2010). The same developments most probably will be repeated for solar energy in the following years.

Another important factor helping the development of wind and solar energy is that the developed countries want to decrease their dependence on foreign fossil fuels as to decrease the wealth outflow and to support the national economy. In addition, the depletion of fossil fuels may cause a huge economic collapse if the current dependence on these sources continues. On the other hand, renewable energy sources are abundant and inexhaustible.

The same problems are also valid for Turkey who is dependent to foreign sources around 75% (Akdag and Guler, 2010). In addition, because of Turkey's dynamic and fast growing economy, there is an ongoing high growth in the electricity demand. For example, the electricity demand increased 5.3% annually between 2000 and 2009 despite the adverse effects of the global economic crisis in 2008 and 2009 (TEIAS, 2010). It is forecasted that the demand will increase 7% annually in the next decade (TEIAS, 2010). To meet this significant increase in demand, Turkey has to install as much as capacity of 35 – 60 GW through 2020 (Kaygusuz, 2011). Unfortunately, Turkey does not have domestic fossil fuel resources, except some low quality lignite to feed this capacity and currently her dependence on the foreign sources are very high.

On the other hand, Turkey has very high wind and solar energy potential. She is the first ranked country in Europe in wind energy potential and one of the most favorable countries in terms of solar energy. Therefore, the utilization of renewable energy sources is the best option to meet the increase in the electricity demand in the future. Based on these concerns, the Renewable Energy Law was enacted in 2005 to incentivize the renewables and the feed-in tariffs were increased in 2010 with the amendment of the mentioned law. In this study, wind and solar energy potential of Turkey are analyzed to find out whether these sources can be utilized economically based on the current regulated prices and the current wind and solar power plant costs collected from numerous sources.

In Chapter 2, electricity generation technology and cost of wind and solar power plants are discussed based on the literature survey. First, wind electricity generation technology which is nearly the same both for onshore and offshore projects are explained. Then, the cost of onshore and offshore power plants is analyzed and some data collected from a numerous studies are given. The same explanations and analysis are also done for solar power technologies which are PV, parabolic trough, Fresnel, tower, solar dish and chimney. Last, the intermittency problem of renewable energy, especially important for wind and PV power plants, are discussed.

In Chapter 3, some background information about Turkish electricity market and her wind and solar energy potential are discussed. First, the history of Turkish electricity industry is summarized and the current structure of Turkish electricity market is explained. Then, some data encompassing installed capacity, total production and the shares of sources and players in the sector are explained. Last, wind and solar energy potential of Turkey are discussed based on the data created by the responsible public institutions.

In Chapter 4, economic analysis of wind and solar energy potential of Turkey is done based on the cost data and the technical parameters given in Chapter 2 and 3. A model for each technology is constructed to calculate cash flows for the lifetime of the power plants. Then, these cash flows are used to calculate payback period, NPV, IRR, LCE, and shut-down price for each technology. Lastly, uncertainty analysis is done for the most promising technologies among the analyzed technologies which are onshore wind, offshore wind, solar PV, solar trough and solar tower.

In Chapter 5, the main results of the economic analysis of wind and solar energy potential of Turkey are summarized.

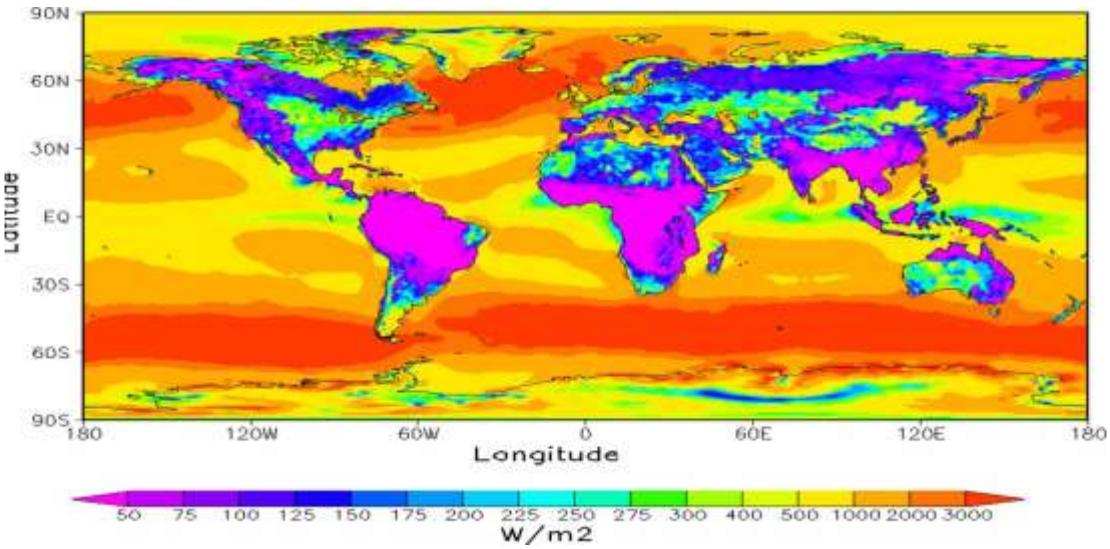
Chapter 2: Technology and Cost of Wind and Solar Energy

In this chapter, electricity generation technology and cost of wind and solar power plants and the intermittency problem of renewables are explained based on the literature survey. First, some information about wind electricity generation technology and costs of wind power plants are examined for onshore and offshore wind technologies. Second, solar energy technologies which are PV, parabolic trough, tower, dish, Fresnel, and chimney are explained and the costs of solar power plants for selected technologies which are solar PV, solar trough and solar tower are discussed. Last, the intermittency problem of renewable power plants like wind and PV power plants are discussed.

2.1. WIND ENERGY: TECHNOLOGY AND COST

Wind energy has become very popular alternative in electricity generation as a result of the technological developments in wind turbine manufacturing, the increase in the price of fossil fuels and the environmental concerns. In addition to these, some advantages such as cleanliness and low cost have helped wind energy to be one of the most promising sources. With the help of all of these factors, wind energy has become the world's fastest growing energy source (Ilkilic and Turkbay, 2010).

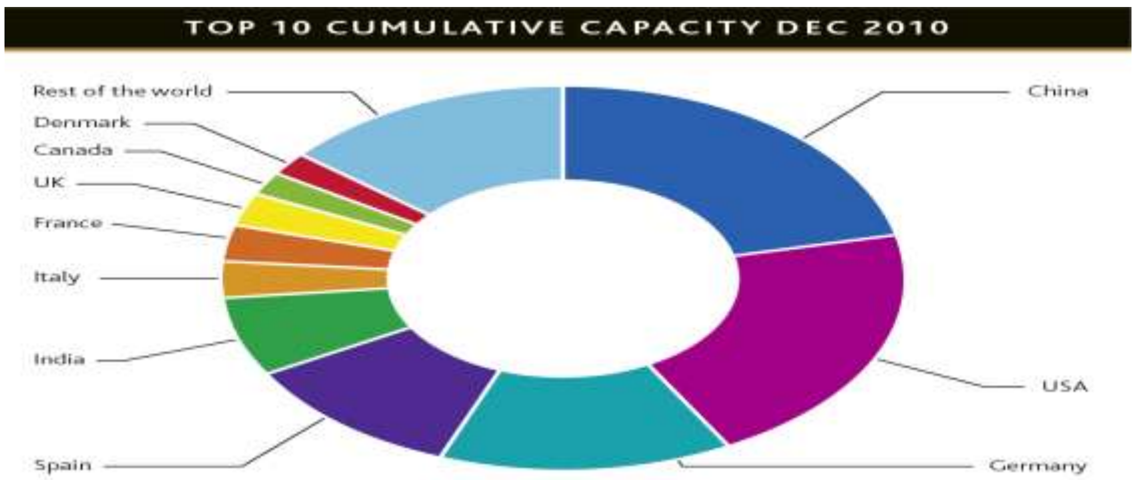
Figure 1: The dispersion of wind energy source in the world



Source: Liu et al., 2009.

Wind energy is abundant all over the world as depicted in Figure 1, but the wind power plants are generally deployed in the Western countries. In fact, global wind power installed capacity reached 194 GW in 2010 with the contribution of 86.3% of this capacity by the top ten countries most of which are European countries. When we look at the top ten countries having the highest wind energy capacity (Figure 2), it can be seen that eight of them are developed countries. However, the first rank country is not a developed country. China who was the third country with a capacity of 25.8 GW and a share of 16.3% in 2009 became the leading country in 2010 with a total installed capacity of 42 GW and a share of 21.8%. She is followed by the US whose market share is slightly over 20%. The US was the leading country before 2010, but in 2010 she built only new capacity of 5 MW while China installed new capacity of 16.5 GW. In the last years, China and India has built lots of new wind turbines to get advantage of decreasing cost of wind energy (GWEC, 2010 and GWEC, 2011). Most probably, this trend in developing countries will be the propellant of the development of the global wind market in the following years.

Figure 2: Top 10 countries having the highest wind installed capacity by 2010



Country	MW	%
China	42,287	21.8
USA	40,180	20.7
Germany	27,214	14.0
Spain	20,676	10.6
India	13,065	6.7
Italy	5,797	3.0
France	5,660	2.9
UK	5,204	2.7
Canada	4,009	2.1
Denmark	3,752	1.9
Rest of the world	26,546	13.7
Total TOP 10	**167,844**	**86.3**
World Total	**194,390**	**100**

Source: GWEC, 2011.

In addition to the analysis of country base, the growth in the installed capacity will also helps us to understand how wind energy has become the most popular energy source in the world. The new installed capacity for each year in the time period between 1996 and 2010 shows that more wind power plants have been built from year to year

(Figure 3). Over the past five years, annual average growth rate of global wind energy capacity has been 27%, mainly driven by China and the US. In addition, the growth of global wind energy market continued even in 2009 and 2010 despite the recent global financial crisis.

Figure 3: Wind energy new capacity growth in the world

Source: GWEC, 2011.

In this section, electricity generation technology and cost of wind energy are discussed. First, some information about wind electricity generation technology is given. Then, the cost of wind power plants are analyzed by focusing on the cost and the other factors affecting the cost of power for onshore and offshore technologies separately.

2.1.1. Technological Aspects

Wind turbines are energy conversion machines that convert wind power to electrical energy through two phases. In the first step, mechanical energy is generated from wind power with the rotation of blades that are exposed to wind. In the second step, the mechanical energy is transferred to the generator through gear system to produce electrical energy.

In this part, the technology of modern wind turbine is explained by focusing on the theory of wind energy utilization, a summary of the developments in the modern wind turbine, and the mechanism of wind turbines. Then, the main systems consisting of a typical wind turbine are discussed.

Theory of Wind Energy Utilization: The power of wind depends on three factors which are the density of air, the area swept by blades, and the speed of wind. The relation between the magnitude of the power and these three factors are given in Equation 1 (Kaygusuz, 2009):

$$P_w = \frac{1}{2}\rho A v^2 \qquad (1)$$

Where P_w is the power of wind; ρ is the air density; A is the swept area of blades; and v is the wind speed.

However, wind turbine cannot convert all of this power to electrical energy, though the proper selection of rotor speed, velocity distribution of wind, and aerodynamics of turbine can increase the efficiency rate (Ilkilic and Turkbay, 2010). In fact, the advances in these factors have contributed to 5% annual increase in the electricity production amount of wind turbines since 1980 (Herbert et al., 2007).

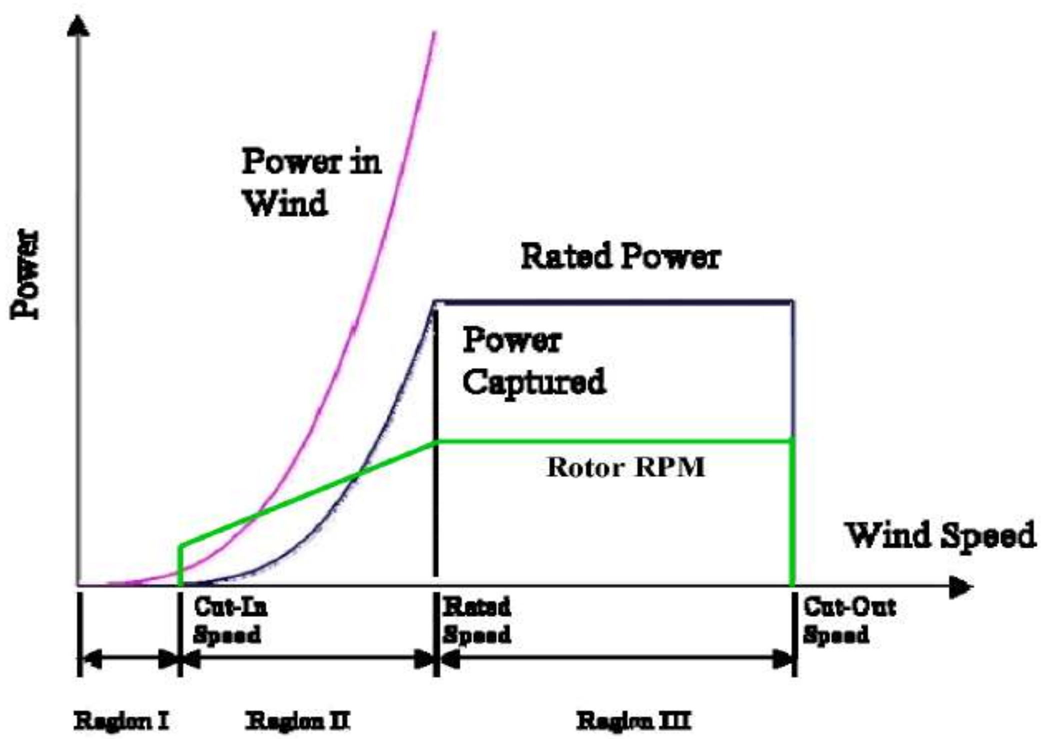
The altitude of the turbine is another important factor considerably affecting the amount of electricity generation. Typically, wind speed increases at the higher altitude according to wind profile power law given in Equation 2 (Celik, 2007).

$$v_{h1} = v_{h2}\left(\frac{h1}{h2}\right)^{\propto} \qquad (2)$$

Where, v_{h1} represents the speed at altitude h1, v_{h2} represents the speed at altitude h2, and α represents the exponential factor that varies with the topography and climatic conditions of the relevant location. It is taken as 0.13 for water areas, 0.16 for shore, 0.24 for wooded plain, and 0.30 for urban areas (Notton et al., 2001).

On the other hand, electricity generation will increase to the third power of the increase in wind speed. For example, if the altitude of turbine is increased by 50%, the speed will increase 6.3% and the electricity generation will increase 21.5%. However, sometimes turbines cannot utilize all of the wind power at high speed because there is a wind speed range for each turbine to work safely. Generally, a turbine starts to generate electricity at 12 mph (cut-in speed), reaches rated capacity at around 30 mph and stops at about 50 mph to prevent overload and damage to turbine (Thresher et al., 2008). This process is depicted in Figure 4.

Figure 4: Power output curve of a typical wind turbine.

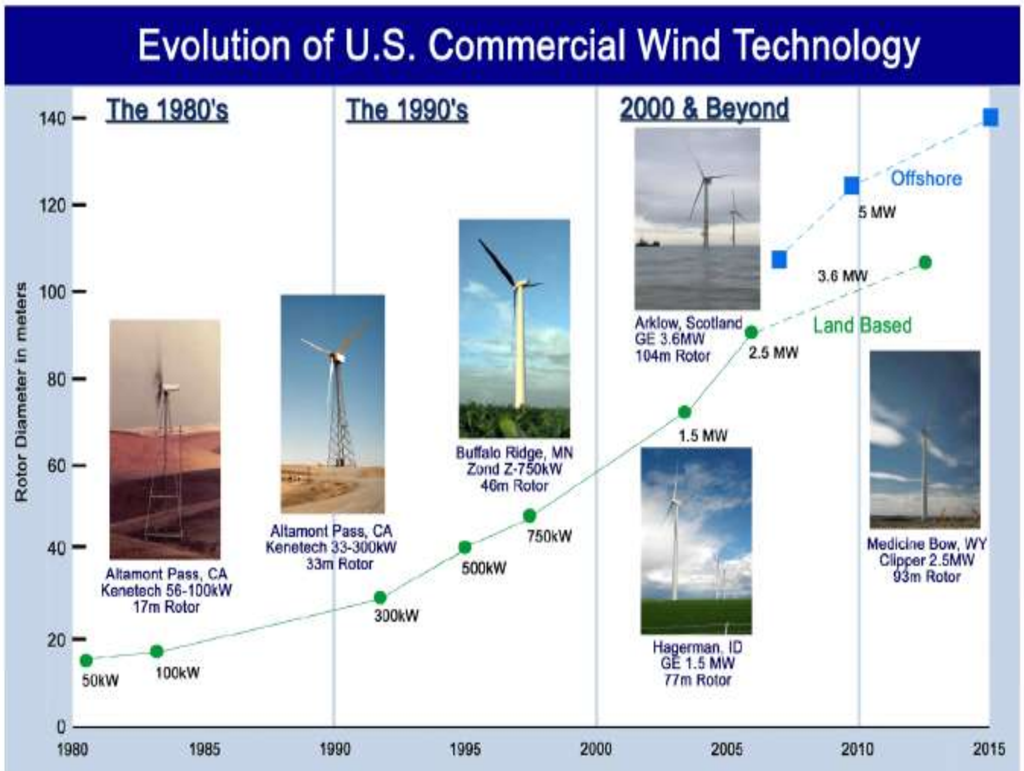


Source: Thresher et al., 2008.

The History of Modern Wind Turbine: the utilization of wind energy is not a new method. Instead, wind power has been utilized for more than thousands years by means of windmills, but the generation of electricity from wind energy started in the 20th century. The main difference between a typical modern wind turbine and a windmill is that windmills have converted wind power to mechanical energy and have utilized this energy directly to do physical jobs while wind turbines have used the mechanical energy to generate electricity (Kaygusuz, 2009). The other important difference is the efficiency rates. Modern wind turbines can convert nearly 50% of wind power into mechanical energy while windmills can utilize only 10% of wind power. According to Betz' Law, 59% of wind power can be utilized at maximum and the current wind turbines have succeeded to reach to 80% of this limit (Ilkilic and Turkbay, 2010).

The most important factor behind the increase in efficiency is the manufacture of large wind turbines with high capacity (Figure 5). In the beginning of 1980s, the turbine size was only 50 kW. Then, the first important improvement occurred with the construction of 330 kW turbines in the early 90s. Another milestone was the invention of wind turbines with a nameplate capacity of 750 kW before the end of the 2nd millennia. The other important development was the installation of the first wind turbine with a capacity of over 1 MW in the beginning of 2000s. Currently, the largest wind turbine was constructed by Enercon in Germany with a capacity of 7.5 MW (Enercon, 2010). The new goal is the manufacturing of a turbine with a capacity of 10 MW (Vidal, 2010). These mega wind turbines are designed to exploit the wind power in high speed wind sites like offshore areas and onshore areas where space is scarce (Ahilan et al., 2008).

Figure 5: The development of wind turbine capacity growth in the last three decades.



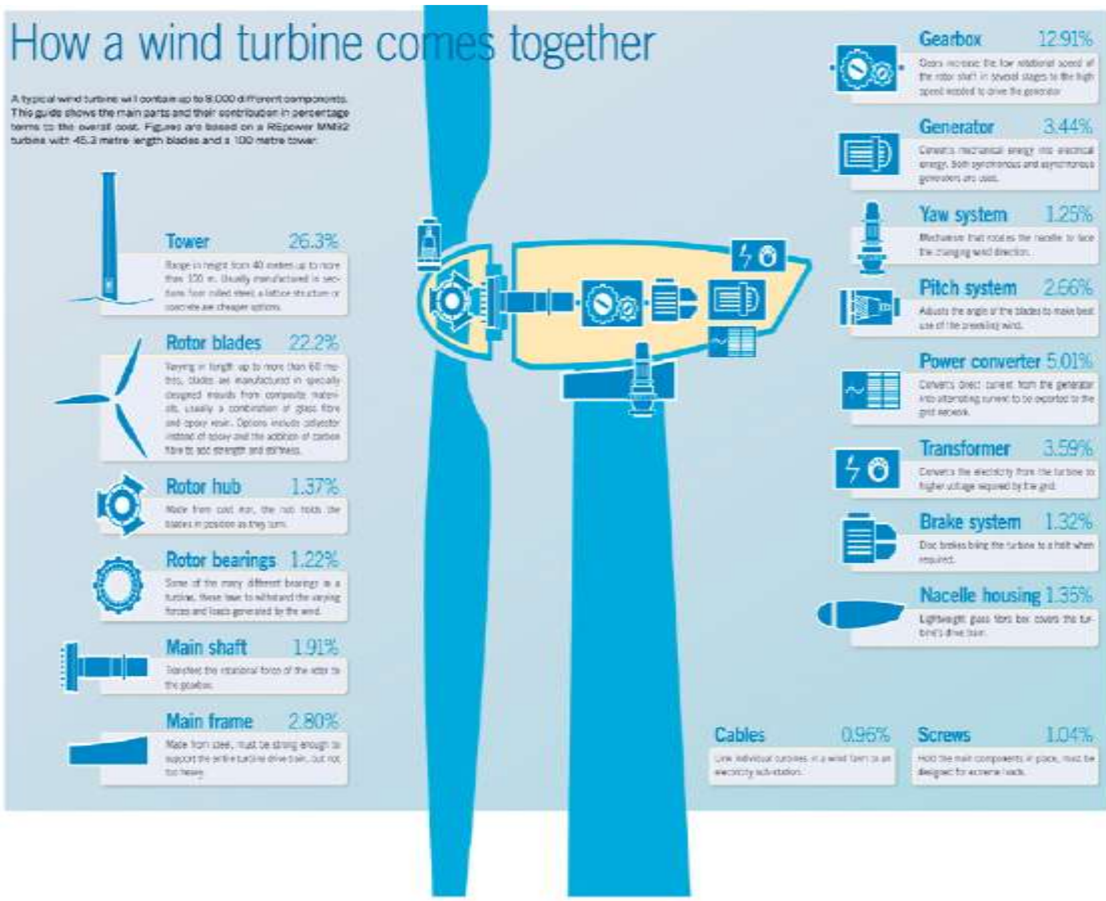
Source: Thresher et al. (2008)

The increase of turbine size has changed the market share of MW-class turbines which represented 95% of total installed capacity in 2007 (Krohn et al., 2009). Thus, the average capacity reached to 1.74 MW in 2009 in the US from 1.66 MW in 2008 (Wiser and Bolinger, 2010).

The construction of larger wind turbines will make it possible to utilize the wind power with higher speed at higher altitude and will increase the amount of electricity generated from a unit area. However, there are some limitations preventing the increase of turbine size. First of all, its extra cost has to be compensated with the increase in the amount of electricity produced. In fact, the diseconomies of scale exists at some sizes because of the "square cube law" which is a situation that "as a wind turbine rotor increases in size, its energy output increases as the rotor-swept area (the diameter squared), while the volume of material, and therefore its mass and cost, increases as the cube of the diameter" (Thresher et al., 2008). The second challenge is the transportation constraints that are specifically relevant for onshore turbine deployment. The current transportation infrastructure does not support cost-effective transportation of large parts. Therefore, many turbine designers expect that the size of onshore turbines will not exceed 3 to 5 MW in the foreseen future because of the logistical constraints (Thresher et al., 2008). As a result, onshore wind turbine manufacturers focus on the production of 1.5-3 MW turbines because of the strong demand for these sizes in the market (Krohn et al., 2009).

The Mechanism of Wind Turbines: The modern wind turbines generally consists of a tower of 60-80 meters high, a three-bladed rotor with a diameter of 70-80 meters, and a drive train containing gearbox, generator, and control systems (Thresher et al., 2008). The main components of a typical wind turbine are depicted in Figure 6. The electricity generation process commences with the rotation of blades which form the rotor system with rotor hub and rotor bearings. The mechanical power generated by the rotation of blades is transferred to the gearbox within the drive train by means of the main shaft which connects rotor to drive train. Then, the gearbox increases the speed of rotation and conveys the mechanical energy to the generator where electricity is produced. Afterwards, the direct current (DC) produced by the generator is converted into the alternating current (AC) by the power converter and then electricity is conveyed to the transformer. The last step is the transformation of low voltage electric current to high voltage to be transferred to the grid. In addition to these main systems, there is also a control system consisting of pitch system, yaw system, and brake system which help the materialization of the electricity production safely and efficiently. To sum up, there are four main systems in a typical wind turbine which are the rotor, the drive train, the control, and the tower. Each of these main systems is explained in this section below.

Figure 6: The main components of a wind turbine (5 MW)



Source: Blanco, 2009.

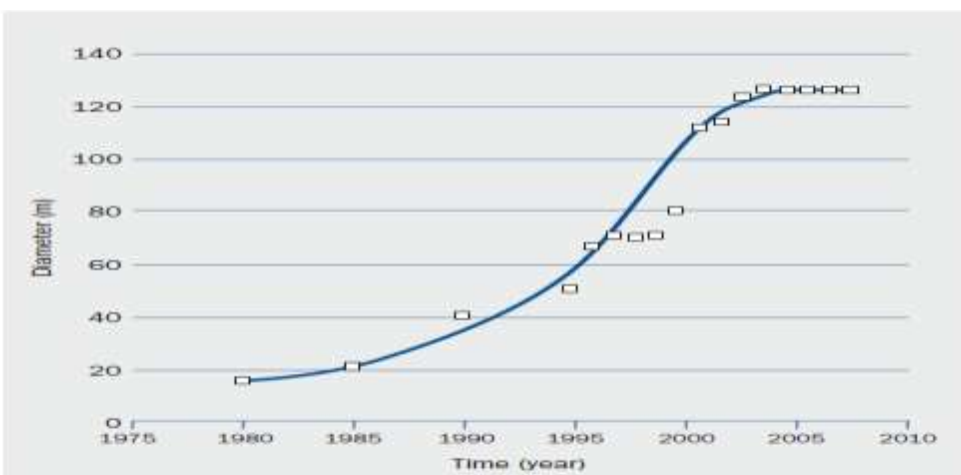
2.1.1.1. The Tower

The tower manufactured from steel is the structure atop which the other parts are mounted. It is put on the concrete foundation which is designed and built based on the site conditions. The most important concern about the tower is the decision of the height which has to be selected to optimize energy production and tower cost for the relevant site's wind and land characteristics (Thresher et al., 2008). The height of the tower is also related to the magnitude of the swept area of the blades. In the current market, the majority of turbines deployed all over the world have tower heights of 60 to 80 m (Thresher et al., 2008). However, for mega size wind turbines the height of tower exceeds 100 meter. For example, the 7.5 MW turbines in Germany have towers of 135 meter high (Enercon, 2010).

2.1.1.2. The Rotor

The second important system of a wind turbine is the rotor system which encompasses rotor blades, rotor hub, and rotor bearings all of which are discussed briefly in this section. In parallel with the increase in the size of turbine, the swept area has also been increased considerably. From the diameter below 20 m in 1980, it reached to the diameter of over 120 m in 2000s as depicted in Figure 7. For example, the diameter of the 7.5 MW wind turbines constructed in Germany is 127 meter (Enercon, 2010).

Figure 7: Historical change of the length of diameter of wind turbines.



Source: Krohn et al., 2009.

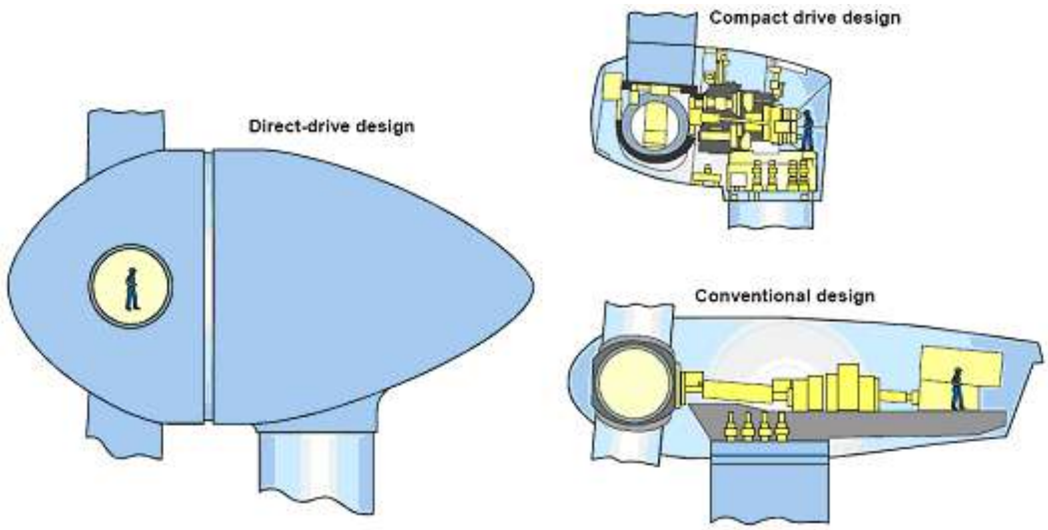
The most important parts of the rotor system are blades because the swept area of them determines the amount of electricity production in a specific site. The larger swept area can be succeeded by increasing the length of blades, but the longer the blades are, the heavier the structure atop the tower is. This adverse effect causes an increase in the cost of blades and tower and eliminates the benefit of the utilization of more wind energy. Therefore, manufacturers have improved the blade design to remove the extra weight in addition to the use of more sophisticated materials like carbon fiber (Thresher et al., 2008).

The other important issue for blades has been the optimal number of blades. As a one-bladed turbine minimizes energy loss, two-bladed and three-bladed ones are preferred because of the advantages of stability, better aerodynamic performance and lower cost. Therefore, one blade option has not been commercialized. Among the other two options, two-bladed rotors are superior in terms of the cost and the weight of the third blade are eliminated. However, they require higher rotational speed to compensate the deficiency of the third blade, so these turbines are not common in the market (Ahilan et al., 2008). As a result, three-bladed designs dominate the market based on the current technical structures of these three options.

2.1.1.3. The Drive Train

The third important system is the drive train which is located within the nacelle. There are several drive train designs like the non-integrated drive train system, the gearless direct drive train system, and the compact drive train system. These systems are given in Figure 8.

Figure 8: Different drive train construction



Source: Ahilan et al., 2008.

The non-integrated drive train design is the conventional option and commonly dominates the market with about 85% market share globally (Ahilan et al., 2008). This system contains a multi stage gearbox (generally three stage gearbox - Thresher et al. 2008) which takes a slow rotation from the rotor system and increases it with the help of several gears before transferring to the generator. The durability and reliability are important problems for this system, so the R&D effort to develop new systems to address these challenges is a hot topic in the wind industry (Thresher et al., 2008).

The second option is the gearless system where the rotation of the rotor is transferred to the generator at the same speed. These turbines has a low speed generator which produce less electricity from the relevant wind energy, but it is compensated by the decreases in the capital cost and O&M cost. The market share of this system is around 15% (Ahilan et al., 2008).

The last option is the compact drive train system which consists of a single stage gearbox and a medium to high speed generator, but it is still on the R&D stage (Ahilan et al., 2008). This system may not supply the same amount of energy compared to the conventional one, though they may increase reliability and durability. For example, a hydraulic system is 10-30% less efficient compared to the conventional system in terms of the transfer of the rotation of the rotor to the generator, but it is so reliable that it works better in any climate condition compared to the conventional system (Williams and Smith, 2010).

2.1.1.4. The Control System

The control system embraces three main control mechanisms which are pitch system, brake system, and yaw system. Pitch system controls the amount of captured power from the wind power and prevents sudden changes in the electricity generation. In other words, the pitch system regulates the rotor speed and thus makes it possible to obtain maximum efficiency from fluctuating wind. Besides, it prevents the rotor to exceed the rotor speed limit in case of high wind speed. The second control mechanism, brake system, is used to stop the rotation of blades in two cases. First, it stops the turbine when the wind speed reaches the survival speed at which it puts the turbine into endanger if it continues to work. Secondly, this mechanism is used during the repair work. The third control system is yaw system which rotates the nacelle and point the turbine into the wind to take advantage of the maximum wind speed.

2.1.2. Cost Analysis

In this section, cost components and technical factors affecting the level of costs are discussed for each wind technology. Firstly, two main cost components which are capital cost and O&M cost and five technical factors which are wind speed, capacity factor, economic lifetime, salvage value, and discount rate are explained for onshore technology. Then, the same items are discussed for offshore technology by especially focusing on the items having different characteristic.

2.1.2.1. Onshore Wind Technology

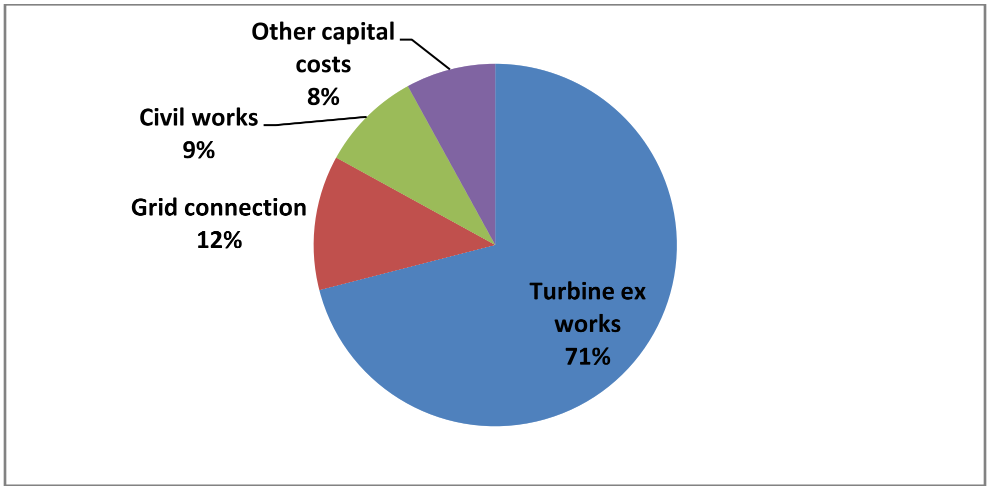
Wind power has become cheaper since 1980 thanks to mainly the increase of the capacity of turbines and the rise of the size of wind power projects (Hammons, 2004). In addition, the efficiency and the reliability of wind turbines has enhanced with the technological improvements. As a result, in the USA the unit cost of wind-generated electricity decreased from ₵35/kWh in 1980s to ₵4/kWh in 2001 (Herbert et al., 2007). Currently, wind-generated electricity is competitive in electricity markets for the sites having high wind speed.

The cost of wind energy projects consists of capital cost and O&M cost. Contrary to conventional energy sources like natural gas, coal and nuclear, wind farms' fuel cost is zero. Among these two main cost components, capital cost constitutes 80% of the total cost of a wind energy project during lifetime while the remaining is stemmed from O&M cost (Blanco, 2009).

In this section, the main cost components and technical parameters of an onshore wind farm are explained and some data collected from the literature are summarized. Firstly, capital cost is discussed by classifying it into three categories: turbine cost, grid connection cost, and other capital cost. Then, the content, the importance and the magnitude of O&M cost are explained. After cost components, five main technical parameters of wind turbines that determine the level of cost and revenue are discussed: wind speed, capacity factor, economic lifetime, salvage value, and discount rate.

Capital Cost: The weight of capital cost is significant for onshore wind farms. The capital cost consists of turbine cost, grid connection cost, civil work cost, and other installation cost; the share of each component in a typical wind project in Europe is given in Figure 9.

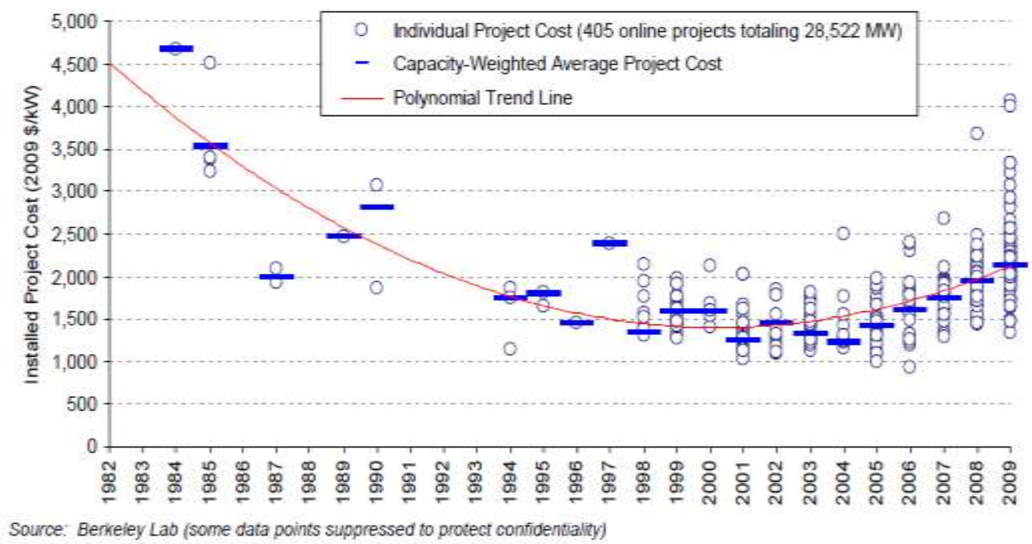
Figure 9: Capital cost distribution of an onshore wind project in Europe



Source: Blanco, 2009.

The enhancement in wind turbine technology provided a continuous decrease in the unit capital cost of wind turbines between 1970s and 2000s as shown in Figure 10, but this downward trend has ended in the beginning of 2000s when the wind technology reached a stable level. The most important factor for this situation was that the capacity of wind turbines reached to the optimal level at around 5 MW. After 2004, the trend reversed and the capital cost has increased mainly because of the reasons including the booming demand for wind turbines, a decline in the value of the U.S. dollar relative to the other currencies, and the increase in the price of materials like steel, copper, lead, cement, aluminum and carbon fiber which are used to manufacture wind turbines (Blanco, 2009, Wiser and Bolinger, 2010).

Figure 10: The trajectory of capital cost in the last 3 decades.



Source: Wiser and Bolinger, 2010.

Each component of capital cost is explained below.

Grid Connection Cost: Grid connection cost consists of the cost of cables, sub-station, connection, and power evacuation systems. In addition, if there is not enough transmission capacity the cost of the upgrade in transmission system should be added to grid connection. In the past, the capacity of wind turbines was low and they were deployed close to the grid, so it was possible to connect these turbines cheaply to the distribution grid. However, nowadays mega wind turbines are generally deployed in the sites far from the current electricity infrastructure, so a great deal of grid connection cost is needed (Blanco, 2009). Some data about grid connection costs are given in Table 1.

Table 1: Grid connection cost for onshore wind projects

Original Value	Calculated Value* ($/MW)	Source
€115.24/kW	152,776	Blanco, 2009
€90-121.5/kW	140,195	EWEA, 2009
€109/kW	144,503	Krohn et al., 2009
10-15% of investment cost		Kumar et al., 2009
4-8% of investment cost		Kenisarin et al., 2006

*The average exchange rate of 2010 is used to convert EUR to USD.

Turbine Cost: Turbine cost constitutes more than 70% of capital cost, so it is the most important cost component for onshore wind projects. In the past, the enhancements in wind turbine technology decreased the turbine cost, but since 2002 the gains from technological enhancements have been overwhelmed by the increase in the cost of material. As a result, unit turbine cost has been increasing in the last years. (Wiser and Bolinger, 2010). Therefore, turbine cost data are collected from the relatively new studies. These data about the cost of turbine is given in Table 2.

Table 2: Turbine cost data for onshore wind projects

Original Value (per kW)	Turbine Capacity (MW)	Calculated Value ($/MW)	Source
$899	1	899,000	Akdag and Guler,2009
$1,042	1.3	1,041,538	Akdag and Guler,2009
$950	2	949,500	Akdag and Guler,2009
$937	2.3	936,957	Akdag and Guler,2009
$514	0.6	514,333	Vardar and Cetin, 2009
$464	1.3	463,846	Vardar and Cetin, 2009
$455	2.5	454,800	Vardar and Cetin, 2009
$1,035		1,035,000	Hrayshat, 2009
65-70% of capital cost			Kumar et al., 2009

Other Capital Cost: Other capital cost consists of the cost of foundation, road construction, buildings, feasibility study, engineering, site improvement, and other items that are not included in turbine cost and grid connection cost. This cost highly varies from country to country and project to project because of two main reasons:

- The weight of labor cost which differs from country to country constitutes a big share of other capital cost (Blanco, 2009).
- The characteristic of a site which differs from site to site is an important factor determining the level of this cost (Krohn et al., 2009).

Some data about this category of capital cost is given in Table 3.

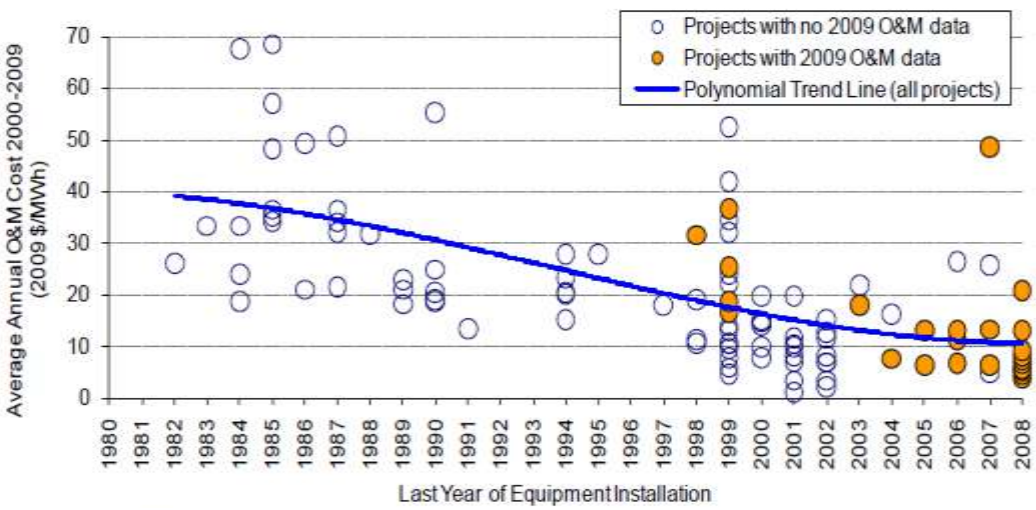
Table 3: Other capital cost data for onshore wind projects

Original Value	Turbine Capacity (MW)	Calculated Value ($/MW)	Source
$14,000 for 0.6 MW	0.6	23,333	Vardar and Cetin, 2009
$18,400 for 1.3 MW	1.3	14,154	Vardar and Cetin,2009
$25,000 for 2.5 MW	2.5	10,000	Vardar and Cetin, 2009
$35.000 for 2.5 MW	2.5	14,000	Rehman et al, 2003
$26,000 for 1.3 MW	1.3	20,000	Rehman et al, 2003
$20,000 for 0.6	0.6	33,333	Rehman et al, 2003
5-15% of capital cost			Kumar et al., 2009
5-12% of capital cost			Kenisarin et al., 2006
20% of capital cost			Diaf et al., 2008

O&M Cost: O&M cost consists of both variable cost including the cost of repair and spare parts and fixed cost spent for insurance, regular maintenance, and land rent. Fuel cost is zero for wind turbines, so the level of O&M cost is the only factor in the determination of unit cost of wind-generated electricity once turbine starts to work.

Like capital cost, O&M cost have also dropped in the last three decades thanks to the improvement in design and the increase in reliability. As a result, unit O&M cost decreased to below ₵1/kWh in 2008 from ₵3-5/kWh in 1980s, which has strengthened the competitive power of wind energy by pushing down the unit electricity cost of wind power plants (Thresher et al., 2008). This downward trend is depicted in Figure 11 which shows the unit O&M cost for different project installed in 1980s, 1990s, and 2000s. When the graph is examined, it can be seen that the capacity-weighted average 2000-09 O&M cost of the projects completed in 1980s is ₵3.2/kWh, while it is 2.2/kWh for the projects installed in 1990s and 0.9/kWh for the projects installed in 2000s.

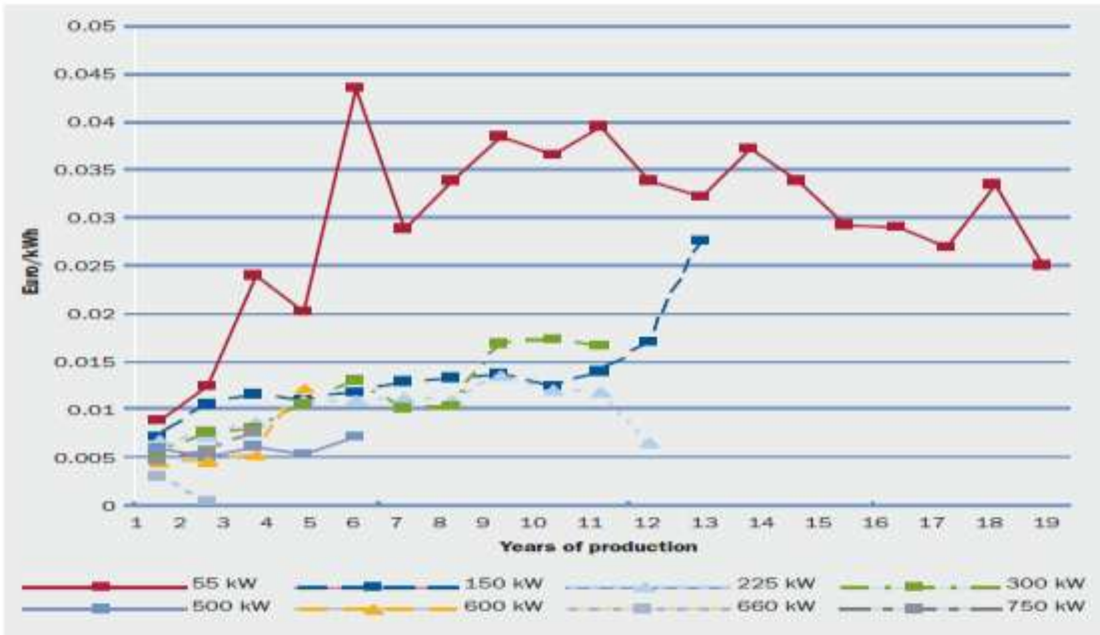
Figure 11: Average O&M cost for some projects installed in different time intervals.



Source: Wiser and Bolinger, 2010.

Some studies have investigated the reason(s) of the decrease in unit O&M cost to find out which one among the factors including the age, the efficiency, and the size of the wind turbines are more important. For example, Jensen et al. (2002) does such an investigation by analyzing the O&M cost of different wind farms having different sizes and different ages and concludes that both factors is effective, but the former one is more effective. The result of this study is given in Figure12.

Figure 12: O&M cost for different wind projects



Source: Jensen et al., 2002.

The data about O&M cost collected from several sources is given in Table 4.

Table 4: O&M cost data for onshore wind projects

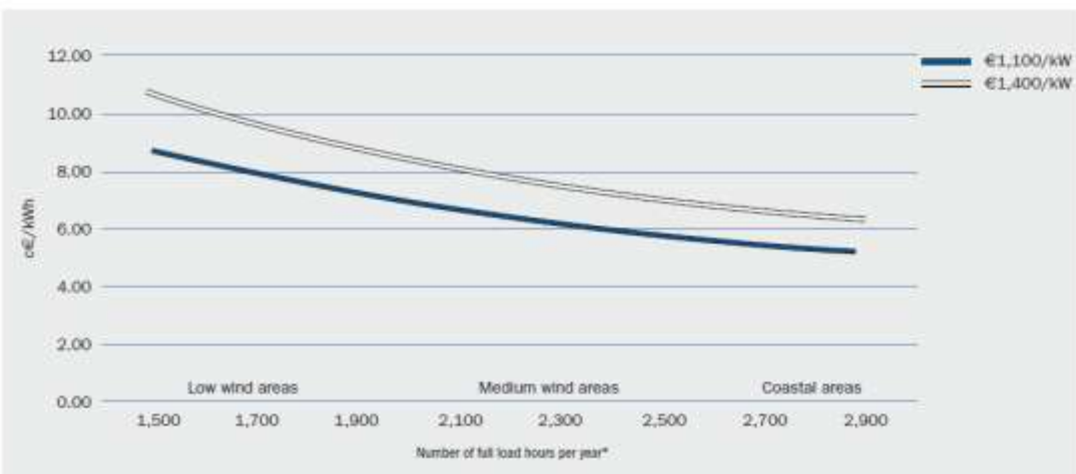
Original Value	Minimum* ($/MWh)	Maximum* ($/MWh)	Calculated Value* ($/MWh)	Source
₵1/kWh			10.00	Thresher et al., 2008
$9/MWh			9.00	Wiser and Bolinger, 2010
1-2 € cent/kWh	13.26	26.51	19.89	Blanco, 2009
$35,000 per turbine with a capacity between 0.6 MW and 2.5 MW	5.33	22.20	13.76	Rehman et al., 2003
1.5 € cent/kWh			19.89	Erik, 2009
1.2-1.5 € cent / kWh	15.91	19.89	17.90	Krohn et al., 2009
₵2.2/kWh			22.00	IEA, 2010 a
$17.5/MWh			17.50	Arslan, 2010

*The average exchange rate of 2010 is used to convert EUR to USD.

In addition to the cost components, the main technical and financial factors affecting the economy of wind power plants are discussed in the remaining part of this section.

Wind Speed: The most important factor in the economy of wind projects is the wind speed of the relevant site. Wind speed is so important that it determines the capacity factor of a wind project and the unit electricity generation cost of a wind farm for given capital cost. This relation between wind speed, capacity factor, and unit cost is given in Figure 13 which shows that unit cost decreases about 50% if the wind farm is deployed in a coastal area instead of low wind areas.

Figure 13: The unit cost for wind farms deployed in different areas having different wind speed.



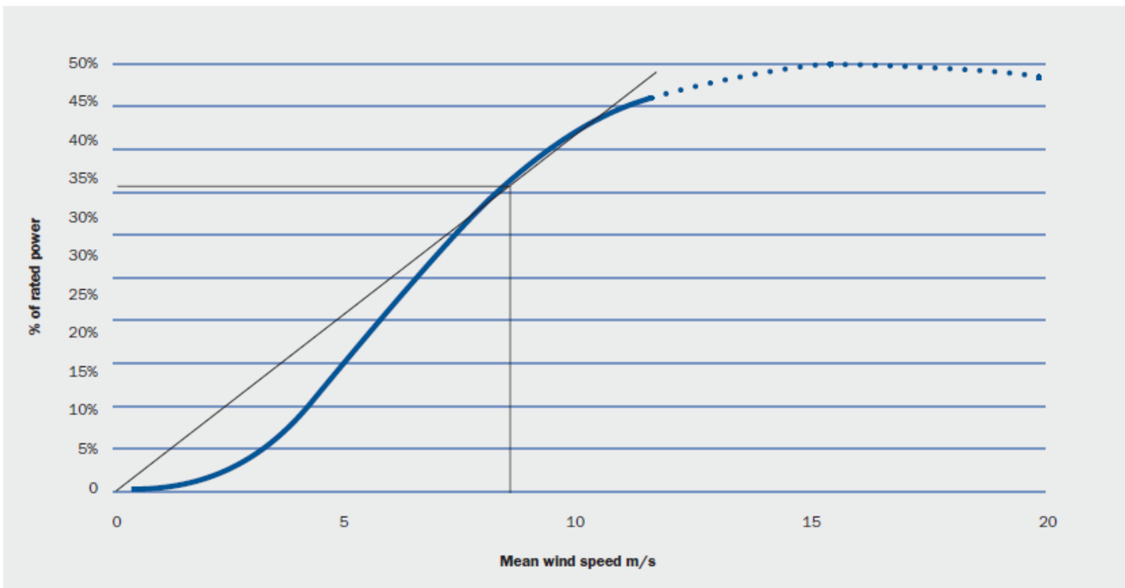
* Full load hours are the number of hours during one year during which the turbine would have to run at full power in order to produce the energy delivered throughout a year (i.e. the capacity factor multiplied by 8,760).

Source: Risø DTU

Source: Krohn et al., 2009.

The importance of wind speed comes from the relative change of the amount of energy when the wind speed change as it is explained in Section 2.1.1: the energy increases with the third power of the increase in the wind speed. For example, the energy of wind becomes eight folds if wind speed doubles. This huge increase in wind energy also pulls up the capacity factor. A theoretical relationship between wind speed and capacity factor is given in Figure 14. If it is taken into account that the average wind speed is mostly between 6 and 12 m/s, the relation can be assumed as linear.

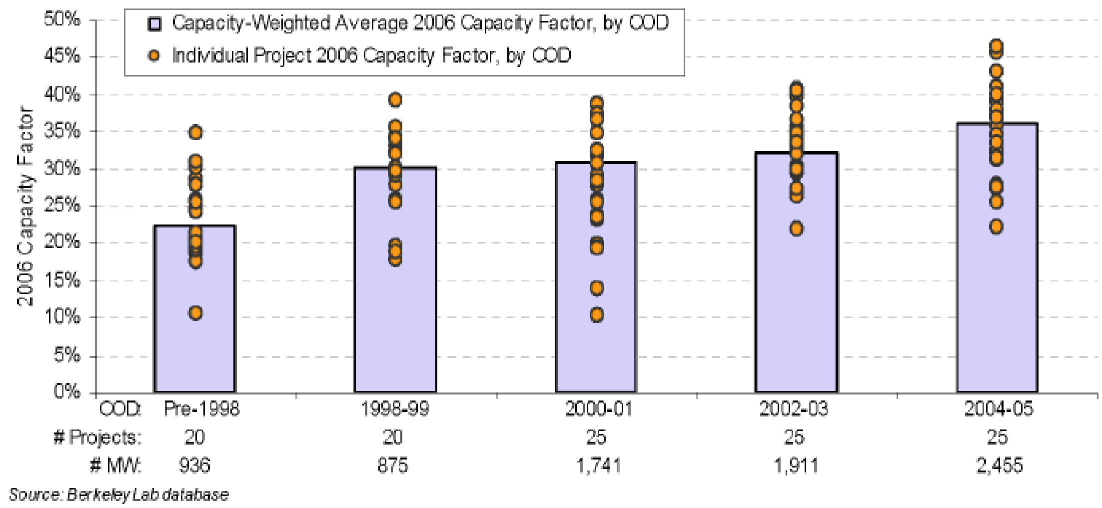
Figure 14: The relationship between wind speed and capacity factor.



Source: Krohn et al., 2009.

Capacity Factor: Capacity factor mainly depends on the wind speed of the site as explained in “Wind Speed” part above and the utilization of wind energy by the turbines which depends on the technology of the turbines. Thanks to the technological improvements in turbine manufacturing, capacity factors for the same wind speed is increasing as shown in Figure 15.

Figure 15: The relationship between capacity factor and turbine deployment year



Source: Thresher et al., 2008.

Wind turbines generally work around 70-85% of the time, but they could not generate maximum capacity at all times of work due to the fluctuation of wind speed. Hence, the capacity factor is much lower than this level. It is generally around 30% for onshore wind turbines and 35% for offshore wind turbines (ODE, 2007). According to IEA (2010a), the capacity factor of wind projects range from 21 to 41% for onshore and 34 to 43% for offshore.

Some capacity factor rates from several studies conducted for different sites having different wind speed are given in Table 5.

Table 5: Capacity factor data for onshore wind projects

Wind Speed (m/s)	Capacity Factor (%)	Source	Wind Speed (m/s)	Capacity Factor (%)	Source
8.40	35.50%	Krohn et al., 2009	7.58	36.30%	Akdag and Guler, 2010
7.60	33.30%	Kenisarin et al., 2006	7.71	38.00%	Akdag and Guler, 2010
7.30	28.50%	Kenisarin et al., 2006	5.52	19.90%	Akdag and Guler, 2010
6.70	26.00%	Kenisarin et al., 2006	9.38	50.30%	Akdag and Guler, 2010
7.10	25.50%	Kenisarin et al., 2006	6.80	30.10%	Akdag and Guler, 2010
6.90	21.90%	Kenisarin et al., 2006	7.28	34.20%	Akdag and Guler, 2010
6.10	21.80%	Kenisarin et al., 2006	9.78	43.70%	Akdag and Guler, 2010
5.57	20.60%	Akdag and Guler, 2010		25-35%	Wiser and Bolinger, 2010
5.56	19.70%	Akdag and Guler, 2010		23.7-31.4%	Akdag and Guler,2009
8.56	44.40%	Akdag and Guler, 2010		19-35%	Blanco, 2009
9.51	49.20%	Akdag and Guler, 2010		30%	ODE, 2007
8.88	40.00%	Akdag and Guler, 2010		23-29%	Krohn et al., 2009
5.52	20.70%	Akdag and Guler, 2010		26%	IEA, 2010a
7.81	40.40%	Akdag and Guler, 2010		35%	Kaygusuz, 2009

Compared with the capacity factors of nuclear and gas plants of 85-90%, these capacity factors are very low, which is the most important obstacle for wind energy investment, especially for the sites having low wind speed.

Economic Lifetime: The last important factor is the economic lifetime of onshore turbines. This time is generally taken as 20 years, but it is also taken as 25 years in some studies (Table 6).

Table 6: Economic lifetime data for onshore wind projects

Original Value (years)	Source
20	Vardar and Cetin, 2009
20	Boccard, 2010
25	Diaf et al., 2008
20	Blanco, 2009
20	Krohn et al., 2009
25	IEA, 2010a
25	Ozerdem et al., 2006

Salvage Value: At the end of the lifetime of an onshore wind farm, the material of plant has a salvage value which is assumed as 20% of the original capital cost by IEA (2010a).

Discount Rate: In the literature, the discount rate is generally assumed to be between 5% and 10%. In this study, the discount rate is not assumed, instead it is calculated and the detail of the calculation is given in Section 4.2.1.1.

2.1.2.2. Offshore Wind Technology

The cost components and technical factors for offshore wind energy is the same as the onshore wind energy, but the shares and the magnitudes of each cost component and the characteristic of technical factors are different. In general, offshore wind power plants generate more electricity with the help of stable wind blow, but the higher capital cost and O&M cost eliminate this advantage and make offshore electricity more expensive compared to onshore. The most important factors making offshore projects more expensive are (Blanco, 2009, Krohn et al., 2009):

- The higher cost of foundation with a share of 21% compared to 5% for onshore.
- The higher grid connection cost.
- The higher transportation costs and the hardness to access to turbines because of weather conditions.

As a result, capital cost of offshore wind power plants is around 50% higher than the ones deployed onshore (Krohn et al, 2009).

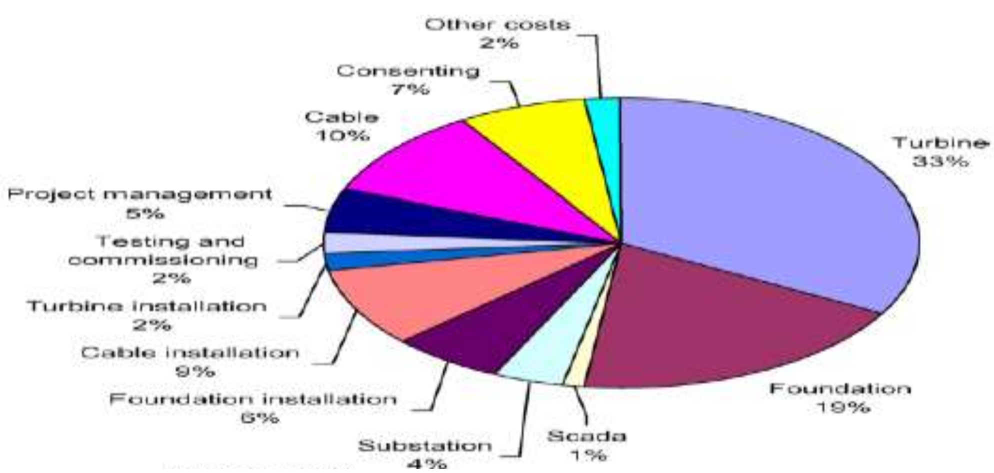
In addition to higher capital cost and O&M cost, the offshore wind projects are different from the onshore projects in terms of the shares of capital cost and O&M cost.

In fact, compared to the onshore wind power plants, the share of O&M cost is higher in the offshore projects by 10 percentage points (Blanco, 2009).

In this section, the main cost components and technical parameters of offshore wind power plants are explained and some data collected from the literature are summarized. Firstly, capital cost is discussed by classifying into three categories: turbine cost, grid connection cost, and civil work and installation cost. Then, the content and the magnitude of O&M cost are examined. After explaining cost components, five main technical parameters of offshore wind technology which are wind speed, capacity factor, economic lifetime, salvage value, and discount rate are explained.

<u>Capital Cost:</u> The weight of capital cost is high for offshore wind farms like onshore. The capital cost consists of turbine cost, grid connection cost, and other capital cost. The share of each component in a typical offshore wind project is given in detail in Figure 16. When the shares are summarized into three categories, it can be seen that the share of turbine cost is 33%, the share of grid connection cost is 24% and the share of other capital cost is 43%.

Figure 16: The detail breakdown of capital cost of a typical offshore power plant



Source: Blanco, 2009.

Each component of capital cost is explained below.

Grid Connection Cost: As explained in Section 2.1.2.1., grid connection consists of cables, sub-station, connection, and power evacuation systems. Some data about grid connection costs specific to offshore projects are given in Table 7.

Table 7: Grid connection cost for offshore wind projects

Original Value	Calculated Value* ($/MW)	Source
€342-475/kW	541,555	Blanco, 2009
£304/kW	469,796	EWEA, 2009
€355/kW	470,629	Krohn et al., 2009
21% of capital cost		Kumar et al., 2009
23% of capital cost		Kenisarin et al., 2006

*In the conversion of EUR to USD and sterling to USD, average exchange rates of 2010 are used.

Turbine Cost: Turbine cost of an offshore wind project has lower share compared to the share of turbine cost in an onshore project, but it is still fairly high with a share changing from 30% to 50% (Blanco, 2009 and Krohn et al., 2009). Some data about the cost of turbine is given in Table 8. Offshore wind projects are not common in the US, so the turbine cost data in the table belong to the European wind market.

Table 8: Turbine cost data for offshore wind projects

Original Value	Turbine Capacity (MW)	Calculated Value* ($/MW)	Source
€594-825/kW		940,596	Blanco, 2009
£1500000 for 2 MW	2	1,159,035	ODE, 2007
£1750000 for 2.5 MW	2.5	1,081,766	ODE, 2007
£2000000 for 3 MW	3	1,030,254	ODE, 2007
£2963000 for 3.6 MW	3.6	1,271,934	ODE, 2007
£325000 for 4 MW	4	1,255,622	ODE, 2007
£3750000 for 5 MW	5	1,159,035	ODE, 2007
€815/kW		1,080,459	Krohn et al., 2009
49% of capital cost			Krohn et al., 2009
47% of capital cost			Kumar et al., 2009

* In the conversion of EUR to USD and sterling to USD, average exchange rates of 2010 are used.

Other Capital Cost: Other capital cost consists of foundations, road construction, buildings, feasibility study cost, engineering cost, site improvement cost, and other costs that are not included in the specific capital cost components. Mainly because of high foundation cost, the share of other capital cost is very high for offshore projects around 40% according to Blanco (2009) and 30% according to Krohn et al., (2009). This big difference between two studies most probably caused by the nature of other capital cost that it is highly varies from country to country and from project to project.

Some data about this category of capital cost is given in Table 9.

Table 9: Other capital cost data for offshore wind projects

Original Value	Calculated Value* ($/MW)	Source
€864-1200/kW	1,368,140	Blanco, 2009
£768/kW	1,186,852	ODE, 2007
€510/kW	676,116	Krohn et al., 2009
31% of total installation cost		Krohn et al., 2009
30% of investment cost		Kumar et al., 2009

* In the conversion of EUR to USD and sterling to USD, average exchange rates of 2010 are used.

O&M Cost: O&M cost of offshore wind power plants are more important compared to onshore because it constitutes 30% of overall cost of a project during lifetime. Offshore projects are not common as onshore projects, so only two sources giving O&M cost for offshore wind projects are found: Krohn et al. (2009) assumes O&M cost as €16/MWh while IEA (2010a) states that it ranges from $11 to 54/MWh.

In addition to cost components, the technical factors affecting the economy of an offshore wind power plant are discussed in the remaining part of this section.

Wind Speed: The detail about wind speed is given in Section 2.1.2.1.

Capacity Factor: The detail about capacity factor is given in Section 2.1.2.1.

Economic Lifetime: The economic lifetime of turbines deployed offshore is higher than the economic lifetime of the ones located onshore. The most important reason of this difference is that wind is less turbulent at sea, so the lifetime of offshore turbines is higher compared to turbines deployed in onshore sites (Krohn et al., 2009). The assumptions about the economic lifetime of offshore wind turbines range from 20 years to 30 years as given in Table 10.

Table 10: Economic lifetime data

Original Value (years)	Source
20	Boccard, 2010
25-30	Blanco, 2009
25-30	Krohn et al., 2009
25	IEA, 2010a

Salvage Value: At the end of lifetime of an onshore wind farm, the material of plant has a salvage value which is assumed as 20% of original capital cost by IEA (2010a).

Discount Rate: In the literature, the discount rate is generally assumed to be between 5% and 10%. In this study, the discount rate is not assumed, instead it is calculated and the detail of calculation is given in Section 4.2.1.1.

2.2. Solar Energy: Technology and Cost

Solar energy is the most abundant and the most available energy source among all energy sources. In addition, it is the main source of other energy forms including fossil fuels, wind and hydro. If we can convert only 0.1% of the solar energy absorbed by the world into electricity with an efficiency factor of 10%, we would generate electricity around four times of the world's current electricity generation (Thirugnanasambandam et al., 2010). However, the ratio of solar power is less than 1% in total electricity consumption of the world mainly because of high capital cost of solar power plants compared to the alternatives.

Nevertheless, solar electricity is getting interest for several reasons. Firstly, the technology is in progress phase and it is widely accepted that the cost will decrease and solar energy will become competitive if the technological developments continue. Secondly, solar energy is a renewable energy which is very important for sustainable development. Thirdly, it is environmental-friendly technology, not emitting any CO_2 and other gases. Last but not least, it is a valuable technology which can produce electricity on remote sites not connected to the grid. Therefore, it is very important to produce economically viable solar power.

In this section, electricity generation technologies and costs of solar energy are discussed by staring with giving some information about two major groups of solar power plant technologies which are photovoltaic (PV) and solar thermal power technologies including parabolic trough, tower, dish, chimney and Fresnel. Then, the costs of solar power plants for selected technologies which are solar PV, solar trough and solar tower are analyzed by focusing on the cost and the other factors affecting the cost of solar-generated electricity.

2.2.1. Technological Aspects

Solar power generation technologies can be classified into two groups which are PV and solar thermal power technologies. The main difference between PV and thermal technologies is the conversion process of solar energy into electrical energy. PV directly produces electricity from solar photons while thermal technologies convert firstly solar energy into heat energy and then to electricity via steam turbines.

In this section, these technologies are explained by discussing their mechanisms, efficiency levels, advantages, disadvantages, usages and major types.

2.2.1.1. Photovoltaic (PV)

PV technology is an application of the photovoltaic effect which can be defined as the electrical potential developed between two dissimilar materials when their junction is illuminated with radiation of photons. This effect was discovered by Becquerel in 1839 and only produced in laboratories until 1954 when the first silicon cell was produced by Bell Laboratories (Patel, 2005). The collision of photons with cells generates PV effect which results in electrons being separated from atoms.

This valuable property of converting solar photons directly to electricity made PV technology an important energy production method for the space programs and satellites. The usage in space programs has supplied a proper environment to enhance this technology to be matured enough to be used also in the earth to produce electricity, especially for the sites not connected to the grid due to high connection cost.

PV cells are manufactured from semiconductor materials having property to produce electric current from photons. This technology generally uses semi-conductor silicon cells called wafers which convert sunlight into DC electricity. In fact, the silicon is doped with phosphorous to help the release of free electrons when the material absorbs the photons. Lots of cells are assembled in a module. The arrangement of these cells in the module is important because it influences the energy production. Similarly, the arrangement of the modules to form an array is also important to produce a specific voltage and the current (Rehman et al., 2007).

The efficiency level of PV technology is considerably low; it is only 15% in the most favorable case of the crystalline silicon wafer cells. The efficiency level is low because PV cells can not convert the majority of solar energy which is contained in the long wavelength part of the solar spectrum. There are also alternative materials like polycrystalline and amorphous cells used to construct PV modules, but they have even lower efficiency around 7.5% (Evans, 2007).

As mentioned, PV cells have been firstly used in space programs and then satellites by the virtue of its low weight. Then, a variety of usages emerged. Today, It is being used to supply power to remote sites, utility peak load shaving, cathodic protection in oil and gas pipelines, remotely located oil fields and gas oil separation plants, telecommunication towers, highway telephones and billboards, off-grid cottages, resorts in desert areas, water pumping for community and irrigation, municipal park lighting, and exterior home lighting (Rehman et al., 2007). The new trend is the usage of cladding buildings to supply electricity for air-conditioning and lighting loads (Patel, 2005).

PV technology has several advantages which have made possible it to be used for several aims. Major advantages are (Patel, 2005):

- The technology is proven,
- It is easy to use,
- The power output matches very well with the peak-load demand, i.e. producing more power on sunny days,
- Short lead times to design, install, and start up a new plant,
- Highly modular; hence, the plant economy is not strongly dependent on size,
- Static structure, no moving parts; hence, no noise,
- High power capability per unit of weight,
- Longer life with little maintenance because of no moving parts,
- Highly mobile and portable because of its light weight.

However, PV technology also has some shortcomings the most important of which is the low efficiency level. In addition, it has also low productivity rate changing in the range of 8.5% in the cloudy sites like the UK to 17.5% in the sunny places like Arizona (Evans, 2007). Furthermore, the PV-cell-manufacturing process is energy intensive; its energy consumption is over 1 kWh/cm^2, though the technological enhancement has been continuously decreasing the energy consumption during manufacturing with the implementation of new production processes (Patel, 2005). The other disadvantage of PV technology is the decrease of efficiency as the temperature increases. The electricity production amount is anti-linear in the temperature range. PV panels heats up when absorbing the infrared radiation and tends to warm significantly in the absence of wind (Demiroren and Yilmaz, 2010).

The PV projects generally have low production capacity lower than 100 kW because they are generally used to compensate electricity demand of sites with low consumption. However, in the recent years, thanks to the new trend in the solar energy production, large PV plants have been constructed. The highest capacity PV plant in the US has a capacity of 14 MW, which was constructed in Nevada. In Europe, the largest plant is being constructed in Germany. This plant will have capacity of 40 MW and the project is planned to be completed by the end of 2009. The other plant is located in Spain with a capacity of 20 MW and is operating now (Taylor et al., 2009).

The research and development works are continuing to find new methods and materials to be used to manufacture PV panels so that energy consumption and manufacturing costs will reduce while efficiency increases. As a result, several alternative cell types have been invented and available in the market today. The major types are single-crystalline, polycrystalline and semi-crystalline silicon, thin-film cell, amorphous silicon, spheral cell, concentrator cell and multi-junction cell. The most widespread technology is the single-crystalline silicon cell which has been the workhorse of the PV technology with 90% share (Lorenz, 2008). It is the most efficient choice with 18% efficiency level at maximum, but it is also the most expensive option. Therefore, some alternative PV technologies have been developed and amorphous silicon, concentrator cell and thin-film cell have become the most popular alternatives among these technologies. Amorphous silicon only uses 1% of material compared to single-crystalline, so it has a huge cost advantage. On the other hand, its efficiency is around half that of crystalline silicon technology. These two technologies are compared in Table 11.

Table 11: Comparison of crystalline and amorphous silicon technologies

	Crystalline Silicon	Amorphous Silicon
Present Status	Workhorse of terrestrial and space applications	New rapidly developing technology, tens of MW of yearly production facilities were commissioned in 1996 to produce low-cost cells
Thickness	200-400 μm (0.004–0.008 in.)	2 μm (less then 1% of that in crystalline silicon)
Raw Material	High	About 3% of that in crystalline silicon
Conversion Efficiency	16–20%	8–10%
Module costs (2004)	$3–5 per watt, expected to fall slowly due to the maturation of this technology	$3–5 per watt, expected to fall rapidly to $2 per watt due to substantial DOE funding to fully develop this new technology

Source: Patel, 2005.

Another important PV type is CPV system which consists of units like dish mirror systems and PV modules. Mirrors reflect the sunlight to PV modules which convert the radiation directly to electricity. These systems have some cost reduction potentials compared with PV systems. First, by concentrating sunlight onto a small cell, the amount of semiconductor can be reduced to produce the same amount of electricity. Second, the use of smaller cells allows for more advanced and efficient cell technology which increases the efficiency level (Stoddard et al., 2006). However, this technology has not been commercialized yet.

2.2.1.2. Solar Thermal Technologies

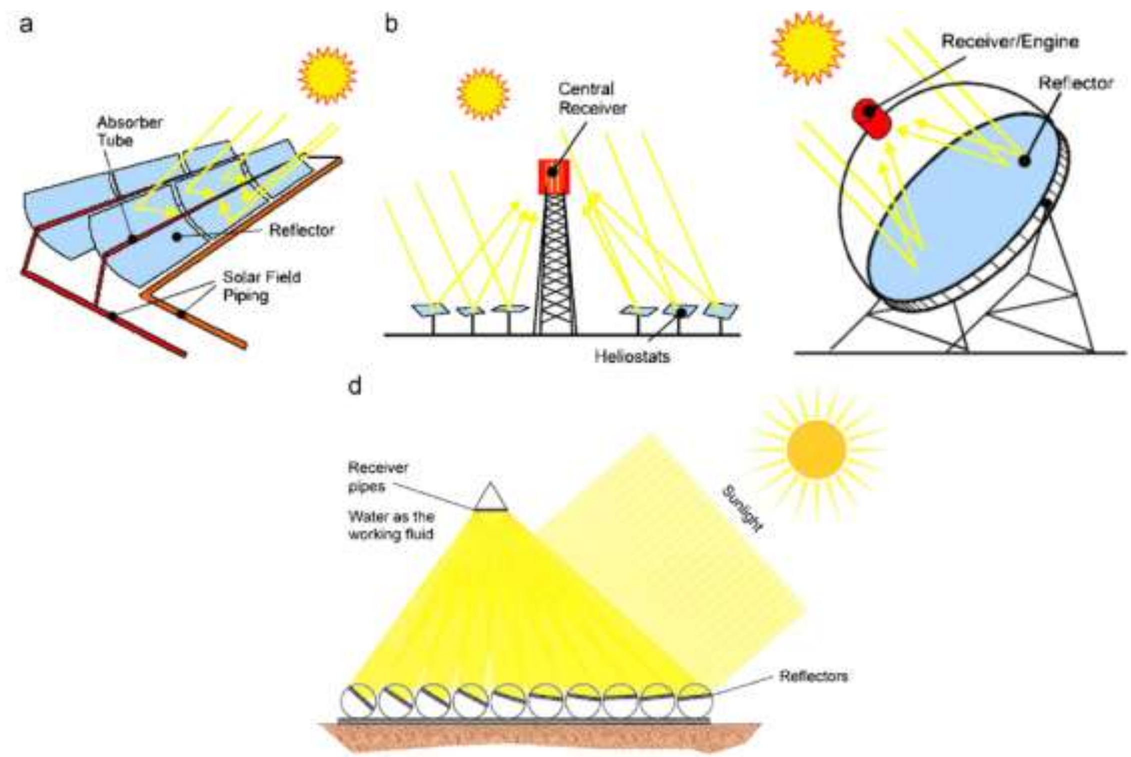
Thermal technologies convert solar energy into electrical energy by means of two successive processes. In the first phase, the sun's energy is converted into high temperature heat energy with the help of various mirror or lens configurations. In the second phase, the heat energy is used to produce electricity through generation system like other thermal power plants (Stoddard et al., 2006). Thermal systems utilize only direct normal insolation (DNI) component of solar insolation which can be concentrated to a point to produce high working fluid temperature. Therefore, a collector system is needed to tract the sun. Some technologies use single-axis tracking system while others use two-axis trackers to reflect sunlight to a central receiver (Pletka et al., 2007). The systems used in the second phase are similar to the ones used in the conventional thermal plants.

In addition to these two main processes, in some plants there is an extra system which is thermal storage system used to store heat. In a storage facility, several heat mediators are used including molten salt, oil, and water, but the most common and the mature method is the use of molten salt which consists of sodium nitrate (60%) and potassium nitrate (40%). The molten salt melts at around 220 ^{0}C and generally stored in a cold tank at 300 ^{0}C. The circulation starts with the transferring of molten salt from the cold tank to the receiver where it absorbs the heat of sunlight reflected by the collector system. Then, the salt whose temperature reaches to around 550 ^{0}C is directed to the hot tank. When needed, the salt in the hot tank is taken and transferred to the heat exchanger where its heat is transferred to water to produce steam. The cooled molten salt is then sent to the cold tank to be used in another circulation process (Poullikkas, 2009). Thermal storage has some important advantages. First, it makes possible to generate electricity when needed instead of only during sunny hours. Thus, the thermal storage increases the dispatchibility of a solar plant. Furthermore, the capacity factor of the relevant power plant increases by means of thermal storage system up to over 50% while it is only about 25% in the lack of storage. Last but not least, the thermal storage eliminates the need for fossil fuel components which are built to make solar thermal plants dispatched when solar energy is not available (EEL, 1999).

Thermal technologies have some valuable properties which has increased the popularity of this group of technologies in the recent years. First of all, these plants have large capacity compared to PV plants, so it can be used to generate electricity to supply whole market vie transmission and/or distribution grids. Therefore, economies of scale exists for these plants which deliver low-cost, and high-value electricity on a large scale. In addition, its usefulness has been demonstrated on commercial scale, as the cheapest available option for solar power Second, compared with PV technologies, thermal technology is economical and more efficient because it eliminates the need of costly PV cells and AC inverters. Third, a solar thermal plant has the ability to store thermal energy from sunlight by using some materials and converts this energy into electricity when needed like during dark or peak-demand periods (Lorenz, 2008).

On the other hand, thermal technologies have some shortcomings. First of all, these plants cannot be installed close to customers because they require almost perfect solar conditions and vast quantities of open space, which are generally possible at a great distance. Therefore, these systems cannot reduce the expense of transmitting and distributing electricity. Secondly, these plants use conventional devices such as pipes, storages and reflectors, whose costs are stable compared with those of the materials used in semiconductor-based PV plants, so the cost reduction for concentrated solar thermal power is, most probably, very limited (Lorenz, 2008). Third, thermal plants require specific climate conditions of clear sky and strong sunlight because only direct insolation can be utilized. Therefore, available sites are limited to desert and desert-like locations (Williges et al., 2010).

Figure 17: Solar thermal power technologies.



Source: Purohit and Purohit, 2010.

There are five solar thermal technologies the four of which are depicted in Figure 17 together: (a) parabolic trough, (b) central receiver (solar tower), (c) parabolic dish, (d) linear Fresnel collectors. In addition to these technologies, the last one is solar chimney technology a scheme of which is given in Figure 19. In the last years, solar thermal technologies have become popular especially in the US and Europe and new plants have been installed. However, so far standard designs for these technologies have not been developed, so each project has its unique design (IEA, 2010b). The main characteristics of these different technologies are discussed in this section.

Parabolic Trough: The parabolic trough system is the most commercially matured solar thermal technology to date among the mentioned technologies. In this system, there are troughs (typically glass mirrors) which are 5 meters wide and deployed in rows up to 100 meters long. The troughs can collect up to 60% of the DNI (EEL, 1999). A field contains many parallel rows of troughs placed on a north-south direction to make it possible for trough to track the sun during daytime (Stoddard et al., 2006). The troughs reflect sunlight on a glass-encapsulated tube located in the focal line of collectors. The tube is full of mediator liquid, generally synthetic oil, having the property of heat-absorbing, which is heated to temperatures of between 300 ^{0}C and 400 ^{0}C (Poullikkas, 2009). The mediator is then used to heat water in the heat exchanger to produce steam which is canalized to a conventional turbine to generate electricity.

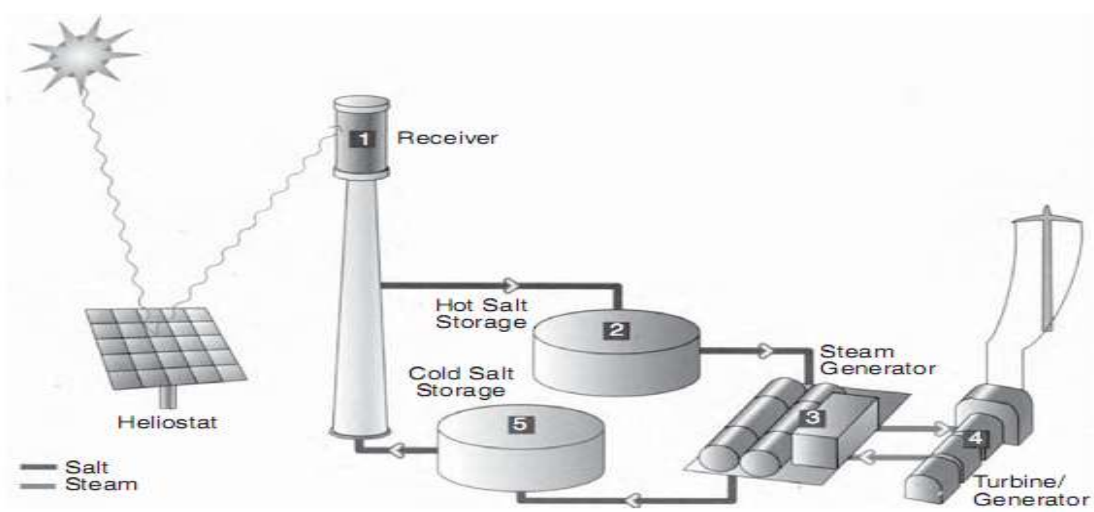
This technology has been used in California since 1990s and there are more than 350 MW of parabolic trough capacity located in the California Mojave Desert (Patel, 2005). The largest single plant has a capacity of 80 MW. These plants have proven a maximum efficiency rate of 21% (WB, 2006).

Solar Tower: This technology produces a much higher concentration up to 600 times, which results in a higher temperature compared to the parabolic trough up to 1,200 ^{0}C (WB, 2006). The collection efficiency of this technology is around 46% and the electricity conversion efficiency is 23% at peak (EEL, 1999). Like trough plants, these plants have to be large-scale capacity (50 MW or larger) because these systems collect heat to drive a central turbine generator (Stoddard et al., 2006).

A scheme of a tower plant having storage property is given in Figure 18. A tower plant consists of heliostats, receiver, hot salt storage tank, cold salt storage tank, steam generator and turbine generator units. In this plant, solar energy is collected by lots of sun-tracking mirrors, heliostats, which reflect the sun's light to the receiver at the top of the tower located in the center of the plant. Receiver that is made of a material resistant to high temperature receives solar energy and converts it to heat. Then, this heat is used to warm up the salt taken from cold salt storage tank. This hot salt is used to produce steam, which drive the turbine to generate electricity. Thus, salt loses its heat and sent to the cold storage to be solidified for a new electricity production cycle.

The mechanism of a solar tower plant resembles to the mechanisms of other thermal plants like coal-fired plants except two properties which are the absence of gas emission and an extra facility to store heat.

Figure 18: The scheme of a solar tower plant



Source: Patel, 2005.

Europe is the pioneer in solar tower technology. The first commercial scale solar tower of 11 MW was constructed in Spain and has been operating since 2007. The second one was also built in Spain and started to operate in 2009 with a capacity of 20 MW. Both plants use water as heat transfer fluid and have 1 hour of storage capacity (NREL, 2009).

Parabolic Dish: A parabolic dish system consists of a solar concentrator and the power conversion unit together in a dish. The concentrator reflects the solar light to the receiver that is a subunit of the power conversion unit located at the focal point of the dish. The receiver converts these lights into heat in a closed hydrogen loop which drives the Stirling engine generating electricity. In these systems, hydrogen is cooled by air, so there is no need for a cold storage. Parabolic dishes' size ranges from 5 to 15 m in diameter and their capacity ranges from 5 to 25 kW (WB, 2006). In order to increase the efficiency, concentrators are built in a two-axis tracking system (Poullikkas et al., 2010). Theoretically, the Stirling engines' conversion efficiency is about 40% (Poullikkas, 2009), but it reached 31.25% in practice which is the highest solar to electric conversion efficiency (Poullikkas et al., 2010).

The main disadvantage of these systems is the absence of storage (Pletka et al., 2007). In addition, they require moving parts, which increases the maintenance cost. However, this technology make possible relatively small capacity (tens of kilowatts) plants, so it is more flexible compared to other solar thermal technologies. Therefore, dishes can be used instead of PV systems for small stand-alone remote sites as a cheaper option (Patel, 2005).

Parabolic dish systems have been built in various sizes from 5 kW to 50 kW since 80s in the US, Germany, Spain and Japan. Currently, there are 9 operational solar dish systems in several countries. However, these systems have been generally constructed for demonstration, not for commercial purposes (Poullikkas et al., 2010).

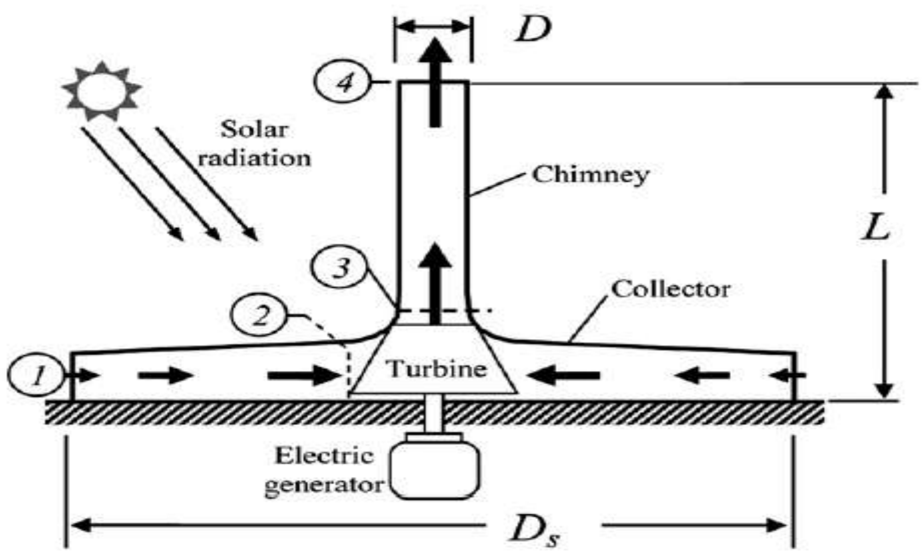
Linear Fresnel Collectors: The structure of the linear Fresnel technology is the same with parabolic trough technology except the collector system which consists of small flat optical faces instead of parabolic troughs. This technology was invested by the French engineer Augustin-Jean Fresnel as a cheaper alternative to parabolic trough. The cost of Fresnel mirror is lower than €7/m^2, one fifth of the cost of parabolic trough. However, it has less efficiency which eliminates the reduction in cost to some extent (Ford, 2008). The mechanism of the system is similar to parabolic trough. The Fresnel mirrors reflect sunlight to a line focus system which is filled with the mediator like oil, or water. If the heat mediator is other than water, the mediator liquid is canalized to heat exchanger where steam is produced to be used to generate electricity.

An Australian company, Ausra, constructed the first Fresnel power plant in the US in 2003 as a test plant. The success of the test plant encouraged the firm to build new ones and she currently has a plant to construct a plant of 177 MW (Purohit and Purohit, 2010).

Solar Chimney: Solar chimney technology is the only solar thermal technology that uses global radiation to generate electricity (ABS Energy, 2005). In this technology sunlight is not reflected, instead directly used to heat air under the collector system. A scheme of solar chimney power plant is represented in Figure 19. There are three main parts of a chimney plant: the collector roof, the chimney, and the wind turbine. Solar radiation heats up the air under the collector roof and then the warm air goes up to the chimney. The hot air that reaches to the chimney gets high speed and derives the wind turbine located in the bottom of the chimney (ABS Energy, 2005). The ground under the collector roof heats during day and it continues to heat air after the sunset, so chimney plants have a natural storage. In addition, if water-filled tubes are placed, the ongoing operation is possible for 24 hours (Viebahn et al., 2008). This natural and easy storage property may play an important role in the future.

In addition to the stable consistent generation, there are some other advantages of chimney technology like low maintenance cost, the simplicity to operate and the durability of the system (Hamdan, 2010). However, it has very low solar to electricity efficiency, around 2% which is one-tenth of parabolic trough and one-fifteenth of solar dish, so it needs a large area of free or very cheap land like deserts (ABS Energy, 2005).

Figure 19: Scheme of a solar chimney plant.



Source: Hamdan, 2010.

An experimental plant was built in Spain in 80s and operated for a while. However, no commercial scale plant has been constructed so far.

2.2.2. Cost Analysis

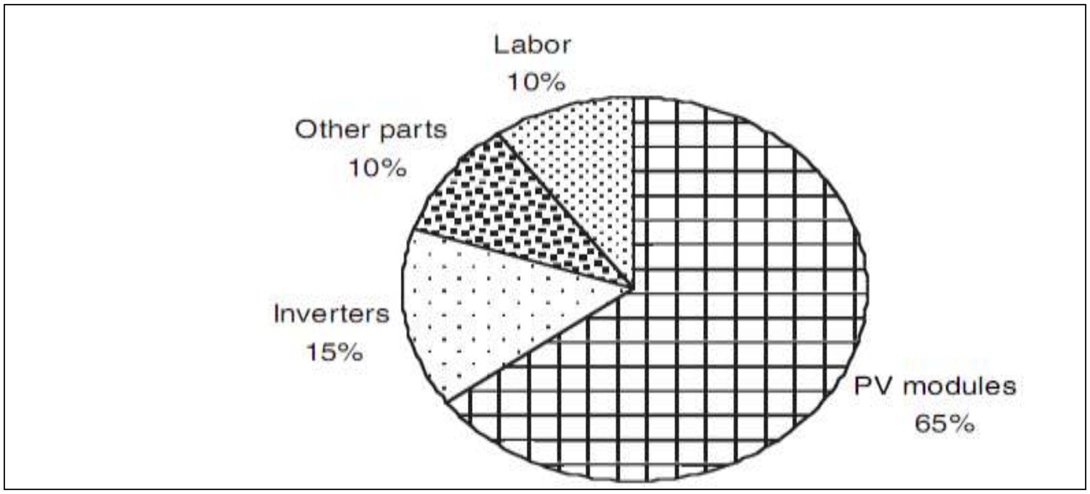
Solar power plants have long working life with zero fuel cost and low maintenance cost, but they require huge initial investment. In other words, the majority of the generation cost of the solar electricity is the cost of financing the initial investment. In this section, main cost components of three relatively common technologies which are PV, parabolic trough, and solar tower are analyzed. For each technology I explain both cost components including power plant construction cost, storage unit cost, land cost, and O&M cost and other factors affecting the economics of a solar thermal plant like economic lifetime, efficiency rate, capacity factor, and land need.

2.2.2.1. PV Technology

The main cost components of a PV plant are capital cost (module cost, inverter cost, grid connection cost, and other installation cost), land cost, and O&M cost. The storage cost is not included because; in PV plants solar energy is directly converted into electricity which cannot be stored. The main technical parameters of PV plants that determine the level of cost and revenue are efficiency rate, degradation rate, global horizontal insolation (GHI), capacity factor, economic lifetime, salvage value, and discount rate.

Capital Cost: The capital cost is expressed in terms of W_p which can be defined as "the power of a cell with an electrical power of 1 W submitted to standard sunlight of 1000 W/m^2" (Hamakawa, 1991). The capital cost contains the cost items of plant which are PV module cost, inverter cost, installation and labor cost and other costs. The shares of these cost categories are given in Figure 20. From the figure, it can be seen that material cost consists of 80%, which shows that there is a large cost-reduction potential which can be realized with the technological developments.

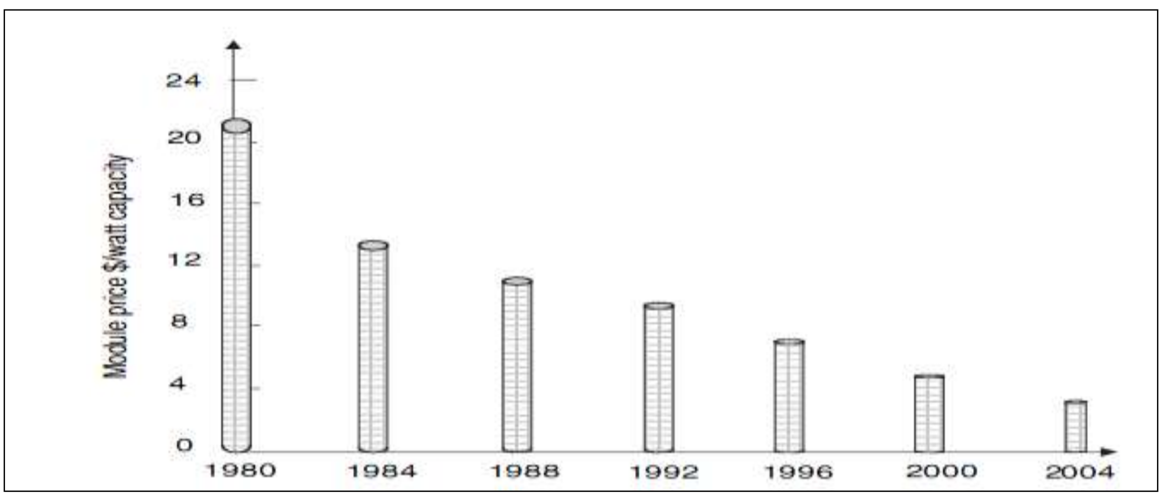
Figure 20: The breakdown of capital cost of a PV plant.



Source: Patel, 2005.

The capital cost has been continuously decreasing by the virtue of technological developments. The capital cost per watt is given in Figure 21 which shows that the cost decreased 75% between 1980 and 2004 from \$20/W to \$4/W (Patel, 2005). In other word, the annual decrease rate was around 6.5%.

Figure 21: PV module price trend for wafer cells



Source: Patel, 2005.

Each component of capital cost is explained below.

Grid Connection Cost: Like wind farms, PV plants are also generally installed in the sites far from the current electricity infrastructure, so a great deal of grid connection cost is needed. Because of this similarity, the data about grid connection cost that is explained in Section 2.1.2 is also relevant for PV plants.

Module Cost: Module cost constitutes more than 60% of PV plants, so it is the most important cost component for this technology. Modules can be produced from different kind of material like crystalline silicon cell and amorphous cell each of which has different cost and efficiency structure. In this study, I use crystalline cell which is the most mature technology, so I only give cost data of this kind of module in Table 12.

Table 12: PV module cost data

Original Value	Calculated Value ($/MW)	Source
65% of initial cost		Patel, 2005
$5.55/W	5,550,000	Rehman et al., 2007
$3.5/W	3,500,000	McGehee and Goh, 2008
$3.5/W	3,500,000	EERE, 2006
$3-5/W	4,000,000	Patel, 2005
$3.38/W	3,380,000	Solarbuzz.com, 2011

Inverter Cost: Inverters are needed for PV plants because these plants generate DC which has to be converted into AC to transport it trough the current grid. The share of inverter cost is around 15% and these equipments are needed to be replaced every 5-10 years (Navigant Consulting Inc., 2006, EERE, 2006, and Rehman et al., 2007). The data about inverter cost is given in Table 13.

Table 13: Inverter cost data for PV plants

Original Value	Calculated Value ($/MW)	Source
15% of investment		Patel, 2005
$0.4/W	400,000	Rehman et al., 2007
$0.5/W	500,000	McGehee and Goh, 2008
$0.46/W	460,000	EERE, 2006
$0.711/W	715,000	Solarbuzz.com, 2011

Other Capital Cost: Other capital cost consists of labor cost, feasibility study cost, engineering cost, site improvement cost, transportation cost, and other costs that are not included in the specific capital cost components. Some data about this category of capital cost is given in Table 14.

Table 14: Other capital cost data for PV plants

Original Value	Calculated Value ($/MW)	Source
20% of investment	800,000	Patel, 2005
$2.42/W	2,420,000	Rehman et al., 2007
$1.79/W	1,790,000	EERE, 2006

Land Cost: The land used to construct PV plants can be bought or rented by the investor. The lands having good solar energy potential are generally arid and not generally possessed by private parties, so the price of the land is cheap. The data about the cost of land is given in Table 15.

Table 15: Land cost data for solar power plant projects

Original Value	Calculated Value ($/m2)	Source
$11/kW		EEL, 1999
2 €/m^2	3	Pitz-Paal et al., 2007
70 €/kW		Pitz-Paal et al., 2007
2 €/m^2	3	Pitz-Paal et al., 2005
69 €/kW		Pitz-Paal et al., 2005

O&M Cost: The main variable cost component for PV plants is O&M cost because the fuel cost is zero. Compared to capital cost, the operating cost is very low as can be seen in Table16.

Table 16: O&M cost data for PV plants

Original Value	Calculated Value ($/kW-y)	Source
0.15% of installed cost	8.83	EERE, 2006
$30/kW per year	30.00	Pletka et al., 2007
$0.03/kWh	39.42	IEA, 2010a

In addition to the cost components, the technical and financial factors affecting the economy of PV plants are discussed in the remaining part of this section.

Efficiency Rate: The efficiency of PV modules to absorb the photons changes according to the chosen type of the cell. It can reach 18% in wafer silicon cells while it may decrease to 7.5% with the use of amorphous cells. There is a competition between different kind of cells having different efficiency rates because there is a trade-off between capital cost and efficiency level. When the total effects of these two factors are taken into account, wafer silicon cells are advantageous. Some values about efficiency rate are given in Table 17.

Table 17: Efficiency rate data for PV plants

Module Type	Efficiency Rate	Source
Crystalline	15.00%	Evans, 2007
Amorphous	7.50%	Evans, 2007
Crystalline	16-20%	Patel, 2005
Amorphous	8-10%	Patel, 2005
Crystalline	13.50%	EERE, 2006
N/A	10-25%	IEA, 2010a

Degradation Rate: This factor is peculiar to PV technology which shows a decline in maximum capacity from year to year. This rate is generally accepted 1% annually (Tidball et al., 2010, and EERE, 2006)

Global Horizontal Insolation (GHI): It highly differs from site to site and the most important criteria in the selection of site because GHI is the most important factor affecting the economy of PV projects.

Capacity Factor: Capacity factor highly depends on the location: In sunny places, this rate reaches to 25% (IEA, 2010c) while decrease to 8.5% in unfavorable places like the UK (Evans, 2007). The data about capacity factors are given in Table 18.

Table 18: PV power plant capacity factor data from the literature

Capacity Factor	Source
19-28%	Rehman et al., 2007
9%	Evans, 2007
18%	Evans, 2007
10-25%	IEA, 2010c
23%	Pletka et al., 2007
13%	IEA, 2010a

Compared with the capacity factors of nuclear and gas plants of 85-90%, these factors are very low, which is the most important obstacle for PV investments.

Economic Lifetime: The other important technical factor is the economic life of the plant which is generally accepted as 30 years in many studies. However, Hamakawa (1991) propose lifetime to be considered more than 30 years based on the results of some accelerated duration tests which showed technical lifetime is over 30 years. The data about economic lifetime is given in Table 19.

Table 19: Economic lifetime data for PV plants

Original Value (years)	Source
30 or more	Hamakawa, 1991
25	IEA, 2010a
25	Rehman et al., 2007
30	McGehee and Goh, 2008
30-40	Singh and Singh, 2010
30	Pletka et al., 2007
30	Stryi-Hipp, 2008
30	EERE, 2006

Salvage Value: At the end of lifetime of a PV plant, the material of the plant has a salvage value which is assumed as 20% of original capital cost by IEA (2010a).

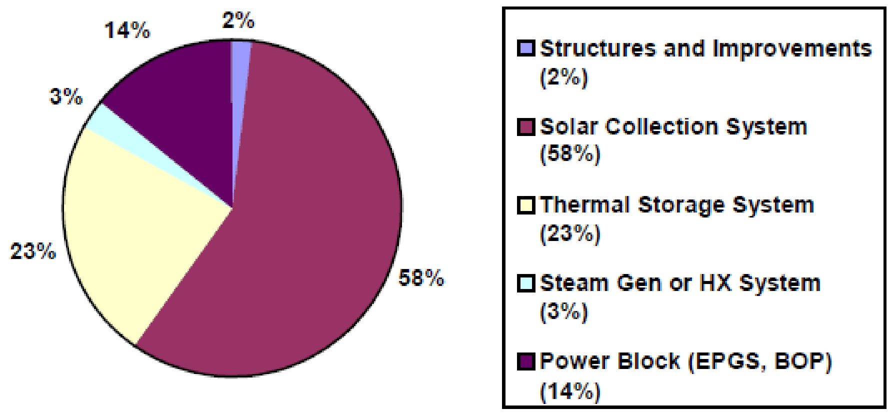
Discount Rate: In the literature, the discount rate is generally assumed to be between 5% and 10%. In this study, the discount rate is not assumed, instead it is calculated and the detail of calculation is given in Section 4.2.1.1.

2.2.2.2. Parabolic Trough Technology

The main cost components of a parabolic trough plant are capital cost (collector system, receiver system, conversion system, storage unit, grid connection, and other installation cost), land cost, and O&M cost. Storage cost is added because the heat energy produced with the reflection of sunlight can be stored in these plants. On the other hand, the main technical and economical parameters of trough plants that determine the level of cost and revenue are efficiency rate, storage efficiency, DNI, field area per kW, land area per kW, capacity factor, economic lifetime, salvage value, and discount rate.

Capital Cost: The capital cost contains grid connection cost, collector system cost, receiver system cost, conversion system cost, storage cost, and other capital cost like the construction of roads, the transportation of equipment. The shares of each unit in a trough plant are given in Figure 22.

Figure 22: The cost breakdown of a trough plant



Source: Beerbaum and Weinrebe, 2000.

Each component of capital cost is explained below.

Grid Connection Cost: Like wind farms and PV plants, trough plants are also installed in the sites far from the current electricity infrastructure, so a great deal of grid connection cost is needed. Because of this similarity, the data about grid connection cost that is explained in Section 2.1.2 should also be deemed relevant for trough plants.

Collector System Cost: Collector system cost which varies based on the level of storage capacity generally constitutes more than the half of total capital cost. In fact, collector system cost increases as the storage capacity gets larger because the heat energy stored in the storage unit is also collected by the collection system during the sunny hours. Therefore, the most important item in terms of cost reduction potential is the collector system. IEA expects 20-40% decrease in collector system cost in the forthcoming years (IEA, 2010b). Some cost data from several sources having different storage capacity is given in Table 20.

Table 20: Collector system cost data for solar trough plants

Original Value	Calculated Value* ($/m^2)	Source
$2308.65/kW with 6 h storage	241	Stoddard et al., 2006
$1534 / kW	234	EEL, 1999
€190/m^2	252	Pitz-Paal et al., 2007
€206m^2	273	Pitz-Paal et al., 2005
€1821/kW with 3 h storage	273	Pitz-Paal et al., 2005
$295/m^2	295	Turchi, 2010
€206/m^2	273	Montes et al., 2009
$234/m^2	234	Sargent & Lundy, 2003
€205/m^2	272	Williges et al., 2010

*The average exchange rate of 2010 is used to convert EUR to USD.

Receiver System Cost: The second system in the chain of electricity production process of a trough plant is the receiver system which receives sunlight reflected by collector system and converts it into heat energy. This system constitutes a lower share of total capital cost around lower than 10%. Some data about receiver system cost is given in Table 21.

Table 21: Receiver system cost data for solar trough plants

Original Value	Calculated Value ($/MW)	Source
$100/kW	100,000	Stoddard et al., 2006
$282/kW	282,000	EEL, 1999
$43/m^2 field		Turchi, 2010

Conversion System Cost: The heat energy is converted into electricity by means of conversion system (power block) which costs around $600/kW with a share of 15-20%. The data about collection system cost is given in Table 22.

Table 22: Conversion system cost data for solar trough plants

Original Value	Value ($/MW)	Source
$387.54/kW	387,540	Stoddard et al., 2006
$493/kW	493,000	EEL, 1999
€435/kW	576,687	Pitz-Paal et al., 2007
$525/kW	525,000	Sargent & Lundy, 2003
$933/kW	933,000	EEL, 1999
$733/kW	733,000	Sargent & Lundy, 2003

Storage Cost: Storage unit makes it possible to run a trough plant whenever needed, but this unit does not exist in all plants, especially ones older than one decade. The alternative of storage unit is hybrid plants which uses fossil fuels (generally natural gas) to generate electricity when the sunlight does not exist. Storage facility is the main difference between solar thermal energy and the other renewables including PV, wind and tidal.

Total storage cost changes based on the capacity: It becomes higher than the cost of power block if storage capacity is high. For example, it costs nearly two times of the cost of power block in case of 12 hours of storage capacity (Sargent & Lundy, 2003). Storage cost is generally given in terms of $/kWh$_{th}$ unit, the costs from several sources are standardized by calculating costs in terms of $/kWhth (Table 23).

Table 23: Storage cost for solar trough plants

Original Value	Calculated Value* ($/kWh)	Source
$579.57/kW for 6 h	32	Stoddard et al., 2006
€10-30/kWh$_{th}$	27	Pitz-Paal et al., 2005
$27.1/kWh$_{th}$	27	Sargent & Lundy, 2003
$30-40/kWh$_{th}$	35	EERE, 2006

*The average exchange rate of 2010 is used to convert EUR to USD.

Other Capital Cost: Other capital cost consists of labor cost, feasibility study cost, engineering cost, site improvement cost, transportation cost, and other cost that are not included in the specific capital cost components. Some data about this category of capital cost is given in Table 24.

Table 24: Other capital cost data for solar trough plants

Original Value	Calculated Value ($/MW)	Source
$1568/kW	1,568,000	Stoddard et al., 2006
$1175/kW	1,157,000	EEL, 1999
20% of installed cost	872,750	Montes et al., 2009

Land Cost: The detail about land cost is given in Section 2.2.21.

O&M Cost: Like PV plants, the main variable cost component for trough plants is also O&M cost due to the absence of the fuel cost. Some data about O&M cost of trough plants are given in Table 25.

Table 25: O&M cost data for solar trough plants

Original Value	Calculated Value* ($/kWh)	Source
$0.020-0.025/kWh	22.50	Pletka et al., 2007
$55/kW-y	20.93	Pletka et al., 2007
%1 of installed cost		Turchi, 2010
$0.011-0.023/kWh	17.00	EEL, 1999
€0.032/kWh	46.04	Pitz-Paal et al., 2005
1.16% of installed cost		Turchi, 2010
$0.02/kWh	20.00	Black and Veatch, 2007
$0.028/kWh	28.00	Sargent & Lundy, 2003

*The average exchange rate of 2010 is used to convert EUR to USD.

After giving the data about cost components, the technical and financial factors affecting the economy of PV plants are also discussed in the remaining part of this section.

Efficiency Rate: As stated in Section 2.2.1.2., the efficiency rate of trough plants can reach to 20% at peak, but it is lower in average. In general, it is around 15% similar to the crystalline silicone cell. Some values about efficiency rate of trough plants are given in Table 26.

Table 26: Efficiency rate data for solar trough plants

Original Value	Source
15%	WB, 2006
14%	EEL, 1999
14%	Poullikkas, 2009
16%	Pitz-Paal et al., 2005

Storage Efficiency: This factor shows the utilization of heat energy stored in the storage facility and slightly varies with the technology used in the construction of the system. It is taken as 95% by Pitz-Paal et al. (2005) and 99% by Sargent & Lundy (2003).

Direct Normal Insolation (DNI): The most important factor in the economy of solar thermal plants is the level of DNI of the relevant site which differs from site to site. In fact, DNI is one of the two main factors with storage capacity determining the capacity factor of a solar thermal plant. According to IEA (2010b), DNI value of a site has to be higher than 2,000kWh/m^2 to build a solar thermal plant.

Land Area: The land area needed to construct a trough plant is important because it determines both the level of total land cost and the capacity of a relevant site. The most important factor determining the land area needed to construct a solar trough power plant is the capacity of the plant. When we look at Table 27, we can see that the land area increases if the capacity of power plant increases. For example, the land size of a plant with 354 MW capacity is 6.4 km^2 while the land area is only 1.6 km^2 of a plant having a capacity of 64 MW.

In addition to the nameplate capacity, the land area of a trough plant depends on several other factors like the design and material of the troughs, storage capacity of the plant, the quality of solar energy in the relevant site and the structure of the land. Among these other factors, the storage capacity highly affects the size of the land as depicted in Table 27. For example, according to Sargent & Lundy (2003), the land area of the plant of 50 MW without storage is only 1,052,000 m^2 while the plant having the same capacity with 9 hour storage capacity needs a land area of 1,675,000 m^2.

In Table 27, I also calculated land area per unit capacity in the forth column to demonstrate the effect of the plant capacity and the storage capacity on the land need for a solar trough plant.

Table 27: Needed land area per unit capacity for solar trough plants

Total Land Area of the Plant (m^2)	Storage (hour)	Plant Capacity (MW)	Land Area (m^2/kW)	Source
6,400,000	-	354	18	Poullikkas, 2009
1,600,000	-	64	25	Poullikkas, 2009
2,000,000	8	50	40	Poullikkas, 2009
2,306,708	-	100	23	Pletka et al., 2007
1,600,000	-	47	34	Pitz-Paal et al., 2007
1,720,000	3	50	34	Pitz-Paal et al., 2005
4,095,435	6	103	40	Turchi, 2010
1,052,000	-	50	21	Sargent & Lundy, 2003
1,675,000	9	50	34	Sargent & Lundy, 2003
3,780,000	12	100	38	Sargent & Lundy, 2003

Collector Field Area: The collector field area shows how much land is needed to build solar energy collector system of a solar trough plant. It highly depends on the plant capacity and the storage capacity. Collector area of trough plants with different plant capacity and storage capacity are given in Table 28. Like the land area per unit capacity, the field area per unit capacity values for different plants are calculated and given in the forth column of the table. When the field area per unit capacity in Table 28 and the land area per unit capacity in Table 27 are compared, it can be concluded that the value of the former is highly lower than the value of the latter. The reason of that difference is that, collectors are only built on a portion of the total land area of the plant; the remaining area is used for other purposes like roads and buildings.

Table 28: Collector field area data for solar trough plants

Total Collector Field Area (m^2)	Storage (hour)	Capacity (MW)	Field Area (m^2/kW)	Source
2,000,000	-	354	6	Poullikkas, 2009
357,200	-	64	6	Poullikkas, 2009
1,151,000	-	200	6	EEL, 1999
1,939,000	12	200	10	EEL, 1999
448,191	-	47	10	Pitz-Paal et al., 2007
442,035	3	50	9	Pitz-Paal et al., 2005
987,540	6	103	10	Turchi, 2010
312,000	-	50	6	Sargent & Lundy, 2003
496,000	9	50	10	Sargent & Lundy, 2003
1,120,000	12	100	11	Sargent & Lundy, 2003

Capacity Factor: The main difference between PV solar systems and solar thermal systems is the level of capacity factor. The capacity factor of the former is around 20% while the capacity factor of the latter may reach 60% with a high storage capacity. This ratio decreases if there exists no storage facility, but still considerably high (around 30%) compared to PV plants' capacity factor. Load factor of solar thermal plants mainly depends on the climate of the relevant site and the storage capacity.

The data about capacity factors collected from several sources are given in Table 29.

Table 29: Solar trough power plant capacity factor data from the literature

Capacity Factor	Source
27-42%	Pletka et al., 2007
28-40%	Stoddard et al., 2006
22-29%	Pitz-Paal et al., 2007
47%	Turchi, 2010
41%	Purohit and Purohit, 2010
29-54%	Sargent & Lundy, 2003

Economic Lifetime: The economic life of a trough plant is generally taken as 30 years. The data about economic lifetime is given in Table 30.

Table 30: Economic lifetime data for solar trough plants

Original Value (years)	Source
30	Turchi, 2010
30	Stoddard et al., 2006
25	IEA, 2010a
25	EEL, 1999
30	Pitz-Paal et al., 2007
20	Poullikkas, 2009
30	Turchi, 2010
30	Montez et al., 2009
30	Sargent & Lundy, 2003

Salvage Value: At the end of lifetime of a trough plant, the material of the plant has a salvage value which is assumed as 20% of original capital cost by IEA (2010a).

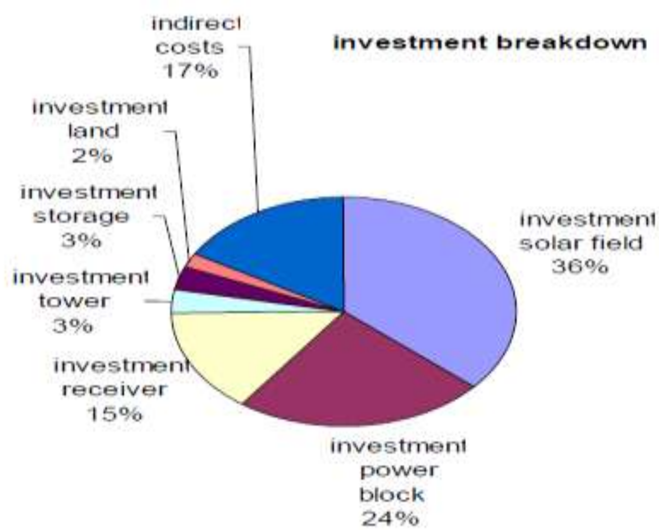
Discount Rate: In the literature, the discount rate is generally assumed to be between 5% and 10%. In this study, the discount rate is not assumed, instead it is calculated and the detail of calculation is given in Section 4.2.1.1.

2.2.2.3. Solar Tower Technology

The main cost components of a solar tower plant are capital cost (collector system, receiver system, conversion system, storage unit, grid connection, and other installation cost), land cost, and O&M cost. It is generally accepted that the construction of a storage facility in a solar tower plant is inevitable, so storage cost is added into our analysis. In addition to cost components, there are also some technical and financial parameters which are also important in the determination of unit production cost and total revenue. These items are efficiency rate, storage efficiency, DNI, land area per kW, field area per kW, capacity factor, economic lifetime, salvage value, and discount rate.

Capital Cost: The capital cost contains grid connection cost, collector system cost, receiver system cost, conversion system cost, storage cost, and other costs like the construction of roads and the transportation of equipment. The breakdown of initial capital cost including land cost for a solar tower plant with 3 hours of storage capacity is given in Figure 23.

Figure 23: The breakdown of capital cost of a solar tower plant



Source: Pitz-Paal et al., 2005.

Each component of capital cost is explained below.

Grid Connection Cost: Like wind farms, solar plants are also generally installed in the sites far from the current electricity infrastructure, so a great deal of grid connection cost is needed. Because of this similarity, the data about grid connection cost that is explained in Section 2.1.2 should be deemed relevant for trough plants.

Collector System Cost: Like the collector system cost of a trough plant, the collector system cost of a tower plant also varies based on the level of storage capacity and has the highest share in the capital cost. However, it is cheaper about 30% than the collector system cost of a trough plant, so its share is lower than 50%. It is expected by IEA that this cost may decrease 20-40% in the forthcoming years (IEA, 2010b). Some cost data from several sources having different storage capacity are given in Table 31.

Table 31: Collector system cost data for solar tower plants

Original Value	Calculated Value* ($/m2)	Source
€150/m^2	199	Pitz-Paal et al., 2005
€1347/kW with 3h storage	199	Pitz-Paal et al., 2005
€132/m^2	175	Schwarzbozl, 2006
$145/m^2	145	Sargent & Lundy, 2003
€146/m^2	194	Williges et al., 2010
€1000/kW with 0.5h storage	194	Kaltschmitt et al., 2007
€171.4/m^2	227	Kaltschmitt et al., 2007

*The average exchange rate of 2010 is used to convert EUR to USD.

Receiver System Cost: The second system in the chain of electricity production process in a tower plant is the receiver system which receives sunlight reflected by collector system and converts sunlight into heat energy. The cost of this system is lower than both the cost of collector and conversion systems. Some data about receiver system cost is given in Table 32.

Table 32: Receiver system cost data for solar tower plants

Original Value	Calculated Value* ($/MW)	Source
$177/kW	177,000	EEL, 1999
$133/kW	133,000	Sargent & Lundy, 2003
€119/kW	57,760	Williges et al., 2010

*The average exchange rate of 2010 is used to convert EUR to USD.

Conversion System Cost: The conversion system used in solar tower plants are similar to the ones used in solar trough plants, so the detail about this item given in Section 2.2.2.2 is also relevant for solar tower projects.

Storage Cost: Storage unit is more common in tower plants compared to trough plants. Total storage cost changes from plant to plant based on the storage capacity and it becomes higher than the cost of power block if the storage capacity is high. Storage cost is generally given in terms of $\$/kWh_{th}$ unit, so the costs from several sources are standardized by calculating costs in terms of $\$/kWh_{th}$ (Table 33).

Table 33: Storage cost data for solar tower plants

Original Value	Calculated Value* ($/kWh)	Source
$420/kW for 6.5h	22	EEL, 1999
14 €/kWh$_{th}$	19	Pitz-Paal et al., 2005
126.7 €/ kW for 3 h	19	Pitz-Paal et al., 2005

*The average exchange rate of 2010 is used to convert EUR to USD.

Other Capital Cost: Other capital cost consists of labor cost, feasibility study cost, engineering cost, site improvement cost, transportation cost, civic works, and other costs that are not included in the specific capital cost components. The only relevant cost datum is given in Pitz-Paal et al. (2005) who assumes this cost as €618/kW.

Land Cost: The detail about land cost is given in Section 2.2.2.1.

O&M Cost: Like other renewables, the main variable cost component for tower plants is also O&M cost because the fuel cost is zero. Some data about O&M cost of trough plants are given in Table 34.

Table 34: O&M cost data for solar tower plants

Original Value	Calculated Value* ($/MWh)	Source
$0.026/kWh	26.000	EEL, 1999
$0.027/kWh	27.000	Sargent & Lundy, 2003
€0.024/kWh	31.817	Kaltschmitt et al., 2007

*The average exchange rate of 2010 is used to convert EUR to USD.

The technical and financial parameters affecting the economy of tower plants are also discussed in the remaining part of this section.

Efficiency Rate: Like PV and trough technologies, the efficiency rate of solar trough plants is around 15%. Some values about efficiency rate of trough plants are given in Table 35.

Table 35: Efficiency rate data for solar tower plants

Original Value	Source
17%	Poullikkas, 2009
16%	EEL, 1999
14%	Pitz-Paal et al., 2005
14%	Sargent & Lundy, 2003
16%	Williges et al., 2010

Storage Efficiency: This factor shows the utilization of heat energy stored in the storage facility and slightly varies with the technology used in the construction of the system. It is taken as 95% by Pitz-Paal et al. (2005).

Direct Normal Insolation (DNI): The detail is given in Section 2.2.2.2.

Land Area: The land area needed to construct a tower plant is important because it determines both the level of total land cost and the capacity of a relevant site. Like a solar trough plant discussed in Section 2.2.2.2., the plant capacity and the storage capacity are the most important factors determining the land area need to construct a solar tower power plant. When we look at Table 36, we can see that the land area increases if the plant capacity and/or the storage capacity of a power plant increase. For example, the land size of a plant with 20 MW capacity is 900,000 m^2 while the land area of a plant having a capacity of 11 MW is only 600,000 m^2. On the other hand, the land area of the plant with 19 MW plant capacity and 15 hours storage capacity is 1,420,000 m^2 which is 58% higher than the land are of the plant having 19 MW plant capacity without storage.

In Table 36, I also calculated land area per unit capacity in the forth column to demonstrate how the plant capacity and the storage capacity affect the area of land needed for a solar tower plant.

Table 36: Needed land area per unit capacity for solar tower plants

Total Land Area of the Plant (m^2)	Storage (hour)	Plant Capacity (MW)	Land Area (m^2/kW)	Source
600,000	1	11	55	Poullikkas, 2009
900,000	-	20	45	Poullikkas, 2009
1,420,000	15	19	75	Poullikkas, 2009
611,000	3	17	36	Pitz-Paal et al., 2005
3,400,000	16	50	68	Sargent & Lundy, 2003

Collector Field Area: The collector field area shows how much land is needed to build solar energy collector system of a tower plant. It highly depends on the plant capacity and the storage capacity. Collector area of plants with different plant capacity and storage capacity are given in Table 37. From the table, it is obvious that the collector area need increases when the plant capacity and/or the storage capacity increase.

In addition, the field area per unit capacity values for each plant are calculated and given in the forth column of the table to demonstrate the effect of total capacity and storage hour on the collector area need for a solar tower plant. When the land area per unit capacity in Table 36 and the collector area per unit capacity in Table 37 are compared, it can be concluded that the value of the latter is highly lower than the value of the former. The reason is that collectors are only built on a portion of the total land area of the plant; the remaining area is used for other purposes like roads, central tower and buildings.

Table 37: Collector field area data for solar tower plants

Total Collector Field Area (m^2)	Storage (hour)	Capacity (MW)	Field Area (m^2/kW)	Source
75,000	1.0	11	7	Poullikkas, 2009
275,000	6.5	30	9	EEL, 1999
826,000	6.5	100	8	EEL, 1999
1,490,000	6.5	200	7	EEL, 1999
152,720	3.0	17	9	Pitz-Paal et al., 2005
720,000	16.0	50	14	Sargent & Lundy, 2003
175,000	0.5	30	6	Kaltschmitt et al., 2007

Capacity Factor: Like trough plant, the capacity factor of a tower plant is also higher than the capacity factor of PV plants and wind farms. This ratio increases based on the capacity of storage facility. Capacity factor of solar thermal plants mainly depends on the climate of the relevant site and the storage capacity. Some capacity factor rates from several studies determined for different sites having different DNI and storage capacity are given in Table 38.

Table 38: Capacity factor data for solar tower plants

DNI (kWh/m^2/year)	Storage Capacity (hour)	Capacity Factor (%)	Source
0.00	6.50	0.45	EEL, 1999
2,940.00	16.00	0.75	Sargent & Lundy, 2003

Economic Lifetime: The economic life of a tower plant is generally taken as 25 or 30 years. The data about economic lifetime is given in Table 39.

Table 39: Economic lifetime data for solar tower plants

Original Value (years)	Source
25	EEL, 1999
30	Pitz-Paal et al., 2005
30	Sargent & Lundy, 2003
25	Kaltschmitt et al., 2007

Salvage Value: At the end of lifetime of a tower plant, the material of the plant has a salvage value which is assumed as 20% of original capital cost by IEA (2010a).

Discount Rate: In the literature, the discount rate is generally assumed to be between 5% and 10%. In this study, the discount rate is not assumed, instead it is calculated and the detail of calculation is given in Section 4.2.1.1.

2.3. INTERMITTENCY AND STORAGE

Intermittency is the most important problem for renewable energy sources which are not continuously available because of some uncontrolled factors. Therefore, to increase the share of these energies in electricity generation portfolio of a system, some measures have to be taken. Regarding wind and solar energy technologies, intermittency is problem especially for wind and PV technologies because solar thermal technologies have cheap heat storage opportunity to mitigate this problem.

In this section, intermittency is discussed by explaining the problems which arose from intermittency, by listing some tools used to solve the intermittency problem, and by giving some information and data about the cost of intermittency.

Intermittency character of wind and PV technologies causes two main problems for an electricity system which are huge fluctuations in electricity production and limited contribution to available peak capacity. Firstly, wind or PV plants utilize energy sources which cannot be stored or controlled, so the continuous change of the amount of available source cause sudden changes in electricity production. Hence, it becomes harder to manage the system, especially during peak periods. Secondly, the contribution of these sources to available peak capacity is very limited due to their unsteady character. For example, during July 16-24, 2006, there was a heat storm in California and the contribution of wind sources at peak was only 5% of total capacity (Pawlak, 2008). This is an extreme case, so generally it is accepted that to replace one unit of conventional generation capacity, three unit capacity of renewable energy is needed (Boccard, 2010).

On the other hand, there are some tools to eliminate or at least to diminish the intermittency problem. Namely, these measures are active grid management, demand side management, load shedding, smart grid, storage, extra reserves and setting limits for intermittent energy sources. Each measure is briefly discussed below.

Active grid management: Active grid management entails the use of improved forecasting methods. Forecasting has been used by the system operators for a long time to estimate the demand for the forthcoming day and hours and plants are recruited accordingly. However, it is needed to use more sophisticated forecasting models to incorporate renewable energy plants in the system. Besides, some flexible mechanisms have to be carried out like the intra hour scheduling which will help to mitigate the intermittency problem in addition to increase the flexibility of the system (Wiser and Bolinger, 2010).

Demand side management: The conventional approach to the management of a grid was to control the supply side by giving directives to generators. However, the incorporation of renewable sources requires more flexibility in the system. Hence, the management system should be revised to provide the participation of the demand side in the system so that system operators may give directives to the participating consumers to decrease the consumption when needed. Demand side management makes it possible to redistribute the load by moving load from peak to off-peak timescales in order to decrease the amount of reserve capacity for renewables.

Load shedding: Load shedding is another way to decrease the consumption of electricity, but it is applied by a system operator unilaterally. This method is generally used in developing countries where available capacity is not enough to meet the demand, especially during peak period. In our context, it can be used to shutdown big consumers to manage the unexpected, marginal outages of renewable plants. This method is not preferred in developed countries, but it can be an alternative to decrease the level of reserves held to compensate the outages with very low probability.

Smart grid: This is another tool used to increase the flexibility of the system. In smart grid, whole system management is computerized and the electricity consumption of appliances at consumers' homes and the electricity generation of plants are controlled by the system.

Storage: Storage facilities are used to shift the availability of energy from one period to another. During off-peak period some amount of electricity generated by wind and PV plants is stored to consume when needed. Currently there are two practical storage solutions which are pumped hydro and compressed air energy storage which have lower unit cost relatively. Pumped hydro requires two bodies of water at different elevations and it is limited to the sufficient hydropower dams, but compressed air storage has huge potential because majority of land is sufficient to be used for this purpose (DeCarolis and Keith, 2006). The additional cost of compressed air storage is assumed as ₵1/kWh by Kaygusuz (2009) and ₵4/kWh by Fthenakis et al. (2009).

Increasing reserves: Another option to manage the intermittency problem is the increase the amount of operational reserves and capacity reserves. The former is a short term solution while the latter is a long term solution. This alternative is one of the easiest ways to apply, but increases the cost of integration of renewables considerably.

Setting limits for renewables: To operate the system without doing any major change in the management of the system, a limit for the share of intermittent energy sources can be set. The limit should be determined based on the structure of the generation sector, the behavior of the consumers, and the characteristics of the relevant renewable sources. This method is another simple method to apply because it does not entail any major change in the system. This ratio is generally accepted as 20% of total generation capacity. However, it has to be determined for each system based on the current circumstances like the dispersion of the renewable energy plants, the share of other conventional sources, and the interconnection capacity to other systems (Kaygusuz, 2009). Currently, there is only one country, Denmark, having 20% share of renewables and she has managed the electricity system without hardship so far (Kaygusuz, 2009).

After giving information about the problems caused by the intermittency and some tools used to mitigate the intermittency problem, lastly the intermittency cost is discussed by stating its content, by explaining the factors affecting the level of intermittency cost, and by giving some cost data from several sources.

Intermittency cost consists of balancing cost arose from the incorporation of renewables and adequacy cost caused by renewables (IEA, 2010b). With the addition of renewables, extra balancing cost that stems from the need for ancillary services to match supply with demand is bore by the system operator. It is estimated to be $1.3 to 3.5/MWh by IEA (2010b). The second item is adequacy cost which exist because of the need for extra generation capacity to use at peak when renewables are not available. IEA (2010b) estimates this cost to be between $0-4.5/MWh. Some data about intermittency cost are given in Table 40.

Table 40: Intermittency cost data

Intermittency Cost	Source
$1.3-8/MWh	IEA (2010b)
₵2/kWh of wind generation	Pavlak (2008)
₵1-4/kWh of wind generation	Krohn et al. (2009)

There are two main factors that play an important role in the level of intermittency cost in a system. Firstly, intermittency cost highly depends on the share of renewables and the cost increases if the share of renewable increases (Krohn et al., 2009). Another factor affecting the level of intermittency cost is the structure of generation portfolio of the system. It becomes lower if generation sector is dominated by gas turbines and hydros because gas plants have low capital cost and high ramp rate and hydros have high ramp rate (DeCarolis and Keith, 2006).

Chapter 3: Electricity Generation Sector and Renewable Energy Potential in Turkey

Turkey is a Eurasian country stretching at the middle of Europe and Asia, and surrounded by the Mediterranean Sea to the south, the Aegean Sea to the west, and the Black Sea to the north. Its population is about 80 million the 70% of which live in urban areas and she has the highest population growth rate among IEA countries (CIA, 2011).

The economy of Turkey, one of the world's first 20 largest economies, is dynamic and grew significantly in the last years despite the last global economic crisis. As a result, the electricity demand is continuously increasing, which compels the construction of new power plants necessary to meet the increasing demand. For example, the electricity demand increased 5.3% annually between 2000 and 2009 despite the adverse effect of the global economic crisis in 2008 and 2009 (TEIAS, 2010). In addition, TEIAS (2010) forecast about 7% annual increase in the electricity demand for the next decade. To meet this significant increase in demand, Turkey has to install as much as 35 – 60 GW of capacity through 2020 (Kaygusuz, 2011). Unfortunately, Turkey does not have domestic fossil fuel resources, except some low quality lignite, to feed this capacity and currently the weight of foreign energy sources in the primary energy consumption is very high more than 75% (Akdag and Guler, 2010). In addition to high dependence on foreign energy sources, the burning of fossil fuels to produce electricity causes environmental problems. Therefore, the utilization of renewable energy sources is the best option to meet the electricity demand in the future. Based on these concerns, the Renewable Energy Law was enacted in 2005 to incentivize the renewables and the feed-in tariffs were increased in 2010 with the amendment of the mentioned law. Currently, Turkey tries to increase the share of renewable in the generation sector.

In the fourth chapter of this study, an economic analysis is conducted for the most promising renewable sources in Turkey which are wind and solar energy to show whether these sources are attractive. Before this analysis, in this chapter, some background information is given about Turkish electricity market and her wind and solar energy potential. In the first section, the history and the current structure of Turkish electricity market is explained to present the framework of the market. In the second section, some data encompassing installed capacity, total production and the shares of sources and players in the sector are explained. Then, the data specific to the electricity generation from wind and solar energy sources are given. Lastly, wind and solar energy potential of Turkey are discussed based on the geographical characteristics of Turkey and the data created by the responsible public institutions are presented.

3.1. Outlook of Electricity Market

In this section, the history of Turkish electricity industry, the structure of the market and the main institutions in the market are discussed.

The history of the sector is explained briefly by dividing it into 3 periods: early years, monopoly period, and liberalization era. The first period started with the commencement of Turkish electricity industry in 1902 when the first electricity generation plant with a capacity of 2 kW was built. The second important step in the early years of the sector was the construction of the first large scale plant in Istanbul in 1913. However, these plants were not connected to each other and there was not any governmental body to monitor and direct the industry until 1935. Then, the first governmental institution, the Electric Power Resources Survey and Development Administration (EIE), was established to identify hydro potential and prepare hydro plant projects (Hepbasli and Ozgener, 2004).

The market structure that was dominated by the independent producers and system operators prevailed until 1963 when the Ministry of Energy and Natural Resources of Turkey (MENR) was established to regulate market and develop energy policy for Turkey (Hepbasli and Ozgener, 2004). This was the first step of the second era in the history of Turkish electricity industry. Then, a new public institution (Turkish Electricity Company – TEK) was established as the single owner of all electricity facilities including generation, transmission and distribution in 1971. In that year, total generation capacity in Turkey was still low around 2,235 MW, which doubled in the following decade (Alboyaci and Dursun, 2008).

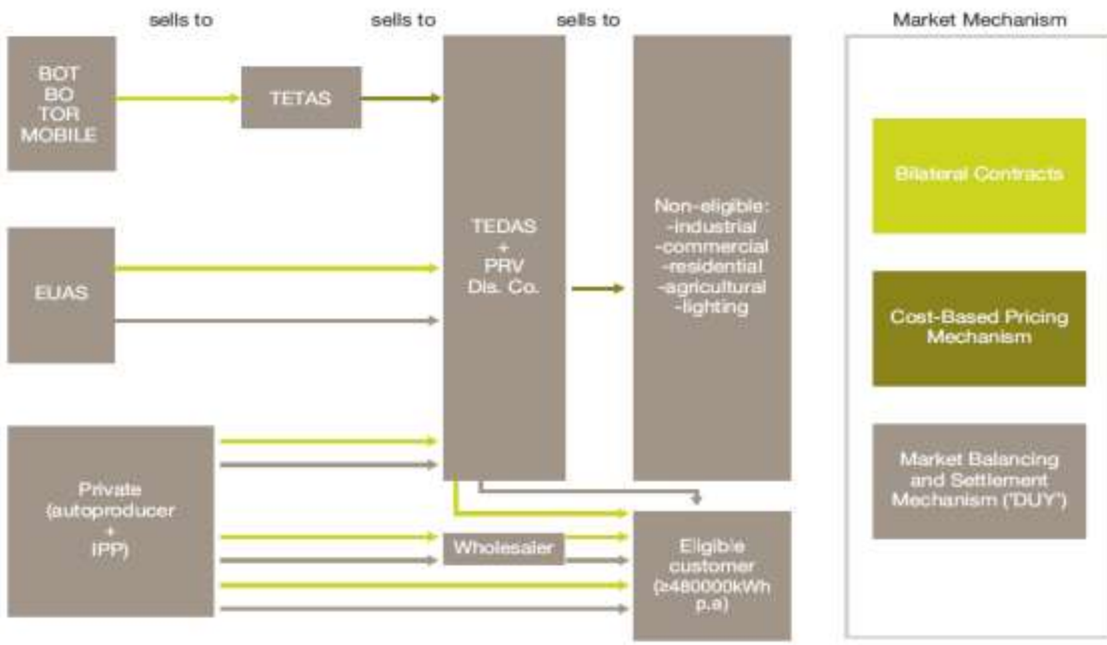
In 1984, the first attempt to a free market was done by lifting the monopoly right of TEK over the market, but this attempt did not change anything in practice. For the same aim, in the following years TEK was split into two bodies as the first step of the privatization. One of them got the possession of generation and transmission assets while other was responsible for distribution system. However, the privatization could not be succeeded and the liberalization did not take off until 2001 (Alboyaci and Dursun, 2008).

The third period which is the liberalization period started in 2001 with the enactment of a new law, Electricity Market Law, having regulations to liberalize the market. With this law, the public company responsible for transmission and generation were split into three companies each of which was responsible an activity of three activities: generation, transmission and wholesale. Also, Energy Market Regulatory Authority of Turkey (EMRA) was established to regulate market with a power encompassing the activities which are giving licenses, putting regulations, and setting tariffs for transmission and distribution activities. One of the main goals of the law is to succeed privatization and it has been successful to some extent with the privatization of some power plants and the majority of distribution systems.

In addition to the privatization, the set up of the day-ahead market based on the marginal pricing model is another important success realized in the third era. Thus, the price has been determined in the market by the bids of market participants including generators and wholesale companies. The third important development in this period was the enactment of Renewable Energy Law in 2005 to incentivize renewable investments and lots of wind farms have been built or started to be constructed since the enactment of this law.

After summarizing the history of Turkish electricity market, the structure of the market is explained briefly. According to the Electricity Market Law enacted in 2001, the activities of the market are classified as generation, transmission, distribution, wholesale, retail sale services, import and export. To conduct any of these activities, a party has to have the relevant license authorized by EMRA. These activities can be classified into four categories which are generation, transmission, distribution and trade. First, generation activities are performed by private sector generation companies, Electricity Generation Co. Inc. (EUAS) and other public sector generation companies formed by the restructuring of the Electricity Generation Co. Inc., autoproducers and autoproducer groups. Autoproducers and autoproducer groups built plants to meet their own electricity need, but they can sell the excess electricity in the market. Generating companies can sell electricity or capacity in free market through bilateral contracts or in the market balancing and settlement mechanism. Second activity regulated in the law is the transmission activity. Transmission can only be conducted by the Turkish Electricity Transmission Co. Inc. (TEIAS) Third activity is distribution which was performed by public companies (TEDAS) until the enactment of the law, but currently the majority of distribution systems are operated by private companies who got the right of operation trough tender mechanism. The other activities are related to trade which are performed by a public wholesale company (TETAS) and private companies. The structure of market is depicted in Figure 24.

Figure 24: Supply structure in the market



Source: PWC, 2009.

Lastly, the roles and responsibilities of the main public institutions in the market are explained. The important public bodies are MENR, EMRA, TEIAS, distribution companies, State Hydraulic Works (SHW), and State Planning Organization (SPO) which are discussed below (PWC, 2009).

- MENR is the public body who is responsible for developing energy policy of the country, examining the energy sources of country, developing local sources, and fostering energy efficiency.
- EMRA is the independent regulatory authority who is administratively and financially autonomous. The responsibility of EMRA is listed in the Law as

issuing Board-approved licenses that set forth the activities to which the legal entities are entitled to and the rights and obligations arising from such activities; regulation of existing contracts within the scope of transfer of operating rights as per the provisions of this Law; monitoring market performance; drafting, amending, enforcing and auditing the performance standards and distribution and customer services codes; setting out the pricing principles indicated in this Law; setting out the pricing principles to be employed for electricity sale to non-eligible consumers with regard to the market conditions; enforcing the formulae regarding the modification of such prices due to inflation and auditing of them; and ensuring the conformity of the market behavior with the provisions of this Law (EML, 2001).

- TEIAS operates transmission system, invests in transmission system when needed, carries out the Market Balancing and Settlement System, manages financial settlement among the market participants, and prepares long term electricity supply and demand projections.
- Distribution companies operate and invest in the regional distribution systems.
- SHW develops hydraulic sources and evaluates and approves the hydro power plant projects.
- SPO assists the government in the development of energy policy.

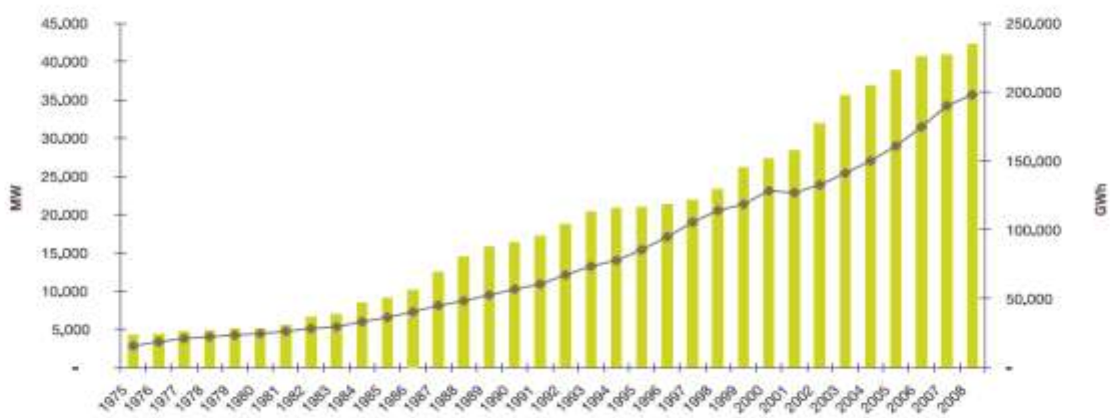
3.2. ELECTRICITY GENERATION SECTOR

In this section, some information about generation capacity and electricity production of Turkish electricity sector is discussed to present the current structure of generation sector. For this aim, firstly total generation capacity and total production figures are given, and then capacity and production are classified in terms of the ownership and source.

The capacity and production amounts encompassing a time period of three decades from 1975 to 2008 are given in Figure 25. During this period, total capacity increased from 4 GW in 1975 to 41.8 GW in 2008 while total production reached to about 198 TWh in 2008 from about 15 TWh in 1975. As a result, from 1975 to 2008 the installed capacity increased about 7% annually and production increased 10% annually. This higher increase in production compared to installed capacity shows that the installed capacity has been used more efficiently since 1975. The increase in national capacity factor during this period also proves the same result: the capacity factor was 43% in 1975 and reached to 54% in 2008. On the other hand, this situation may also interpreted as there is a continuous higher increase in the demand than the increase in the installed capacity and it may result in an unmet demand in the following years if this trend continues.

However, in 2009 the production decreased by 2% and became 194 TWh because of the economic crisis, though the installed capacity amount increased to 44.7 GW (7% increase) in the same year (TEIAS, 2010). This development may decrease the risk of unmet demand in the short term.

Figure 25: Electricity production and installed capacity of Turkey (1975-2008)

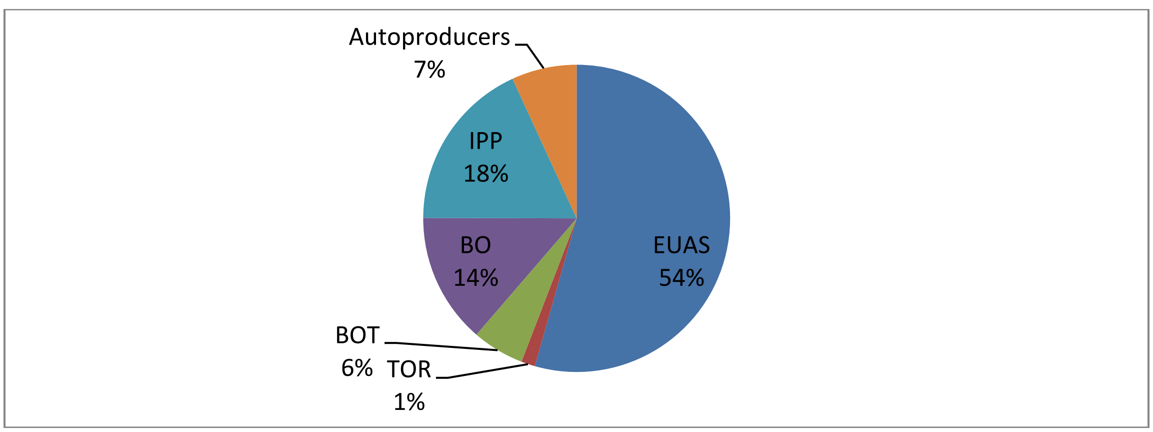


Source: Kaygusuz, 2011.

After giving detail about the general framework of generation sector, the shares of several players in the generation sector is discussed because it is important to understand the current structure of the sector. The most important characteristic of the sector is that the market share of public is still very high despite the privatization efforts since 1984 and the liberalization process starting in 2001. The state controls 54% of the installed capacity directly and 21% indirectly through the systems which are Build-Operate-Transfer (BOT), Build-Operate (BO), and Transfer of Operational Rights (TOR) contracts (IEA, 2010d). The share of privately controlled capacity is only 25% which belongs to autoproducers and independent power producers (IPP). This market structure is one of the most important obstacles against the free market because the state can easily control and determine electricity price which should be determined in the market to institutionalize the free market framework.

The share of each producer group in the capacity is given in Figure 26 for 2009. Currently, the share of private sector is only 25% (18%-IPP and 7%-autoproducers), but it is expected to increase in the following years because the majority of new plants will be built by private companies. According to TEIAS (2010), the capacity of new power plants that are planned to be built until 2017 will be about 17 GW and 13.5 GW of this total capacity will be constructed by the private sector.

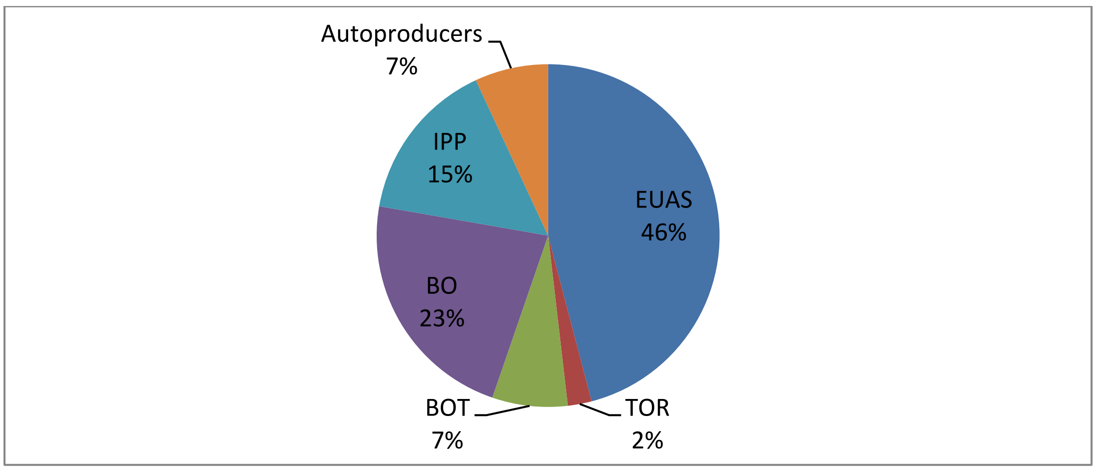
Figure 26: The share of each player in total installed capacity



Source: TEIAS, 2010.

The power of the state over the generation sector is larger if we look at the shares in the production. Despite a decrease in the share of EUAS (46%), total share of the state with BO, BOT and TOR reaches to 78% while IPP can only produce 15% and autoproducers can generate 7% of total production in 2009 (Figure 27). The high share of BO, BOT, and TOR is a result of the type of power plants operated by them. These plants are generally natural gas plant which has a high capacity factor compared to the other plants.

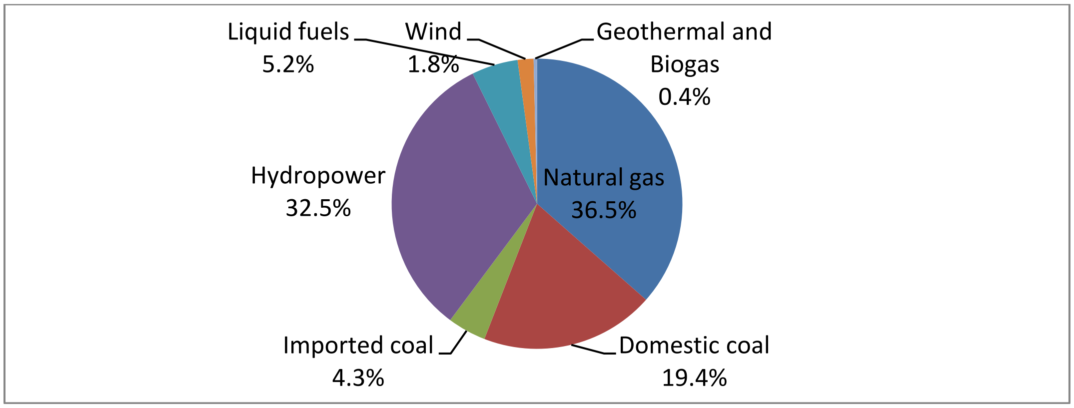
Figure 27: The share of each player in total production in 2009



Source: TEIAS, 2010.

In addition to the shares of different player in generation sector, the weight of different sources helps to understand the structure of the sector. The shares of sources in installed capacity are given in Figure 28 for 2009. Natural gas is the dominant source in the sector with a share of 36.5% while the share of all other fossil fuel sources is around 30%. There is not any nuclear plant in Turkey, so the remaining 35% belongs to renewables which are hydropower, wind, geothermal and biomass. Nonetheless, except large hydropower plants with a share of 32.5%, all other renewable sources are still marginal.

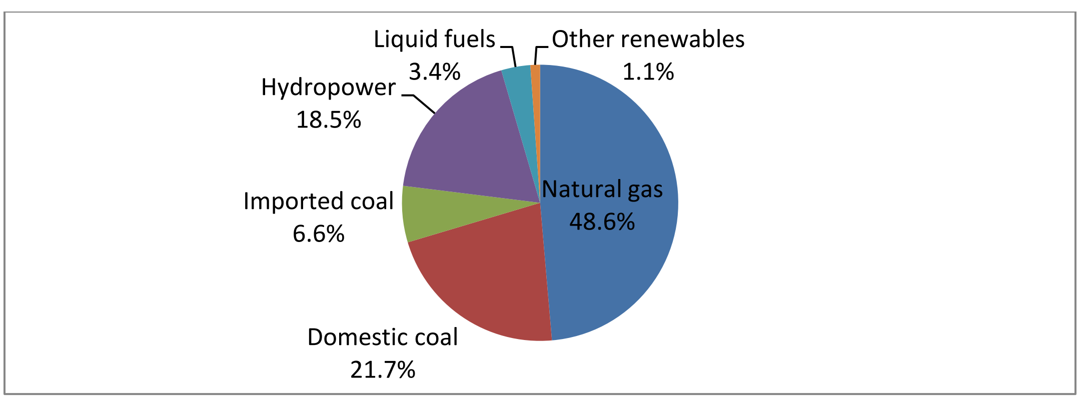
Figure 28: The share of different sources in total installed capacity



Source: IEA, 2010d and TEIAS, 2010.

On the other hand, the share of sources in the production is different from the breakdown of installed capacity (Figure 29). Natural gas is still the dominant one and it supplies nearly the half of the electricity consumed. The second source providing the highest contribution to the electricity production is domestic coal, though its share in installed capacity is 13 percentage points lower than hydropower. The share of renewables is only 18.6% which is nearly 17 percentage points lower than the share of renewable in installed capacity. This low share is a result of low capacity factors of these sources.

Figure 29: The share of different sources in total production in 2009



Source: IEA, 2010d and TEIAS, 2010.

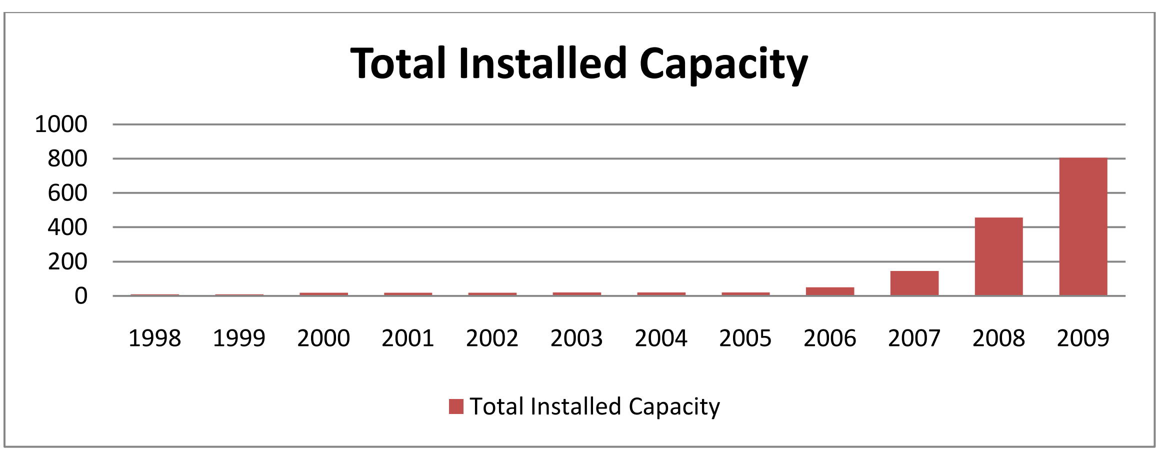
3.3. Electricity Generation from Wind and Solar Energy

In this section, electricity generation from wind energy and solar energy in Turkey will be discussed by giving a brief history and explaining the current situation for each source.

The history of modern wind energy in Turkey started in 1986 with the installation of the first wind turbine having a capacity of 55 kW in the Western part of Turkey (Aras, 2003). The height of the turbine is 24.5 m and the blade diameter is 14 m. The first large scale facility was built in 1998 in the same region with a capacity of 1.5 MW. In this farm, there are three turbines of 500 kW each. This wind farm's annual electricity production is estimated at around 4.5 GWh (Alboyaci and Dursun, 2008).

The interest in wind energy increased with the enactment of Renewable Energy Law in 2005 which set a minimum price for renewable energy as ₵5.5/kWh. In the following years, total installed capacity soared with the installation of lots of new wind power plants (Figure 30). Thus, total installed capacity exceeded 100 MW in 2007 and 800 MW in 2009, though it was only 20 MW until 2005 (Durak, 2010).

Figure 30: Wind energy installed capacity of Turkey



Source: Durak, 2010.

Currently, there are 41 operating wind farms with a total capacity of 1,367 MW. Two of these farms are operated by private companies under BOT contracts and the remaining farms are independent system operators (EMRA, 2011). In addition, there are 19 wind projects under construction with a total capacity of 750 MW as of March, 2011 (TWEA, 2011). Once these new projects are completed, total installed capacity will reach to 2,117 MW which will generate 5,560 GWh annually under the assumption of 30% capacity factor.

Contrary to wind energy, there is not any solar power plant in Turkey. There are only small PV modules which are used in remote service areas such as telecom stations, forest fire observation towers and highway emergency and total capacity of these modules is estimated as 0.3 MW (EIE, 2011)

3.4. Wind and Solar Energy Potential of turkey

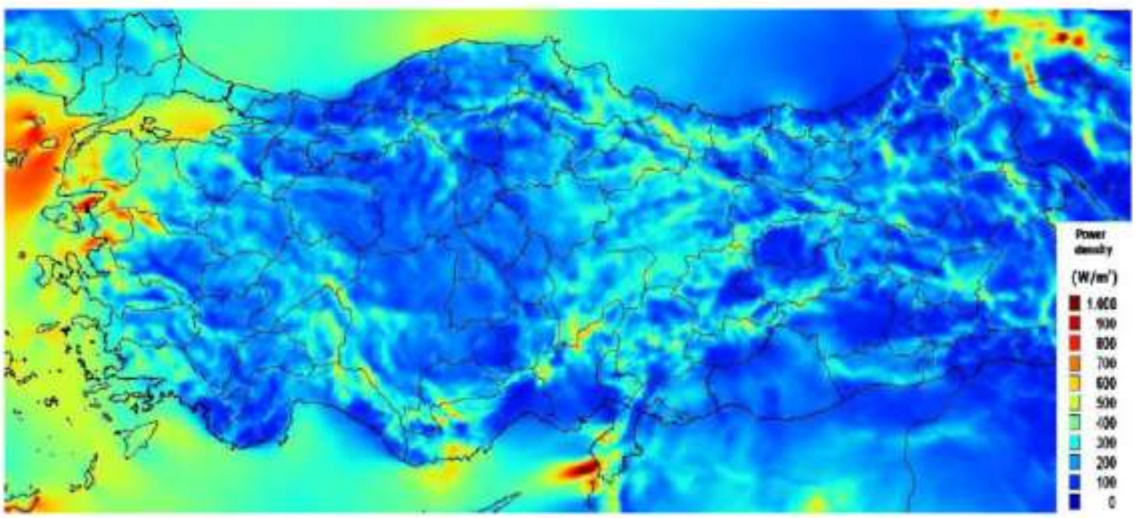
The position of a country in terms of the geography and its territorial characteristics determine her renewable energy potential. Turkey has advantageous position in terms of these criteria both for wind and solar energy. First, Turkey has a large wind potential because she has a large coastal area and many mountain-valley structures. Second, she has a good solar energy potential because her territory lies between latitudes 36 and 42N within the North sunny belt lying between latitudes 20 and 40N.

In this section, some details about the potential of wind and solar energy of Turkey are given and the potential of each source is classified into subgroups to make the data usable to carry out economic analysis.

3.4.1. Wind Energy Potential

Turkey has a land surface area of 774,815 km^2 having a long seashore surrounded by the Black Sea, the Aegean Sea and the Mediterranean Sea along three sides, so it has a good wind potential thanks to windy areas close to the seashore (Hepbasli and Ozgener, 2004). In addition, Turkey has a mountainous terrain, so there are lots of mountain-valley structures in the inner areas (Arslan, 2010). When we look at the Wind Energy Potential Atlas of Turkey (REPA) prepared by EIE in 2006 showing power density at 50 m altitude (Figure 31), we can see that most of the areas having high wind potential are located in the coastal area in the West close to the Aegean Sea and in the South close to the Mediterranean Sea, and some sites scattered in the inland.

Figure 31: The wind map of Turkey



Source: Akdag and Guler, 2010.

In the last decade, two wind energy potential atlases were prepared in Turkey. The first one was prepared by using the data provided by Turkish State Meteorological Service- TSMS and the technical potential was estimated at 88,000 MW and the economical potential was estimated at 10,000 MW. However, the high interest starting with the enactment of the Renewable Energy Law in 2005 made it necessary to prepare a new wind atlas by using more sophisticated methods. Therefore, TSMS and EIE prepared a more accurate map by using numerical weather prediction methodology at 200x200 m resolution for different heights in 2006. According to this second map given in Figure 31, the technical potential of Turkey is estimated to be 131,756 MW at 50 m altitude. This capacity is total capacity of the sites having a wind power density greater than 300 W/m^2 (equivalent to a wind speed of 6.5 m/s) and suitable to install wind turbines (Akdag and Guler, 2010).

When we compare the potential of Turkey to the potentials of other European countries which are given in Table 41, we can see that she has the highest potential even with the capacity of 83,000 MW calculated based on the first wind map of Turkey (Kenisarin, 2006).

Table 41: European OECD countries' wind potential

European OECD countries	Territory (thousand km^2)	Specific wind potential (class >3) (thousand km^2)	Side potential (km^2)	Technical potential	
				MW	TWh/yr
Turkey	781	418	9960	83000	166
UK	244	171	6840	57000	114
Spain	505	200	5120	43000	86
France	547	216	5080	42000	85
Norway	324	217	4560	38000	76
Italy	301	194	4160	35000	69
Greece	132	73	2640	22000	44
Ireland	70	67	2680	22000	44
Sweden	450	119	2440	20000	41
Iceland	103	103	2080	17000	34
Denmark	43	43	1720	14000	29
Germany	357	39	1400	**12000**	24
Portugal	92	31	880	7000	15
Finland	337	17	440	4000	7
The Netherlands	41	10	400	3000	7
Austria	84	40	200	2000	3
Belgium	31	7	280	2000	5
Switzerland	41	21	80	1000	1
Luxemburg	3	0	0	0	0

Source: Kenisarin et al., 2006.

In addition to high potential, Turkey has three important advantages in terms of wind energy. First, in most of the windy sites, wind speed is higher in summer when the annual peak occurs (Alboyaci and Dursun, 2008). Hence, the need for reserve capacity to compensate the intermittency of wind power plants is lower in Turkey. Second, wind regime differs from site to site. In other word, when wind speed decreases in some places, it increases in other sites (Malkoc, 2009). Hence, the operating reserve need is also low for wind power plants in Turkey. Lastly, windy sites are generally close to the highly populated and highly industrialized cities of Turkey (Malkoc, 2009). Therefore, the cost of connection and the cost of transmission are relatively low for wind energy.

To make the economic analysis of wind energy potential of Turkey, a total potential value is not enough; instead the classification of wind potential according to wind characteristics is needed. For this aim, the data provided by Malkoc (2009) based on the results of REPA is used in this study.

In REPA, seven wind classes are used which are weak, low, medium, good, high, excellent and extraordinary. The characteristics of these wind classes including wind speed range and wind power density at 50 m are given in Table 42.

Table 42: Wind classes and characteristics

Item Description	Wind Class	Wind Speed (m/s)	Wind Density Power (W/m^2)
Weak	1	<5.5	< 200
Low	2	5.5 - 6.5	200 – 300
Medium	3	6.5 – 7.0	300 – 400
Good	4	7.0 – 7.5	400 – 500
High	5	7.5– 8.0	500 – 600
Excellent	6	8.0 – 9.0	600 – 800
Extraordinary	7	> 9.0	> 800

Source: Malkoc, 2009.

In the preparation of REPA and the calculation of potential of each wind class the suitable areas are determined based on a numerous criteria. For example, the area up to 100 meter close each side of highways, railroads and the shoreline, forests, the sites closer than 3 km to airports, and the sites closer than 500 m to cities are excluded in the determination of suitable sites.

In addition, the suitable areas are decreased to some extent for the unforeseeable factors. After scrutinized works, the onshore and the offshore wind energy potentials of Turkey are calculated and classified according to the wind classes in Table 42. The results are given in Table 43 for the onshore and in Table 44 for the offshore. For offshore potential, only the sea land having sea depth of lower than 50 m is included.

Table 43: Onshore wind energy potential of Turkey at 50 m

Item Description	Wind Class	Wind Speed (m/s)	Wind Density (W/m2)	Suitable area (km2)	Ratio to total area	Potential Capacity (MW)
Medium	3	300–400	6.5–7.0	15,395	2.12%	76,977
Good	4	400–500	7.0-7.5	4,825	0.66%	24,126
High	5	500–600	7.5-8.0	1,910	0.26%	9,550
Excellent	6	600–800	8.0-9.0	731	0.10%	3,657
Extraordinary	7	>800	>9.0	11	0.00%	53
Total				22,873	3.14%	114,363

Source: Malkoc, 2009.

Table 44: Offshore wind energy potential of Turkey at 50 m

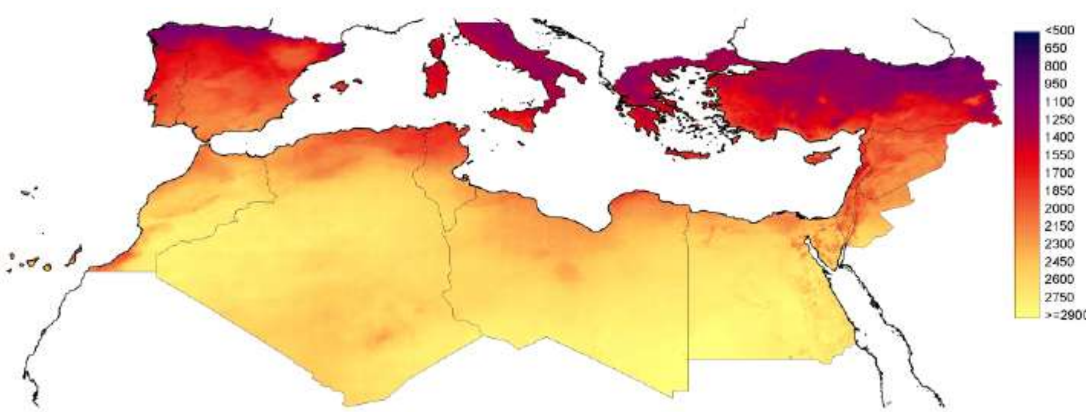
Item Description	Wind Class	Wind Speed (m/s)	Wind Density (W/m^2)	Suitable area (km^2)	Ratio to total area	Potential Capacity (MW)
Medium	3	300–400	6.5–7.0	1,386	9.26%	6,930
Good	4	400–500	7.0-7.5	1,027	6.86%	5,133
High	5	500–600	7.5-8.0	689	4.60%	3,445
Excellent	6	600–800	8.0-9.0	349	2.33%	1,743
Extraordinary	7	>800	>9.0	29	0.19%	143
Total				3,479	23.24%	17,393

Source: Malkoc, 2009.

3.4.2. Solar Energy Potential

Turkey lies between 36 and 42th north latitudes which is located in the North hemisphere sunny belt encompassing the latitudes between 20 and 40N (Viebahn et al., 2008). When we look at the potential of DNI of the Mediterranean Area located in the sunny belt of the North hemisphere (Figure 32), we can see that Turkey lies between the similar latitudes as the countries having good solar potential like Italy and Spain. This favorable position may be utilized in Turkey in the following years.

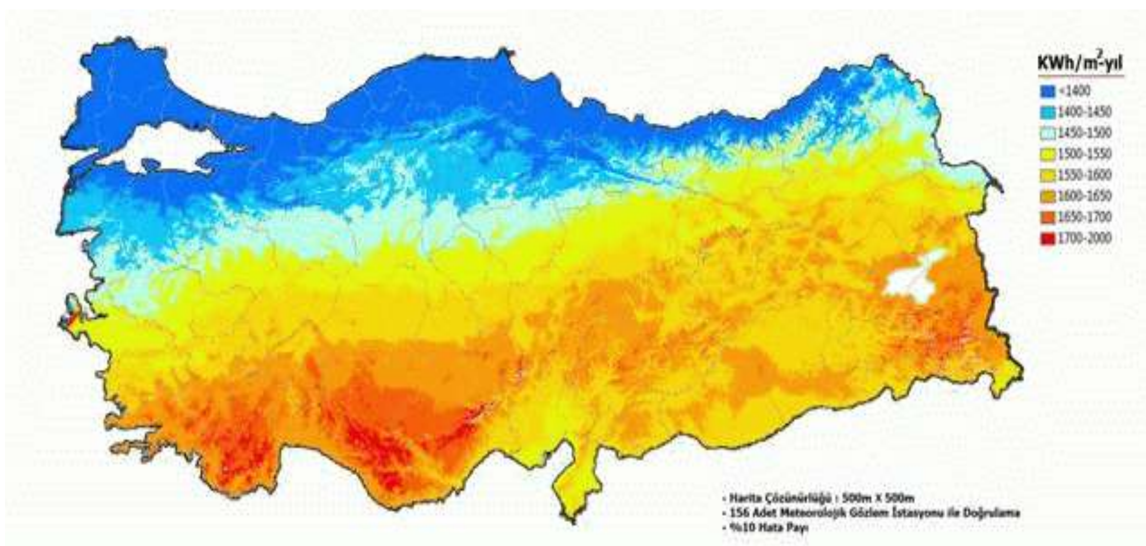
Figure 32: DNI potential map for the Mediterranean Area in 2002



Source: Pitz-Paal, et al., 2005.

The solar energy potential of Turkey was estimated by a study conducted by EIE and TSMS based on the solar radiation data measured by TSMS between 1966 and 1982. According to this study, the annual average solar radiation is estimated to be 1,311kWh/m^2-y and the total annual average radiation period is calculated as 2,640 hours. However, based on the recognition that the measured data was lower than the actual solar data, the collection of new data by EIE and TSMS was started in 1992. According to this second study which has not been completed yet, the actual radiation values are 20-25% higher than the first measurements (EIE, 2011). The solar map set up by using the first study is given in Figure 33. When we analyze the map, we can see that solar radiation and sunshine duration highly differs from region to region: it is higher in the South and the Southeast regions of Turkey.

Figure 33: GHI map of Turkey



Source: Limitsizenerji, 2010

The different solar radiation and duration values for main seven regions and selected cities are given in Table 45. According to the table, the highest value exists in the Southeast Anatolia region with a GHI of 1,492kWh/m^2-y and duration time of 3,016 hours.

Table 45: Solar energy potential of seven region and selected cities

Region	Radiation energy			Sunshine duration period		
	Average (kW h/m^2 y)	Maximum (kW h/m^2 y)	Minimum (kW h/m^2 y)	Average (h/y)	Maximum (h/month)	Minimum (h/month)
Southeast Anatolia	1492	2250	600	3016	408	127
Diyarbakır	1448	2400	620	2947	390	112
Mediterranean	1453	2112	588	2924	360	102
Antalya	1378	2160	528	3062	386	140
Central Anatolia	1434	2112	504	2712	381	98
Ankara	1492	2448	506	2662	380	80
Aegean	1407	2028	492	2726	371	96
İzmir	1230	1965	456	2770	387	109
East Anatolia	1395	2196	588	2694	374	167
Erzurum	1299	2016	580	2618	354	100
Marmara	1144	1992	396	2528	351	88
İstanbul	1329	2220	456	2370	357	78
Black Sea	1086	1704	408	1966	274	84
Trabzon	1009	1728	420	1672	202	96

Source: Kaygusuz and Sari, 2003.

Despite the good potential, the use of solar energy to generate electricity has been only restricted to small PV module constructed for small service needs. Currently, there is not any solar power plant in Turkey, though common use of solar energy for hot water production, especially in the sunny coastal region in the West and the South.

To make the economic analysis of solar energy potential of Turkey, average potential value is not enough; instead the classification of the potential according to solar characteristics is needed. Unfortunately, there is not a data set about solar energy potential of Turkey like the one for wind energy. The most reliable and comprehensive datum is about total suitable land area which is 4,600 km^2 with a GSI of 1,650 kWh/m^2-y or more. This value is calculated by EIE (Limitsizenerji, 2010). In addition to this value, there is a value for Adana region, one of the most prominent regions for solar projects in

Turkey. According to Kaygusuz (2011), Adana region has a suitable land area of 879 km^2 with a GSI of 1,980 kW/m^2 or more.

Chapter 4: Economic Analysis of Wind and Solar Energy in Turkey

In this chapter, economic analysis of wind and solar energy potential of Turkey is done based on the cost data and the technical parameters given in Section 2.1.2 and 2.2.2 and the energy potential given in Section 3.4.1 and 3.4.2. We, firstly, construct model for each technology to calculate cash flows. Then, cash flows are used to conduct economic analysis by calculating payback period, NPV, IRR, LCE, and shut-down price. Lastly, uncertainty analysis is held for two most promising technologies which are onshore wind and solar tower to see the probabilistic distribution of NPV and LCE to make more accurate and reliable conclusions about these technologies.

4.1. Cash Flow Calculations

In this section, the cash flow calculations are explained for onshore wind, offshore wind, solar PV, solar trough and solar tower technologies. Firstly, the inputs are discussed by stating the assumptions about each of them and by specifying the value taken for each input. Then, the outputs of calculations are given for each technology.

4.1.1. Inputs

In this part, parameters used in the calculation of cash flows are explained by classifying into six categories: common inputs, onshore wind, offshore wind, solar PV, solar parabolic trough, and solar tower. The detail explanation about cost components and technical factors like capacity factor is done in Section 2.1.2 and 2.2.2 and the detail information about the potential of wind and solar energy is given in Section 3.3.1 and 3.3.2, so in this section it is discussed only how the value of an input is determined and what kind of assumptions is made.

4.1.1.1. Common Inputs

Although each technology has different characteristics, some parameters, especially the financial ones are the same. In this part, I discuss these common inputs which are salvage value, expected inflation, tax rate, debt payment period, weight of debt, weight of equity, cost of debt, cost of equity, WACC and depreciation period.

Salvage Value: Salvage value is taken as 20% of original capital cost based on the assumption of IEA (2010a).

Inflation: All monetary items are expressed in USD because both the majority of costs and renewable energy feed-in tariffs in Turkey are given in USD. Therefore, the long-run expected inflation rate of USD is used in the calculations. The expected inflation rate is taken as 2.5% annually because it has been used the majority of the similar studies like Rehman et al. (2007), Schwarzbozl (2006), Stoddard et al. (2006), Turchi (2010), and Sargent & Lundy (2003).

Tax Rate: The prevailing corporate tax rate in Turkey which is 20% is used.

Debt Payment Period: It is assumed as 10 years.

Weight of Debt: The share of debt in the financing of the investment cost is assumed to be 50%.

Weight of Equity: The share of equity is assumed as 50%.

Cost of Debt: Cost of debt is calculated according to Equation 3.

$$r_d = r_f + DRP + CRP \qquad (3)$$

Where, r_d represents cost of debt, r_f represents risk-free rate, DRP represents the debt risk premium, and CRP represents the country risk premium.

For risk-free rate, the average of daily indices of the 10-year US Treasury bond for period between 02.01.2010 to 01.28.2011 is taken. This value is 3.17%. Each of DRP and CRP is assumed as 2%. Thus, the cost of debt is calculated as 7.17%.

Cost of Equity: Cost of equity is calculated based on the CAPM model by adding it a country risk premium (Equation 4).

$$r_e = r_f + \beta_l \times r_M + CRP \quad (4)$$

Where, r_e represents cost of equity, r_f represents risk-free rate, β_l represents levered beta (equity beta) which measure the risk of levered company relative to the market, r_M represents the market premium, and CRP represents the country risk premium.

The assumptions about the value of CRP and r_f are explained in the cost of debt part, so it is needed to determine the market risk premium and levered beta. As the market risk premium which shows the difference between expected market return and expected risk-free return, I take the value calculated from the long term historic data. This value is taken as 7.62% that is calculated from the data encompassing a period from 1928 to 2010 by Damodaran (2011a). On the other hand, the levered beta is calculated by using Equation 5 (Watson and Heed, 2006)

$$\beta_l = \beta_u \times (1 + (1-t) \times D/E) - \beta_d \times (1-t) \times D/E \quad (5)$$

Where, β_l represents levered beta which measure the risk of levered company relative to the market, β_u represents unlevered beta which measure the risk of unlevered company relative to the market, t represents the prevailing tax rate, D represent the debt, E represents the equity, and β_d represents debt beta which measure the risk of debt relative to the market.

The unlevered beta values, D/E ratios and tax rates are collected from Damodaran (2011b) which is given in Table 46. By using the data in the table, firstly, debt betas are calculated for these four groups of energy companies. Then, the levered betas are calculated from these debt betas and unlevered betas are calculated by using Turkish corporate tax rate of 20%. The average of these levered betas (1.04) is used to calculate cost of equity.

Table 46: Average levered and unlevered betas of energy companies

Industry Name	Number of Firms	Average Beta	Market D/E Ratio	Tax Rate	Unlevered Beta
Canadian Energy	10	1.14	28.44%	10.36%	0.91
Electric Util. (Central)	23	0.78	96.84%	25.40%	0.45
Electric Utility (East)	25	0.73	74.73%	30.56%	0.48
Electric Utility (West)	14	0.75	83.18%	31.47%	0.48

As a result, by taking risk-free rate as 3.17%, levered beta as 1.04, market risk premium as 7.62%, and country risk premium as 2%, the cost of equity is calculated as 13.12%.

Weighted Average Cost of Capital (WACC): The WACC is used as the discount rate in the model. It is calculated by using Equation 6.

$$WACC=w_d \times r_d \times (1-t)+w_e \times r_e \quad (6)$$

Where, w_d represents weight of debt (50%), r_d represents cost of debt (7.17%), t represents tax rate (20%), w_e represents weight of equity (50%), and r_e represents cost of equity (13.12%). By using these items, WACC is calculated as 9.43%.

Depreciation Period: Depreciation period is assumed to be equal to the expected lifetime of the relevant plant technology.

The values of all common inputs which are used in the calculations are given in Table 47 together.

Table 47: The common inputs

Item Description	Value
Salvage Value	20%
Inflation	2.50%
Tax Rate	20%
Debt Payment Period (years)	10
Weight of Debt	50%
Weight of Equity	50%
Cost of Debt	7.17%
Cost of Equity	13.12%
WACC	9.43%

4.1.1.2. Onshore Wind

In this section, the values of inputs particular to onshore wind model are discussed. These inputs are cost of turbine, grid connection cost, civil work and installation cost, O&M cost, potential onshore wind capacity, capacity factor, lifetime, and electricity price.

Cost of Turbine: The turbine cost is taken as $786,872/MW that is the mean of different values ranging from $454,800/MW to $1,041,538/MW.

Grid Connection Cost: The grid connection cost is taken as $145,824/MW that is the mean of different values ranging from $119,315/MW to $161,075/MW.

Civil Work and Installation Cost: The civil work and installation cost is taken as $19,137/MW that is the mean of different values ranging from $10,000/MW to $33,333/MW.

O&M Cost: The O&M cost $16.24/MWh that is the mean of different values ranging from $5.33/MWh to $26.51/MWh.

Wind Energy Capacity: The onshore capacity figures for 5 wind classes (from 3 to 7) are taken from Malkoc (2009). The values are given in Table 43.

Capacity Factor: Capacity factor is the most crucial component for renewable energy projects because it is the most important factor determining the production and the revenue. This factor is determined by the quality of the renewable energy and there are a lot of factors affecting the quality. However, this study does not investigate the economic feasibility for a specific site, so only the most important factor, annual average wind speed, is used to estimate the capacity factor for each wind class.

For this aim, a linear regression model is constructed because between wind speeds of 6 and 12 m/s there is a linear relation between wind speed and capacity factor as depicted in Figure 14. In the model, capacity factor is dependent variable and wind speed is independent variable.

The sample for the model was collected from two sources which are Akdag and Guler (2010), and Kenisarin et al. (2006). The former study gives capacity factors for 14 sites in Turkey with good wind source. However, the wind speed of each site was measured at different altitude, so wind speed at 80 meter is calculated for all 14 sites by using the formula in Equation 7.

$$v_A/v_B = (h_A/h_B)^\wedge(1/7) \qquad (7)$$

Where, v_A represents wind speed at altitude 80 m, v_B represents wind speed at the original altitude, h_A represents the altitude of 80 m, and h_B represents the original altitude. The original and calculated wind speed values are given in Table 48.

Table 48: The wind speed calculation for 14 different site

Site #	Original Height (m)	Original Wind Speed (m/s)	Turbine Height (m)	Calculated Speed (m/s)	Capacity Factor (%)
1	10	4.14	80	5.57	21%
2	10	4.13	80	5.56	20%
3	10	6.36	80	8.56	44%
4	50	8.89	80	9.51	49%
5	50	8.3	80	8.88	40%
6	10	4.1	80	5.52	21%
7	10	5.8	80	7.81	40%
8	10	5.63	80	7.58	36%
9	10	5.73	80	7.71	38%
10	10	4.1	80	5.52	20%
11	10	6.97	80	9.38	50%
12	10	5.05	80	6.80	30%
13	10	5.41	80	7.28	34%
14	10	7.27	80	9.78	44%

Source: Calculated by the author based on the data from Akdag and Guler (2010).

The whole sample set used in the regression model is given in Table 49.

Table 49: The sample for the regression model to estimate capacity factor

Speed (m/s)	Capacity Factor (%)	Speed (m/s)	Capacity Factor (%)
5.52	20.70%	7.58	36.30%
5.52	19.90%	7.60	33.30%
5.56	19.70%	7.71	38.00%
5.57	20.60%	7.81	40.40%
6.10	21.80%	8.40	35.50%
6.70	26.00%	8.56	44.40%
6.80	30.10%	8.88	40.00%
6.90	21.90%	9.38	50.30%
7.10	25.50%	9.51	49.20%
7.28	34.20%	9.78	43.70%
7.30	28.50%		

Source: Akdag and Guler, 2010 and Kenisarin et al., 2006.

The estimation of the parameters of the regression model, the regression tool in Excel is used. The results are given in Table 50.

Table 50: The results of the regression model to estimate capacity factor

Statistics	Values
Sample size	21
Coefficient of wind speed	0.07
F value	142
R square	88%
Intercept	-0.195
t-Stat of intercept	-4.4
t-Stat of Coefficient	11.9

Lastly, the capacity factors for different wind speeds that are used to analyze the potential of Turkey are estimated by using the regression model. For this calculation, the middle point for each wind speed class is taken. The estimated capacity factors are given in Table 51.

Table 51: Capacity factors for different wind speeds onshore

Wind Class	Wind Speed at 50 m (m/s)	Wind Speed Average (m/s)	Capacity Factor (%)
3	6.5 – 7.0	6.75	28%
4	7.0-7.5	7.25	31%
5	7.5-8.0	7.75	35%
6	8.0- 9.0	8.50	40%
7	> 9.0	9.00	44%

Lifetime: In the literature, there are two common values which are 20 years and 25 years, but 20 years is more common. Hence, the lifetime is taken as 20 years for onshore wind turbines.

Price: According to the Renewable Energy Law, the regulated price of wind-generated electricity is ₵7.3/kWh for the first 10 years of operation. If all mechanical parts are produced in Turkey, there is an extra payment which is ₵3.7/kWh for the first 5 years of operation. It is assumed that the half of this bonus payment is added to the price for the first 5 years. As a result, the price is taken as ₵9.2/kWh for the first 5 years and ₵7.3/kWh for the remaining lifetime.

A summary of the values of the eight inputs peculiar to the onshore wind calculation model is given in Table 52.

Table 52: The onshore wind model inputs

Item Description	Minimum	Maximum	Determined Value
Cost of turbine	$454,800/MW	$1,041,538/MW	$786,872/MW
Grid connection cost	$119,315/MW	$161,075/MW	$145,824/MW
Civil work and installation cost	$19,137/MW	$10,000/MW	$33,333/MW
O&M cost	$16.24/MWh	$5.33/MWh	$26.51/MWh
Wind capacity			
6.75 m/s			76,977 MW
7.25 m/s			24,126 MW
7.75 m/s			9,550 MW
8.50 m/s			3,657MW
9.00 m/s			53 MW
Capacity factor			
6.75 m/s			28%
7.25 m/s			31%
7.75 m/s			35%
8.50 m/s			40%
9.00 m/s			44%
Lifetime	20 years	25 years	20 years
Price			
First 5 years			₵9.2
After 5 years			₵7.3

4.1.1.3. Offshore Wind

In this section, the values of inputs particular to offshore wind model are discussed. These inputs are cost of turbine, grid connection cost, civil work and installation cost; O&M cost, potential onshore wind capacity, capacity factor, lifetime, and electricity price.

Cost of the Turbine: The turbine cost is taken as $1,122,338/MW that is the mean of different values ranging from $787,476/MW to $1,271,934/MW.

Grid Connection Cost: The grid connection cost is taken as $493,993/MW that is the mean of different values ranging from $453,395/MW to $629,715/MW.

Civil Work and Installation Cost: This cost highly changes from country to country and it is very low in Turkey compared to the developed countries. Contrary to onshore wind civil work and installation cost, I could not find any data belonging to a project conducted in Turkey or in a similar country, so the minimum value in the literature is added to the model. The minimum value is $676,116/MW (Krohn et al., 2009)

O&M Cost: The O&M cost is taken as $26.86/MWh that is the mean of different values ranging from $11.00/MWh to $54.00/MWh.

Wind Energy Capacity: The offshore capacity figures for 5 wind classes (from 3 to 7) are taken from Malkoc (2009). The values are given in Table 44.

Capacity Factor: Offshore wind installed capacity in the world is very small, so I could not collect enough data to construct a model to estimate the capacity factor for offshore projects. Therefore, the results of the model constructed for onshore are used with a revision. Capacity factor is generally expected to be higher for offshore wind farm compared to onshore farm because the fluctuation in wind is low and the duration of stable wind is considerably higher offshore. Based on this superiority of offshore wind, I assume that the capacity factor for an offshore turbine will be 20% higher than the capacity factor of an onshore turbine deployed at a site having the same annual average wind speed. The calculated capacity factors are given in Table 53.

Table 53: Capacity factors for different wind speeds for offshore wind projects

Wind Class	Wind Speed (m/s)	Wind Speed Average (m/s)	Capacity Factor (%)
3	6.5 – 7.0	6.75	33%
4	7.0-7.5	7.25	38%
5	7.5-8.0	7.75	42%
6	8.0- 9.0	8.50	48%
7	> 9.0	9.00	52%

Lifetime: In the literature, three different lifetimes which are 20 years, 25 years, and 30 years have been used. I assume it as 25 years in the model.

Price: Feed-in tariffS in Turkey is the same for onshore and offshore wind power plants. The detail about the price is given in Section 4.1.1.2.

A summary of the values of the eight inputs peculiar to the offshore wind calculation model is given in Table 54.

Table 54: The offshore wind model inputs

Item Description	Minimum	Maximum	Determined Value
Cost of turbine	$787,476 /MW	$1,271,934/MW	$1,122,338/MW
Grid connection cost	$453,395/MW	$629,715/MW	$493,993?MW
Civil work and installation cost	$676/MW	$1,590,860/MW	$676,116/MW
O&M cost	$11.00/MWh	$54.00/MWh	$27/MWh
Wind capacity			
6.75 m/s			6,930 MW
7.25 m/s			5,133 MW
7.75 m/s			3,445 MW
8.50 m/s			1,743MW
9.00 m/s			143MW
Capacity factor			
6.75 m/s			33%
7.25 m/s			38%
7.75 m/s			42%
8.50 m/s			48%
9.00 m/s			52%
Lifetime	20 years	30 years	25 years
Price			
First 5 years			₵9.2
After 5 years			₵7.3

4.1.1.4. Solar PV

In this section, I discuss the values of inputs particular to PV solar model. These inputs are module cost, inverter cost, grid connection cost, land cost, other capital cost, O&M cost, efficiency rate, available capacity per unit area, suitable land area, available capacity, capacity factor, expected lifetime, degradation rate, and price.

<u>Module Cost:</u> The module cost values in different studies range from $3,380,000/MW to $5,550,000/MW. In this study, I take $3,380,000/MW because it is the current market price in January 2011 stated by solarbuzz.com (2011).

Inverter Cost: The inverter cost is also taken from solarbuzz.com (2011) and its value is \$715,000/MW. Inverter is replaced every 10 years (Diaf et al., 2008) and it is assumed that O&M cost contains inverter replacement cost.

Grid Connection Cost: I assume the grid connection cost is the same as onshore wind, so it is taken as \$145,824/MW.

Land Cost: Land cost is assumed to be €/2/m^2 (Pitz-Paal et al., 2007).

Other Capital Cost: Other capital cost consists of civil work, deployment cost, and electrical system costs excluding inverter cost. The minimum value of the collected data from several sources is taken because these costs are expected to be lower in Turkey. It is taken as \$800,000/MW from Patel (2005).

O&M Cost: The O&M cost is assumed as \$25.59/MWh that is the mean of different values ranging from \$7.34/MWh to \$39.42/MWh.

Efficiency Rate: I assume crystalline cell technology is used with a 15% efficiency rate.

Available Capacity per Unit Area: Based on the assumption of the efficiency rate to be 15%, I calculate the capacity of PV module per m^2 area as 150 W based on the the maximum global radiation of 1,000 W/m^2 (Poullikkas, 2009).

Suitable Land Area: Suitable land area in Turkey for solar energy generation with different global solar insolation values are given in Table 55.

Table 55: Suitable land area for solar power plant projects

GSI	Land Area	Source
>=1,980 kWh/m^2	879 km^2	Limitsizenerji, 2010
>=1650 kWh/m^2	4,600 km^2	Kaygusuz, 2011

Based on the data given in the table, I generate two type of sources to use in calculations which are: (1) a land area of 879 km^2 with a GSI of 1,980kWh/m^2, (2) a land area of 3,721 km^2 (the remaining area after subtracting 879 km^2) with a GSI of 1,815 kWh/m^2 which is the midpoint of the range in Table 55.

Available Capacity: The available capacity is calculated by multiplying available capacity per m^2 and the half of suitable land area. I assume only the half of the suitable area will be used to setup modules, the remaining will be used for other purposes like roads. The calculated capacities are given in Table 56.

Table 56: Available capacity for solar power plant projects

GSI (kW/m^2-y)	Land Area (km^2)	Available Capacity (MW)
1,815	3,721 km^2	279,075
1,980	879 km^2	65,925

Capacity Factor: As stated in Section 4.2.1.2, capacity factor is the most crucial component for renewable energy projects because it is the most important factor affecting the level of revenue. Like wind energy, a linear regression model is constructed to estimate the capacity factor for different GHI values.

The sample for the model is collected from Rehman et al. (2007) who calculated capacity factor for 41 different places with different solar energy characteristics in Saudi Arabia. The sample set used in the regression model is given in Table 57.

Table 57: The sample for the regression model to estimate capacity factor for PV plants

Location	GHI (MWh/m^2)	CF	Location	GHI (MWh/m^2)	CF
1	2.03	24%	22	2.07	24%
2	1.72	19%	23	2.21	25%
3	1.94	22%	24	2.21	25%
4	1.64	19%	25	1.87	21%
5	2.04	23%	26	2.32	26%
6	1.91	22%	27	2.17	24%
7	1.66	19%	28	2.26	26%
8	2.12	24%	29	2.03	23%
9	1.73	19%	30	1.71	19%
10	1.78	20%	31	2.06	23%
11	2.04	23%	32	2.19	24%
12	2.00	23%	33	2.18	24%
13	2.23	25%	34	2.46	27%
14	2.15	24%	35	2.09	23%
15	1.98	22%	36	2.21	24%
16	2.40	24%	37	1.70	19%
17	2.56	28%	38	1.87	21%
18	2.22	25%	39	1.84	21%
19	1.98	22%	40	2.13	24%
20	2.32	26%	41	2.53	28%
21	1.83	20%			

Source: Rehman et al., 2007.

To estimate the parameters of the regression model, the regression tool in Excel is used. The results are given in Table 58.

Table 58: The results of the regression model to estimate capacity factor for PV plants

Statistics	Values
Intercept	0.014
GHI	0.105
F	938.88
R Square	96%
Standard Error	0.005
t-Stat of Intercept	1.95
t-Stat of GHI	30.64

Lastly, the capacity factors for two GHI values that are used to analyze the potential of Turkey are estimated by using the regression model. The estimated capacity factors are given in Table 59.

Table 59: Capacity factors for different GHI values

GHI (MW/m^2)	Capacity Factor (%)
1.82	20.45%
1.98	22.19%

Lifetime: In the literature, there are two common values which are 25 years and 30 years, but 30 years is more common. Hence, the lifetime is taken as 30 years.

Degradation Rate: The PV modules lose their capacity from year to year and it is generally assumed 1% per year in the literature like the work of EERE (2006) and Tidball et al. (2010).

Price: According to the Renewable Energy Law, the regulated price of solar based electricity is ₵13.3/kWh for the first 10 years of operation. If all mechanical parts are produced in Turkey, there is an extra payment which is ₵6.7/kWh for PV for the first 5 years of operation. It is assumed that the half of this bonus payment is added to the price for the first 5 years. As a result, the price for PV is taken as ₵16.7/kWh for the first 5 years and ₵13.3/kWh for the remaining lifetime.

A summary of the values of the inputs peculiar to the PV solar calculation model is given in Table 60.

Table 60: The solar PV model inputs

Item Description	Minimum	Maximum	Determined Value
Module cost	$454,800/MW	$1,503,363/MW	$882,312MW
Inverter cost	$400,000/MW	$715,000/MW	$715,000/MW
Grid connection cost			$145,824/MW
Land cost			$2.65/m2
Other capital cost	$1,790,000/MW	$2,420,000/MW	$1,790,000/MW
O&M cost	$7.34/MWh	$39.42/MWh	$25.59/MWh
Efficiency rate	13.5%	20%	15%
Technical capacity per m^2			150 W
Suitable land area 1,815 kWh/m^2 1,1980 kWh/m^2			 3,721 km^2 879 km^2
Available capacity 1,815 kWh/m^2 1,1980 kWh/m^2			 279,075MW 65,925 MW
Capacity factor 1,815 kWh/m^2 1,1980 kWh/m^2			 20.45% 22.19%
Lifetime	30 years	40 years	30 years
Degradation rate			1%
Price First 5 years After 5 years			 ₵16.7 ₵13.3

4.1.1.5. Solar Trough

In this section, I discuss the inputs particular to the parabolic trough model. These inputs are conversion system cost, receiver cost, collector cost, grid connection cost, land cost, other capital cost, storage cost, O&M cost, storage capacity, suitable land area, land area per kW, field area per kW, solar field area, available capacity, capacity factor, expected lifetime, and price.

Conversion System Cost: The conversion system cost consists of the electricity production system and its values in different studies range from \$387,540/MW to \$933,000/MW. In this study, I take the average value of \$608,038/MW.

Receiver Cost: The receiver cost values in the literature are stated both in terms of plant capacity and solar field area. In this study, the latter approach is preferred and the cost is taken as \$43/m^2 from Turchi (2010).

Collector Cost: The collector cost also depends on the solar field area and it is taken as \$263/m^2 which is the average of values ranging from \$234/m^2 to \$295/m^2.

Grid Connection Cost: I assume the grid connection cost is the same as onshore wind, so it is taken as \$145.824/MW.

Land Cost: Land cost is assumed to be €/2/m^2 (Pitz-Paal et al., 2007).

Other Capital Cost: Other capital cost consists of civil work and all other cost not included in the specific capital cost components mentioned above. The minimum of the data collected from several sources is taken because these costs are expected to be lower in Turkey. It is taken as \$872,750/kW from Montes et al. (2009).

Storage Cost: The cost of the construction for storage unit varies from \$27/kWh$_{th}$ to \$35/kWh$_{th}$ with an average value of \$30/kWh$_{th}$ which is taken into account in this study.

O&M Cost: The O&M cost is assumed as \$25.75/MWh that is the mean of different values ranging from \$17.00/MWh to \$46.05/MWh.

Storage Capacity: I assume 16 hours storage capacity to increase the capacity factor of the plant and to dispatch the capacity more effectively. To satisfy 16 hours operation without sunlight, the amount of storage capacity in terms of thermal energy is calculated by using Equation 8.

$$SC=(S/SE)/HE \qquad (8)$$

Where, SC represents the storage capacity (kWh_{th}/kW), S represents storage capacity in terms of hour, SE represents the thermal efficiency of storage unit, HE represents the heat to electricity efficiency.

Storage capacity in terms of time is assumed as 16 hours, the thermal efficiency of storage unit is assumed as 95% (Pitz-Paal et al., 2005), and heat to electricity efficiency is assumed 36% that is the average of the values ranging from 26% to 40%. Under these assumptions, the storage capacity is calculated as 47 kWh_{th} per kW.

Suitable Land Area: Suitable land area in Turkey for solar energy generation with different DNIs is calculated from the data given in the relevant part of Section 4.1.1.4. There are not the DNI values for Turkey, so the DNI values are calculated by multiplying GSI values by the factor of 1.15 which is calculated from the relevant data belonging to Bari (Italy) and Tabernas (Spain) lying in the similar latitudes and having similar climate (DGS, 2005). The results that are used in calculations are: (1) a land area of 879 km^2 with a DNI of 2,277kWh/m^2, (2) a land area of 3,721 km^2 with a DNI of 2,087kWh/m^2.

Land Area per unit capacity: Needed land area per unit capacity for a plant with 16 hours storage capacity is assumed to be 42 m^2/kW based on the values from Sargent & Lundy (2003).

Field Area per unit capacity: Needed solar field area per unit capacity for a plant with 16 hours storage capacity is assumed to be 12 m^2/kW based on the values from Sargent & Lundy (2003).

Solar Field Area: To determine solar field area, the ratio of solar field area per unit capacity to land area per unit capacity is used. Suitable land area is multiplied by this ratio for each land category to find solar field area. The results are given in Table 61.

Table 61: Solar field area for solar trough projects

DNI	Land Area	Solar Field Area
2,087 kWh/m^2	3,721 km^2	1,103 km^2
2,277 kWh/m^2	879 km^2	261 km^2

<u>Available Capacity:</u> The available capacity is calculated by dividing suitable land area to the needed land area per unit capacity and the result is tabulated in Table 62.

Table 62: Available capacity for solar trough projects

DNI	Land Area	Available Capacity
2,087 kWh/m^2	3,721 km^2	88,385 MW
2,277 kWh/m^2	879 km^2	20,879 MW

<u>Capacity Factor:</u> As stated in Section 4.2.1.2, capacity factor is the most crucial component for renewable energy projects because it is the most important factor affecting the level of revenue. Like wind and PV solar models, a linear regression model is constructed to estimate the capacity factor depending on DNI and storage capacity. The sample set and the sources are given in Table 63.

Table 63: The sample for the regression model to estimate capacity factor for solar trough projects

DNI ($kWh/m^2/year$)	Storage Capacity (ST) (hour)	Capacity Factor (%)	Source
2,701	0	30%	Pletka et al., 2007
2,701	3	35%	Pletka et al., 2007
2,701	6	42%	Pletka et al., 2007
2,665	0	29%	Pletka et al., 2007
2,665	3	35%	Pletka et al., 2007
2,665	6	42%	Pletka et al., 2007
2,482	0	27%	Pletka et al., 2007
2,482	3	32%	Pletka et al., 2007
2,482	6	39%	Pletka et al., 2007
2,628	0	29%	Pletka et al., 2007
2,628	3	34%	Pletka et al., 2007
2,628	6	41%	Pletka et al., 2007
2,014	0	22%	Pitz-Paal et al., 2007
2,014	3	29%	Pitz-Paal et al., 2005
2,724	6	47%	Turchi, 2010
2,200	7.5	41%	Purohit and Purohit, 2010
2,940	0	29%	Sargent & Lundy, 2003
2,940	9	47%	Sargent & Lundy, 2003
2,940	12	54%	Sargent & Lundy, 2003
2,940	16	75%	Sargent & Lundy, 2003
2,700	0.5	24%	Kaltschmitt et al., 2007

The regression tool in Excel is used to estimate the parameters of the regression model. Firstly, the estimation is done with intercept, but the calculated t-value of the intercept term which is 0.77 is lower than the t-table value, so it is rejected. Therefore, the estimation is repeated without intercept. The result of this second model which is used in the study is given in Table 64.

Table 64: The results of the regression model to estimate capacity factor for solar trough projects

Statistics	Values
Sample Size	21
DNI	0.00010
SC	0.02422
F	1892.74
R Square	1.00
Standard Error	0.03
t-Stat of DNI	28.97
t-Stat of SC	15.72

Lastly, the capacity factors are estimated for different DNI values and the fixed storage hour capacity of 16 hours. The estimated capacity factors are given in Table 65.

Table 65: Capacity factor values for different DNI values

DNI (kW/m^2-y)	Capacity Factor (%)
2,087	60.13
2,277	62.08

Lifetime: In the literature, there are two common values which are 25 years and 30 years, but 30 years is more common. Hence, the lifetime is taken as 30 years.

Price: According to Renewable Energy Law, the regulated price of solar based electricity is ₵13.3/kWh for the first 10 years of operation. If all mechanical parts are produced in Turkey, there is an extra payment which is ₵5.5/kWh for solar thermal for the first 5 years of operation. It is assumed that the half of this bonus payment is added to the price for the first 5 years. As a result, the price for thermal is taken as ₵16/kWh for the first 5 years and ₵13.3/kWh for the remaining lifetime.

A summary of the values of the inputs peculiar to the trough solar calculation model is given in Table 66.

Table 66: Solar trough model inputs

Item Description	Minimum	Maximum	Determined Value
Conversion system cost	\$387,540/MW	\$933,000/MW	608,038/MW
Receiver cost			\$43/m^2
Collector cost	\$234/m^2	\$295/ m^2	\$263/ m^2
Grid connection cost			\$145,824/MW
Land cost			\$2.65/m2
Other capital cost			\$872,750/MW
Storage cost	\$27/kWh_{th}	\$35/ kWh_{th}	\$30/ kWh_{th}
O&M cost	\$17.00/MWh	\$46.05/MWh	\$25.75/MWh
Storage capacity			47kWh_{th}/kW
Suitable land area 2,087 kWh/m^2 2,277 kWh/m^2			 3,721 km^2 879 km^2
Land area per kW			42
Field area per kW			12
Solar field area 2,087 kWh/m^2 2,277 kWh/m^2			 1,103 km^2 261 km^2
Available capacity 2,087 kWh/m^2 2,277 kWh/m^2			 88,385 MW 20,879 MW
Capacity factor 2,087 kWh/m^2 2,277 kWh/m^2			 60.13% 62.08%
Lifetime	25 years	30 years	30 years
Price First 5 years After 5 years			 ₵16.0 ₵13.3

4.1.1.6. Solar Tower

In this section, I discuss the inputs particular to parabolic trough model. These inputs are conversion system cost, receiver cost, collector cost, grid connection cost, land cost, other capital cost, storage cost, O&M cost, storage capacity, suitable land area, land area per kW, field area per kW, solar field area, available capacity, capacity factor, expected lifetime, and price.

Conversion System Cost: The same value in Section 4.2.1.5 is used.

Receiver Cost: The receiver cost values in the literature are stated in terms of unit capacity. The values range from \$133,000/MW to \$177,000/MW with an average of \$155,920/kW. I take the average value.

Collector Cost: The collector cost also depends on the solar field area and it is taken as \$190/m^2 which is the average of values ranging from \$145/m^2 to \$227/m^2.

Grid Connection Cost: I assume the grid connection cost is the same as the onshore wind, so it is taken as \$145.824/MW.

Land Cost: Land cost is assumed to be €/2/m^2 (Pitz-Paal et al., 2007).

Other Capital Cost: Other capital cost consists of civil work and all other costs not included in the other capital cost components. It is taken as \$819,293/MW from Pitz-Paal et al. (2005).

Storage Cost: The cost of the construction for storage unit varies from \$19/kWh$_{th}$ to \$22/kWh$_{th}$ with an average value of \$20/kWh$_{th}$ which is taken into account in this study.

O&M Cost: The O&M cost is assumed as \$28.27/MWh that is the mean of different values ranging from \$26.00/MWh to \$31.82/MWh.

Storage Capacity: I assume 16 hours storage capacity to increase the capacity factor of the plant and to dispatch the capacity more effectively. To satisfy 16 hours operation without sunlight, the amount of storage capacity in terms of thermal energy is calculated by using Equation 8 given in Section 4.1.1.5.

In the equation, storage capacity in terms of time is assumed as 16 hours, the thermal efficiency of storage unit is assumed as 95% (Pitz-Paal et al., 2005), and heat to electricity efficiency is assumed 40% that is the average of values ranging from 38% to 41%. Under these assumptions, the storage capacity is calculated as 43 kWh_{th} per kW.

Suitable Land Area: The same value in Section 4.2.1.5 is used.

Land Area per Unit Capacity: The needed land area per unit capacity for a plant with 16 hours storage capacity is assumed to be 68 m^2/kW based on the values from Sargent & Lundy (2003).

Field Area per Unit Capacity: The needed solar field area per unit capacity for a plant with 16 hours storage capacity is assumed to be 14 m^2/kW based on the values from Sargent & Lundy (2003).

Solar Field Area: To determine solar field area, the ratio of solar field area per unit capacity to land area per unit capacity is used. Suitable land area is multiplied by this ratio for each land category to find solar field area. The results are given in Table 67.

Table 67: Solar field area for solar tower projects

DNI	Land Area	Solar Field Area
2,087 kWh/m^2	3,721 km^2	788 km^2
2,277 kWh/m^2	879 km^2	166 km^2

Available Capacity: The available capacity is calculated by dividing suitable land area to the needed land area per unit capacity and the results are tabulated in Table 68.

Table 68: Available capacity for solar tower projects

DNI	Land Area	Available Capacity
2,087 kWh/m^2	3,721 km^2	54,721 MW
2,277 kWh/m^2	879 km^2	12,926 MW

Capacity Factor: The same capacity factors in Section 4.2.1.5 are used.

Lifetime: In the literature, there are two common values which are 25 years and 30 years and I take the lifetime as 30 years.

Price: The detail is given in Section 4.1.1.5.

A summary of the values of the inputs peculiar to the tower solar calculation model is given in Table 69.

Table 69: Solar tower model inputs

Item Description	Minimum	Maximum	Determined Value
Conversion system cost	\$387,540/MW	\$933,000/MW	608,038/MW
Receiver cost	\$133,000/MW	\$177,000/MW	\$155,920/MW
Collector cost	\$145/m^2	\$227/ m^2	\$190/ m^2
Grid connection cost			\$145,824/MW
Land cost			\$2.65/m2
Other capital cost			\$819,293/MW
Storage cost	\$19/kWh_{th}	\$22/ kWh_{th}	\$20/ kWh_{th}
O&M cost	\$26.00/MWh	\$31.82/MWh	\$28.27/MWh
Storage capacity			43kWh_{th}/kW
Suitable land area 2,087 kWh/m^2 2,277 kWh/m^2			 3,721 km^2 879 km^2
Land area per kW			68 m^2/kW
Field area per kW			14 m^2/kW
Solar field area 2,087 kWh/m^2 2,277 kWh/m^2			 788 km^2 166 km^2
Available capacity 2,087 kWh/m^2 2,277 kWh/m^2			 54,721 MW 12,926 MW
Capacity factor 2,087 kWh/m^2 2,277 kWh/m^2			 60.13% 60.08%
Lifetime	25 years	30 years	30 years
Price First 5 years After 5 years			 ₵16.0 ₵13.3

4.1.2. Outputs (Cash Flow Components)

In this section, outputs of the calculations are discussed by classifying them into three categories: onshore wind, offshore wind, and solar. I state the values of electricity production, revenue, capital cost, salvage value, depreciation, O&M cost, annual debt payment, debt principle, debt interest, tax and free cash flow for each technology for selected years.

4.1.2.1. Onshore Wind

Electricity Production: For each wind class, the annual electricity production was calculated from available capacity and capacity factor based on Equation 9.

$$P_i = CF_i \times C_i \times 8760 \quad (9)$$

Where, i show the wind class, P_i shows the annual electricity generation for the wind class i, CF_i shows the capacity factor of the wind class i, C_i shows the available capacity of the wind class i.

The results of calculations are given in Table 70.

Table 70: Electricity production at different wind speeds for onshore wind projects

Wind Class	Wind Speed at 50 m (m/s)	Wind Speed Average (m/s)	Capacity Factor (%)	Available Capacity (MW)	Annual Production (MWh)
3	6.5 – 7.0	6.75	28	76,977	187,315,477
4	7.0-7.5	7.25	31	24,126	66,109,468
5	7.5-8.0	7.75	35	9,550	29,096,623
6	8.0- 9.0	8.50	40	3,657	12,826,597
7	> 9.0	9.00	44	53	202,591

Revenues: I assume the regulated price for wind energy in the law for the first 10 years will not change also after 10 years. The annual revenues for the first 5 years and after 5th year are calculated based on the annual electricity production and the regulated price and the results are given in Table 71.

Table 71: Annual revenues for onshore wind projects

Wind Speed Average (m/s)	Annual Production (MWh)	Annual Revenue (first 5 years)	Annual Revenue (after 5th year)
6.75	187,315,477	$17,233,023,852	$13,674,029,796
7.25	66,109,468	$6,082,071,015	$4,825,991,131
7.75	29,096,623	$2,676,889,351	$2,124,053,507
8.50	12,826,597	$1,180,046,926	$936,341,582
9.00	202,591	$18,638,327	$14,789,107

Capital Cost: The capital cost for each category of wind is calculated by using Equation 10.

$$CC_i=(T+G+CWI)\times Ci \qquad (10)$$

Where, i show the wind class, CC_i shows the total installation cost for the wind class i, T shows the cost of turbine per MW, G shows the grid connection cost per MW, CWI shows the civil work and installation cost per MW, C_i shows the available capacity of the wind class i.

The capital cost, annual depreciation and salvage values at the end of lifetime for each wind speed are given in Table 72.

Table 72: Capital cost for onshore wind projects

Wind Speed Average (m/s)	Available Capacity (MW)	Capital Cost	Salvage Value	Depreciation
6.75	76,977	$73,269,285,007	$14,653,857,001	$3,663,464,250
7.25	24,126	$22,964,074,653	$4,592,814,931	$1,148,203,733
7.75	9,550	$9,089,548,034	$1,817,909,607	$454,477,402
8.50	3,657	$3,481,195,850	$696,239,170	$174,059,793
9.00	53	$50,561,368	$10,112,274	$2,528,068

Other Cash Outflows: In addition to capital cost, there are three other cash outflow items which are O&M cost, annual debt payment, and tax payment. The main assumptions about these costs are:

- O&M cost will increase at the inflation rate annually,
- Debt payment will be the fixed amount annually during the debt payment period while the interest payment and principle payment will change year by year.
- Tax payment will also change year by year based on the net revenue.

The first year values of these items are given in Table 73.

Table 73: Other cash outflow items for onshore wind projects

Wind Speed (m/s)	O&M Cost	Annual Debt Payment	Principle	Interest	Tax
6.75	$3,042,254,454	$5,256,674,972	$2,630,481,946	$2,626,193,026	$1,580,222,424
7.25	$1,073,706,379	$1,647,548,171	$824,446,202	$823,101,968	$607,411,787
7.75	$472,568,170	$652,125,917	$326,328,993	$325,796,924	$284,809,371
8.50	$208,321,131	$249,756,977	$124,980,377	$124,776,600	$134,577,880
9.00	$3,290,341	$3,627,505	$1,815,232	$1,812,273	$2,201,529

Free Cash Flow: Free cash flows are given in Table 74.

Table 74: Free cash flows for onshore wind projects ($1,000,000)

Wind Speed	0	1	5	6	10	15	20
6.75 m/s	-$73,269	$12,611	$12,190	$9,226	$8,703	$8,233	$19,504
7.25 m/s	-$22,964	$4,401	$4,259	$3,215	$3,040	$2,877	$6,392
7.75 m/s	-$9,090	$1,920	$1,859	$1,401	$1,327	$1,256	$2,640
8.50 m/s	-$3,481	$837	$812	$610	$579	$548	$1,074
9.00 m/s	-$51	$13	$13	$10	$9	$9	$16

4.1.2.2. Offshore Wind

Electricity Production: For each wind class, the annual electricity production was calculated from available capacity and capacity factor based on Equation 9 given in Section 4.2.2.1. The results of calculations are given in Table 75.

Table 75: Electricity production at different wind speeds for offshore wind projects

Wind Class	Wind Speed at 50 m (m/s)	Wind Speed Average (m/s)	Capacity Factor	Available Capacity (MW)	Annual Production (MWh)
3	6.5 – 7.0	6.75	33%	6,930	20,235,872
4	7.0-7.5	7.25	38%	5,133	16,878,929
5	7.5-8.0	7.75	42%	3,445	12,595,236
6	8.0- 9.0	8.50	48%	1,743	7,333,524
7	> 9.0	9.00	52%	143	653,171

Revenues: I assume the regulated price for wind energy in the law for first 10 years will not change also after 10 years. The annual revenues for the first 5 years and after 5th year are calculated based on the annual electricity production and the regulated price and the results are given in Table 76.

Table 76: Annual revenues for offshore wind projects

Wind Speed Average (m/s)	Annual Production (MWh)	Annual Revenue (first 5 years) ($)	Annual Revenue (after 5th year) ($)
6.75	20,235,872	1,861,700,216	1,477,218,650
7.25	16,878,929	1,552,861,472	1,232,161,820
7.75	12,595,236	1,158,761,710	919,452,226
8.50	7,333,524	674,684,222	535,347,263
9.00	653,171	60,091,762	47,681,507

Capital Cost: The capital cost for each category of wind is calculated by using Equation 10 in Section 4.2.2.1. The capital cost, annual depreciation and salvage values are given in Table 77.

Table 77: Capital cost for offshore wind projects

Wind Speed Average (m/s)	Available Capacity (MW)	Capital Cost	Salvage Value	Depreciation
6.75	6,930	$15,886,471,652	$3,177,294,330	$635,458,866
7.25	5,133	$11,767,586,968	$2,353,517,394	$470,703,479
7.75	3,445	$7,897,020,102	$1,579,404,020	$315,880,804
8.50	1,743	$3,994,725,775	$798,945,155	$159,789,031
9.00	143	$327,177,981	$65,435,596	$13,087,119

Other Cash Outflows: In addition to capital cost, there are three other cash outflow items which are O&M cost, annual debt payment, and tax payment. The main assumptions about these costs are given in Section 4.2.2.1.

The first year values of these items are given in Table 78.

Table 78: Other cash outflow items for offshore wind projects

Wind Speed Average (m/s)	O&M Cost	Annual Debt Payment	Principle	Interest	Tax
6.75	$3,042,254,454	$1,139,768,430	$570,349,183	$569,419,246	$22,674,585
7.25	$1,073,706,379	$844,260,728	$422,474,780	$421,785,948	$41,415,206
7.75	$472,568,170	$566,568,487	$283,515,375	$283,053,112	$44,314,699
8.50	$208,321,131	$286,599,972	$143,416,904	$143,183,067	$34,952,991
9.00	$3,290,341	$23,473,251	$11,746,201	$11,727,049	$3,547,240

Free Cash Flow: Free cash flows are given in Table 79.

Table 79: Free cash flows for offshore wind projects ($1,000,000)

Wind Speed	0	1	5	6	10	15	20	25
6.75 m/s	-$15,886	$1,296	$1,214	$862	$781	$695	$608	$3,064
7.25 m/s	-$11,768	$1,058	$994	$719	$638	$567	$500	$2,307
7.75 m/s	-$7,897	$776	$730	$526	$468	$416	$366	$1,573
8.50 m/s	-$3,995	$443	$417	$299	$267	$238	$208	$814
9.00 m/s	-$327	$39	$37	$26	$24	$21	$18	$68

4.1.2.3. Solar

Electricity Production: For each solar technology, the annual electricity production was calculated from available capacity and capacity factor based on Equation 11.

$$P_i = CF_i \times C_i \times 8760 \quad (11)$$

Where, i represents the solar quality, P_i shows the annual electricity generation for the solar quality i, CF_i shows the capacity factor of the solar quality i, C_i shows the available capacity of the solar quality i.

The results of calculations are given in Table 80.

Table 80: Electricity production for solar projects

Technology	Solar Quality	Capacity Factor (%)	Available Capacity (MW)	Annual Production (MWh)
PV	1,815 kWh/m^2	20.45	279,075	500,012,380*
	1,1980 kWh/m^2	22.19	65,925	128,128,357*
Trough	2,087 kWh/m^2	60.13	88,385	465,585,812
	2,277 kWh/m^2	62.08	20,879	113,539,423
Tower	2,087 kWh/m^2	60.13	54,721	288,252,393
	2,277 kWh/m^2	62.08	12,926	70,294,260

*These production amount is the first year value, which will decrease by 1% annually because of the degradation characteristic of PV plants.

Revenues: I assume that the regulated price in the law for solar energy will not change. The annual revenues for the first 5 years and after 5th year are calculated based on the annual electricity production and the regulated price and the results are given in Table 81.

Table 81: Annual revenues for solar projects

Technology	Solar Quality	Annual Production (MWh)	Annual Revenue (first 5 years)	Annual Revenue (after 5th year)
PV	1,815 kWh/m^2	500,012,380*	$83,502,067,399	$63,242,404,115
	1,1980 kWh/m^2	128,128,357*	$21,397,435,678	$16,205,889,463
Trough	2,087 kWh/m^2	465,585,812	$74,493,729,952	$61,922,913,023
	2,277 kWh/m^2	113,539,423	$18,166,307,628	$15,100,743,215
Tower	2,087 kWh/m^2	288,252,393	$46,120,382,809	$38,337,568,210
	2,277 kWh/m^2	70,294,260	$11,247,081,634	$9,349,136,608

Capital Cost: The capital cost for each category of wind is calculated for each solar technology and the results are given in Table 82 with the other capital cost related items which are depreciation and salvage values.

Table 82: Capital cost for solar projects

Technology	Solar Quality	Available Capacity (MW)	Capital Cost (1,000,000)	Salvage Value (1,000,000)	Depreciation (1,000,000)
PV	1,815 kWh/m^2	279,075	$1,416,634	$283,327	$47,221
	1,1980 kWh/m^2	65,925	$334,647	$66,929	$11,155
Trough	2,087 kWh/m^2	88,385	$614,992	$122,998	$20,500
	2,277 kWh/m^2	20,879	$145,278	$29,056	$4,843
Tower	2,087 kWh/m^2	54,721	$298,799	$59,760	$9,960
	2,277 kWh/m^2	12,926	$70,584	$14,117	$2,353

Other Cash Outflows: In addition to capital cost, there are three other cash outflow items which are O&M cost, annual debt payment, and tax payment.

The first year values of these items are given in Table 83.

Table 83: Other cash outflow items for solar projects

Technology	Solar Quality	O&M Cost (1,000,000)	Annual Debt Payment (1,000,000)	Principle (1,000,000)	Interest (1,000,000)	Tax (1,000,000)
PV	1,815 kWh/m^2	$7,141	$101,636	$50,859	$50,776	$0
	1,1980 kWh/m^2	$1,687	$24,009	$12,014	$11,995	$0
Trough	2,087 kWh/m^2	$11,987	$44,122	$22,079	$22,043	$3,993
	2,277 kWh/m^2	$2,923	$10,423	$5,216	$5,207	$1,039
Tower	2,087 kWh/m^2	$8,150	$21,437	$10,727	$10,710	$3,460
	2,277 kWh/m^2	$1,987	$5,064	$2,534	$2,530	$875

Free Cash Flow: Free cash flows are given in Table 84.

Table 84: Free cash flows for solar projects ($1,000,000)

	0	1	6	10	20	30
PV (1,815 kWh/m^2)	-$1,416,634	$76,361	$55,163	$51,832	$43,526	$264,166
PV (1,980 kWh/m^2)	-$334,647	$19,711	$14,297	$13,461	$11,337	$63,199
Trough (2,087 kWh/m^2)	-$614,992	$58,514	$45,371	$42,253	$38,308	$132,413
Trough (2,277 kWh/m^2)	-$145,278	$14,204	$11,013	$10,268	$9,311	$31,508
Tower (2,087 kWh/m^2)	-$298,799	$34,511	$26,540	$24,807	$22,239	$67,128
Tower (2,277 kWh/m^2)	-$70,584	$8,384	$6,447	$6,032	$5,408	$15,990

4.2. FINANCIAL ANALYSIS OF RENEWABLE ENERGY OPTION

In this section, payback periods, NPV and IRR are analyzed for all wind and solar technologies to assess the viability, stability and profitability of the projects.

4.2.1. Payback Period Analysis

Payback is used to determine how rapidly a project returns its initial investment to the investor. Payback can be calculated based on the nominal cash flows or the discounted cash flows. The latter one is preferred because it takes into account the time value of money. If the sum of discounted cash flows of a project becomes lower than the initial investment, discounted payback period does not exist. Such a project should be rejected because it will cause a negative NPV. The most important shortcoming of this criterion is that it does not say anything about the cash flows after the payback period.

Table 85: Payback periods

Technology	Lifetime	Simple Payback	Discounted Payback
Wind Onshore			
6.75 m/s	20	7	12
7.25 m/s		6	9
7.75 m/s		5	8
8.50 m/s		5	6
9.00 m/s		4	6
Wind Offshore			
6.75 m/s	25	18	-
7.25 m/s		16	-
7.75 m/s		14	-
8.50 m/s		12	-
9.00 m/s		11	-
Solar PV			
1,815 kWh/m^2	30	28	-
1,980 kWh/m^2		25	-
Solar Trough			
2,087 kWh/m^2	30	13	-
2,277 kWh/m^2		13	-
Solar Tower			
2,087 kWh/m^2	30	11	-
2,277 kWh/m^2		10	-

Both simple and discounted payback periods are calculated for each class of each source and the results are given in Table 85. To discount cash flows, I use WACC (9.43%) calculated in Section 4.1.1.1. In terms of simple payback periods, all projects can return initial investment back, but this period is very long for offshore wind and all solar technologies. It is only viable for onshore wind projects which can return the initial investment within 7 years at most. On the other hand, discounted payback period is longer than the lifetime for all technologies except the onshore wind technology. As a result, it is obvious that only onshore wind projects can return the initial investment in terms of both nominal cash flows and discounted cash flows.

4.2.2. NPV Analysis

The most common financial tool to evaluate a project is NPV analysis which is the sum of discounted cash lows. NPV has some advantages which are;

- It shows the overall profitability of a project
- It provides a very sharp criterion to accept or reject a project: Only the projects having positive NPV should be accepted.
- If the discounted payback period of a project is lower than the lifetime, NPV helps us to find out the effect of the remaining cash flows after payback period on the profitability of the project.

On the other hand, NPV has some shortcomings. First, it does not measure the risk of cash flows. Second, it is not a sufficient criterion to measure the profitability of a project in terms of the rate of return of the project. Instead, positive NPV only shows that the rate of return of the relevant project is higher than the discount rate.

Table 86: NPV values

Technology	Capacity	Capital Cost per MW	NPV	NPV per MW
Wind Onshore				
6.75 m/s	76,977 MW	$951,833	$19,614,808,950	$254,814
7.25 m/s	24,126 MW		$9,396,308,775	$389,466
7.75 m/s	9,550 MW		$5,005,069,502	$524,117
8.50 m/s	3,657MW		$2,655,591,225	$726,095
9.00 m/s	53 MW		$45,722,877	$860,747
Wind Offshore				
6.75 m/s	6,930 MW	$2,292,447	$(6,608,725,487)	$(953,651)
7.25 m/s	5,133 MW		$(4,187,712,305)	$(815,809)
7.75 m/s	3,445 MW		$(2,348,844,653)	$(681,852)
8.50 m/s	1,743MW		$(838,719,593)	$(481,315)
9.00 m/s	143MW		$(49,612,733)	$(347,623)
Solar PV				
1,815 kWh/m^2	279,075 MW	$5,076,177	$(819,499,958,555)	$(2,936,486)
1,980 kWh/m^2	65,925 MW		$(180,670,616,938)	$(2,740,548)
Solar Trough				
2,087 kWh/m^2	88,385 MW	$6,958,116	$(138,984,895,718)	$(1,572,498)
2,277 kWh/m^2	20,879 MW		$(29,700,539,986)	$(1,422,517)
Solar Tower				
2,087 kWh/m^2	54,721 MW	$5,460,450	$(20,115,336,268)	$(367,601)
2,277 kWh/m^2	12,926 MW		$(2,868,283,013)	$(221,892)

NPV and NPV per unit capacity are calculated for all technologies based on a discount rate of 9.43% and the results are given with the relevant capacity and capital cost per MW capacity values in Table 86. Only wind onshore technology has positive NPV values which increase as the wind quality increases. If wind speed is equal to or more than 9 m/s, NPV per MW capacity nearly reaches to the capital cost per MW. Among the remaining technologies, solar tower technology generates the highest NPV which is -$221,892/MW when the DNI equals to 2,277kWh/m^2. As a result, only onshore wind projects can be accepted in terms of NPV analysis when a discount rate of 9.43% is used. However, under the assumption of lower WACC rate, the other technologies may also be attractive enough with a positive NPV.

4.2.3. IRR Analysis

IRR is the discount rate at which a project will generate zero NPV, so it can be compared to the WACC of the relevant project to determine the projects having a WACC lower than IRR. It is preferable to NPV because it is simple to compare different projects having different initial capital cost and different NPV values.

Table 87: IRR Values

Technology	Capacity	Capital Cost per kW	IRR
Wind Onshore			
6.75 m/s	76,977 MW	$951,833	13.47%
7.25 m/s	24,126 MW		15.55%
7.75 m/s	9,550 MW		17.62%
8.50 m/s	3,657MW		20.70%
9.00 m/s	53 MW		22.74%
Wind Offshore			
6.75 m/s	6,930 MW	$2,292,447	3.07%
7.25 m/s	5,133 MW		4.02%
7.75 m/s	3,445 MW		4.92%
8.50 m/s	1,743MW		6.26%
9.00 m/s	143MW		7.15%
Solar PV			
1,815 kWh/m^2	279,075 MW	$5,076,177	1.34%
1,980 kWh/m^2	65,925 MW		1.93%
Solar Trough			
2,087 kWh/m^2	88,385 MW	$6,958,116	6.49%
2,277 kWh/m^2	20,879 MW		6.78%
Solar Tower			
2,087 kWh/m^2	54,721 MW	$5,460,450	8.55%
2,277 kWh/m^2	12,926 MW		8.90%

IRR values of all technologies are given in Table 87. When we look at the table, we can see that IRR values range from 1.34% belonging to solar PV to 22.74% belonging to onshore wind. As expected, onshore wind projects' IRR values are higher than WACC while IRR values of all other projects are lower. The most promising technology among the remaining ones is solar tower whose IRR is very close to WACC.

4.3. Market Analysis

In addition to financial analysis, market analysis is also done for wind and solar energy electricity generation technologies in Turkey. As explained in Section 3.2, currently Turkish electricity generation sector is dominated by three technologies which are natural gas plants, hydropower and coal plants. These renewable sources have to compete with these dominant technologies in the market, so the unit electricity generation cost for a wind or solar technology has to be equals to or lower than the cost of the dominant technologies. However, currently there are feed-in tariffs for renewable energy in Turkey, so our criteria for market analysis will be the regulated prices. In this section, two important indicators which are entrance price (LCE) and shut-down price are discussed to see the potential of each technology to enter into the market.

4.3.1. Entrance Price Analysis

For entrance price analysis, I use levelized cost of electricity which is a very practical tool to compare the unit cost of different generation technologies based on their economic lifetime. In the real world, electricity prices are continuously changes, so LCE cannot be realized, but it is hard to incorporate this reality in the analysis. Therefore, LCE remains the most common criteria to compare different technologies (IEA, 2010a).

The LCE is the price of electricity that equalizes the discounted cash outflows and the discounted cash inflows of a project. In other word, it is the price at which the project is break even. The formula of LCE is given in Equation 12 (IEA, 2010a).

$$LCE_i = \frac{C_i + \sum_1^{T_i}(CF_{it}/(1+WACC)^t)}{\sum_1^{T_i}(P_{it}/(1+WACC)^t)} \qquad (12)$$

where, i represents the technology, t represents the years from 1 to T, T represents the lifetime of the relevant technology i, C_i represents the initial capital cost of the technology i, CF_{it} represents the cash flow of the technology i in the year t, and P_{it} represents the electricity production of the technology i in the year t. In this calculation there are two important assumptions: (1) The discount rate is stable both for cost and revenues, and (2) the electricity price is fixed over the economic life of the project (IEA, 2010a).

In the literature, there are lots of studies calculating and analyzing LCE values of electricity generation technologies. The results of calculations of these studies show that the onshore wind power plant technology is the only renewable energy technology that is competitive in the electricity market. Among these studies, I can mention Patel (2005), Blodgett and Slack (2009), Klein et al. (2007), PWC (2010), and Blanco (2009).

In this section, the feed-in tariffs are used to evaluate the LCE values of different wind and solar technologies. The calculated LCE values and the feed-in tariffs are given in Table 88.

Table 88: LCE of wind and solar power generation technologies

Technology	Capital Cost per kW	Regulated Price	LCE
Wind Onshore 6.75 m/s 7.25 m/s 7.75 m/s 8.50 m/s 9.00 m/s	$951,833	₵9.2 (first 5 years) ₵7.3 (after 5th year)	$62 $57 $53 $49 $47
Wind Offshore 6.75 m/s 7.25 m/s 7.75 m/s 8.50 m/s 9.00 m/s	$2,292,447	₵9.2 (first 5 years) ₵7.3 (after 5th year)	$112 $103 $96 $87 $83
Solar PV 1,815 kWh/m^2 1,980 kWh/m^2	$5,076,177	₵16.7 (max for the first 5 years) ₵13.3 (min for the first 5 years) ₵13.3 (after 5th year)	$326 $301
Solar Trough 2,087 kWh/m^2 2,277 kWh/m^2	$6,958,116	₵16.0 (max for the first 5 years) ₵13.3 (min for the first 5 years) ₵13.3 (after 5th year)	$164 $160
Solar Tower 2,087 kWh/m^2 2,277 kWh/m^2	$5,460,450	₵16.0 (max for the first 5 years) ₵13.3 (min for the first 5 years) ₵13.3 (after 5th year)	$139 $136

Based on the data in the table, it can be concluded that:

- The LCE values for all wind speeds are lower than the minimum regulated price for onshore wind energy,

- The LCE values for all wind speeds are higher than the minimum regulated price for offshore wind energy, but the LCE of an offshore project deployed in a site having a wind speed equals to or more than 8.5 m/s is lower than the maximum price that is valid only for the first five year if all material is manufactured in Turkey.
- The LCE is two-fold of the maximum regulated price for solar PV technology, so this technology has the lowest chance to penetrate into the Turkish electricity market.
- Solar trough technology has a LCE that is equal to the maximum regulated price if DNI is high, but this price is only valid for the first five years. As a result, this technology cannot be deployed in the short run, but it can be a promising alternative in the long run with the decrease of initial capital cost.
- Solar tower technology is the most promising one except onshore wind technology. Its LCE values are between the minimum and the maximum price. If the equipment can be procured domestically at the costs used in this study, solar tower power plants may be deployed in short to medium term.

4.3.2. Shut-down Price Analysis

Shut-down price that shows the level of market price in which a plant stops to produce is also an important factor for the market analysis of alternative liquid fuel sources. Generally, it is preferable for a source to have low margin between market entrance price and shut down price because this will increase the flexibility and decrease the level of risk. Thus, it will be easier to enter into the market when the price goes up at or above the market entrance price and to exit out of the market when the price goes down below the shut down price with low loss. However, wind and solar energy power plants have very high fixed costs which make it nearly impossible to get out of the market.

Table 89: Shut-down prices of wind and solar technologies

Technology	Capital Cost per kW	Regulated Price	LCE
Wind Onshore 6.75 m/s 7.25 m/s 7.75 m/s 8.50 m/s 9.00 m/s	$951,833	¢9.2 (first 5 years) ¢7.3 (after 5th year)	$16/MWh
Wind Offshore 6.75 m/s 7.25 m/s 7.75 m/s 8.50 m/s 9.00 m/s	$2,292,447	¢9.2 (first 5 years) ¢7.3 (after 5th year)	$27/MWh
Solar PV 1,815 kWh/m^2 1,980 kWh/m^2	$5,076,177	¢16.7 (first 5 years) ¢13.3 (after 5th year)	$13/MWh
Solar Trough 2,087 kWh/m^2 2,277 kWh/m^2	$6,958,116	¢16 (first 5 years) ¢13.3 (after 5th year)	$26/MWh
Solar Tower 2,087 kWh/m^2 2,277 kWh/m^2	$5,460,450	¢16 (first 5 years) ¢13.3 (after 5th year)	$28/MWh

Shut-down prices are given in Table 89. When we analyze the table, we can conclude that shut-down price of all technologies are low, especially for solar PV and onshore wind technologies. Therefore, these power plants will not be shut down unless the price decreases very low level which is very low probability under the current conditions.

4.4. UNCERTAINTY ANALYSIS

Three types of uncertainty analysis which are static sensitivity, partially dynamic sensitivity, and Monte Carlo analysis are done in this section. These analyses are carried out in terms of NPV and LCE for onshore wind technology with a wind speed of 7 - 7.5 m/s and solar tower technology with a DNI of 2,277kWh/m^2-y.

4.4.1. Onshore Wind Technology

Three different methods which are static sensitivity, partially dynamic sensitivity, and Monte Carlo analysis are used to conduct uncertainty analysis for onshore wind energy potential with a speed of 7 – 7.5 m/s. These analyses are done for only NPV and LCE.

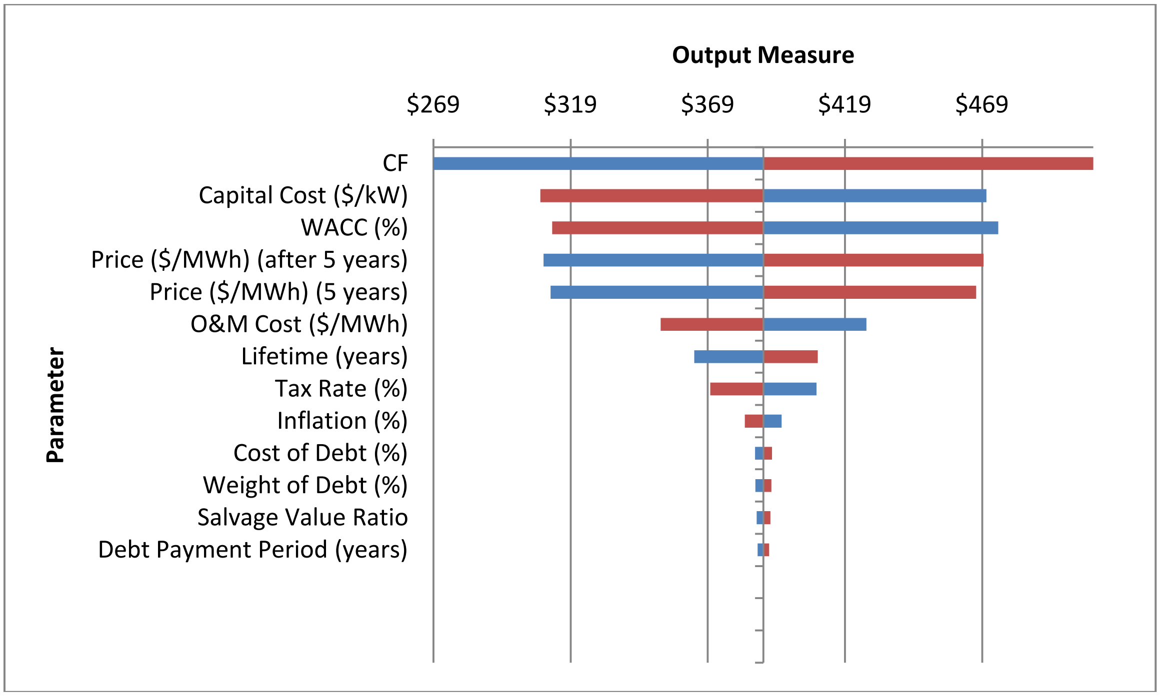
I start with the analysis of NPV per unit capacity which is used instead of total NPV because it can be comparable to capital cost per kW value to understand the magnitude of extra profit or loss. First, static sensitivity analysis is done by changing each parameter at a time by increasing or decreasing 10% to find the effect on NPV (Table 90). This simple sensitivity analysis shows that the most important factors affecting the level of NPV are capacity factor; capital cost, WACC, and price each of which generates at least 20% change on NPV when the value of one of these inputs is changed by 10%. Among the remaining parameters, only O&M cost has ability to change NPV more than or equal to 10% when the parameter increased or decreased by 10%.

Table 90: The results of static sensitivity analysis for NPV per kW for onshore wind

DATA TABLE					PARAMETER INFO			
Parameter	-10 Pct	+10 Pct	Range	Base Case Result	Base Case	% Sensitivity	-%	+%
CF	$269	$510	$241	$389	31%	10.00	28%	34%
Capital Cost ($/kW)	$471	$308	$163	$389	$952	10.00	$856,650	$1,047,016
WACC (%)	$475	$312	$163	$389	9.43%	10.00	8.48%	10.37%
Price ($/MWh) (after 5 years)	$309	$470	$160	$389	$73	10.00	$66	$80
Price ($/MWh) (5 years)	$312	$467	$155	$389	$92	10.00	$83	$101
O&M Cost ($/MWh)	$427	$352	$75	$389	$16.24	10.00	$14.62	$17.87
Lifetime (years)	$364	$409	$45	$389	20	10.00	18	22
Tax Rate (%)	$409	$370	$39	$389	20%	10.00	18%	22%
Inflation (%)	$396	$383	$14	$389	2.50%	10.00	2.25%	2.75%
Cost of Debt (%)	$386	$393	$6	$389	7.17%	10.00	6.45%	7.89%
Weight of Debt (%)	$387	$392	$6	$389	50%	10.00	45%	55%
Salvage Value Ratio	$387	$392	$5	$389	20%	10.00	18%	22%
Debt Payment Period (years)	$387	$392	$4	$389	10	10.00	9	11

Based on the results of the static sensitivity analysis in Table 90, a Tornado chart is also constructed to visualize how each parameter affects the level of NPV by changing only one parameter at a time (Figure 34). When we look at the chart, we can see that the most important parameter is capacity factor with a potential of around 30% change in NPV as it is increased or decreased by 10%. The second factor is capital cost which generates about 20% change in NPV per MW.

Figure 34: Tornado analysis chart for NPV per kW for onshore wind



After the static analysis, a partially dynamic sensitivity analysis is done by changing two parameters at a time to see the effect of the simultaneous changes on NPV. For this aim, capacity factor and capital cost per unit capacity values are used because these two parameters are the most important factors affecting the level of NPV as seen from Tornado chart in Figure 34. For capital cost, minimum and maximum values are taken as $584/kW and $1,236/kW with an increment of $65/kW; and for the capacity factor, minimum, maximum and increment are taken as 26%, 35%, and 1%, respectively. The result of this analysis is given in Table 91.

Table 91: Two-way data sensitivity analysis for NPV per kW for onshore wind

Capacity Factor	Capital Cost ($/kW)									
	$584	$657	$729	$801	$874	$946	$1,019	$1,091	$1,164	$1,236
27%	$539	$477	$415	$353	$292	$230	$168	$106	$44	$(18)
28%	$578	$516	$454	$392	$330	$268	$206	$144	$82	$21
29%	$616	$554	$492	$430	$368	$307	$245	$183	$121	$59
30%	$654	$593	$531	$469	$407	$345	$283	$221	$159	$97
31%	$693	$631	$569	$507	$445	$383	$322	$260	$198	$136
32%	$731	$669	$608	$546	$484	$422	$360	$298	$236	$174
33%	$770	$708	$646	$584	$522	$460	$398	$337	$275	$213
34%	$808	$746	$684	$623	$561	$499	$437	$375	$313	$251
35%	$847	$785	$723	$661	$599	$537	$475	$414	$352	$290
36%	$885	$823	$761	$699	$638	$576	$514	$452	$390	$328

The two-way data sensitivity analysis show that in the best case where capacity factor is maximum (36%) and capital cost is minimum ($584/kW) NPV per kW becomes $885 while in the worst case it becomes -$18. Among a hundred values, there is only one value that is lower than zero. As a result, it can be concluded that onshore wind projects constructed in an area having a wind speed of 7.25 m/s or more has a slight probability of having negative NPV.

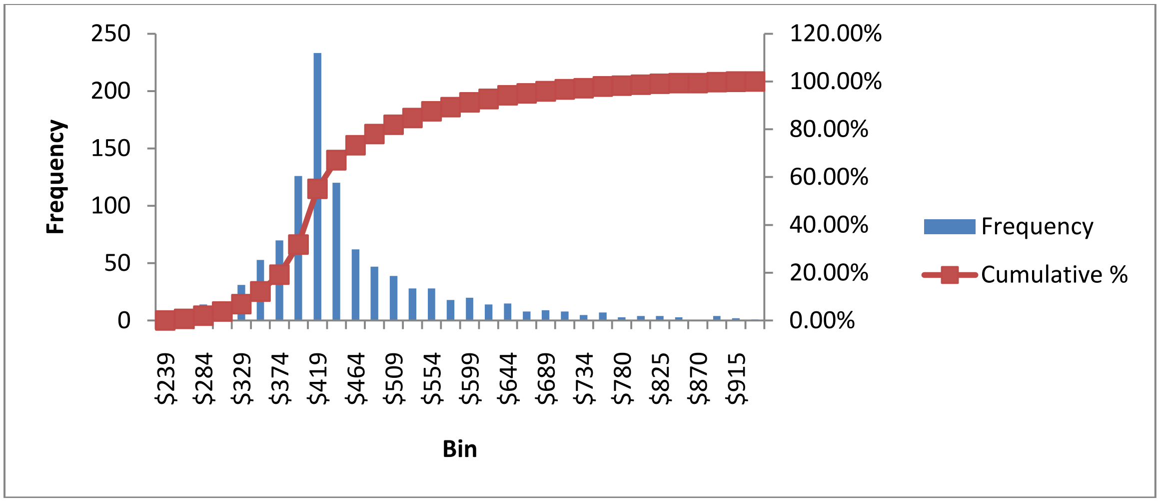
Lastly, a Monte Carlo analysis is conducted to see the probabilistic distribution of NPV values. In this analysis, some parameters are considered as fix, some of them are assumed as probabilistic, and some are calculated from other parameters. The assumptions about the parameters are given in Table 92.

Table 92: The assumptions about parameters of Monte Carlo analysis for onshore wind

Parameter	Distribution	Minimum	Maximum	Most Probable
Capital Cost ($/kW)	Uniform	$584	$1,236	
O&M Cost ($/MWh)	Uniform	$5.33	$26.51	
CF	Uniform	28%	34%	
Capacity (MW)	Fixed			
Salvage Value Ratio	Triangular	5%	20%	20%
Lifetime (years)	Triangular	20	25	20
Tax Rate (%)	Fixed			
Inflation (%)	Uniform	1%	4%	
Price ($/MWh) (5 years)	Triangular	73	110	92
Price ($/MWh) (after 5 years)	Triangular	73	110	73
Debt Payment Period (years)	Uniform	5	25	
Cost of Debt (%)	Triangular	5.17%	9.17%	7.17%
Cost of Equity (%)	Triangular	10.50%	24.03%	13.11%
Weight of Debt (%)	Uniform	0%	100%	
Weight of Equity (%)	Calculated			
WACC (%)	Calculated			

I do not have enough data to predict the distribution of each parameter, so I assume uniform distribution if I cannot prefer one value to another; and I assume triangular distribution if there is a most probable value. Excel is used to generate random numbers for the variables having uniform distribution, but the random numbers for the variables having triangular distribution cannot be generated in Excel. Therefore, Easyfit program is used to generate random numbers for these parameters. I generate 1,000 random numbers for each variable and calculated 1,000 NPV values by using Excel. The histogram of NPV per kW values is given in Figure 35.

Figure 35: The histogram for NPV per kW for onshore wind



When the values and the histogram are analyzed, it can be concluded that:

- The distribution of NPV values is very close to normal distribution.
- The average NPV value is $440/kW.
- The lowest NPV value is $239/kW and the highest NPV value is about $937/kW.
- The standard deviation of these 1,000 values is $103/kW.
- All values are positive and higher than $239/kW. Based on the capital cost of $952/kW, this NPV value is sufficiently high to invest on the relevant wind projects.
- Even in the worst probable case, NPV is still positive and considerably high. In other words, the probability of negative NPV is zero. This is parallel to the result of two-way sensitivity analysis where there is only one negative NPV.
- Based on the current regulatory framework and current cost structure, to invest in the wind energy in Turkey with an average wind speed of 7.25 m/s and over is very attractive.

The same analyses are carried out for LCE of the chosen onshore wind class. The results for static sensitivity analysis that is done by changing each parameter 10%

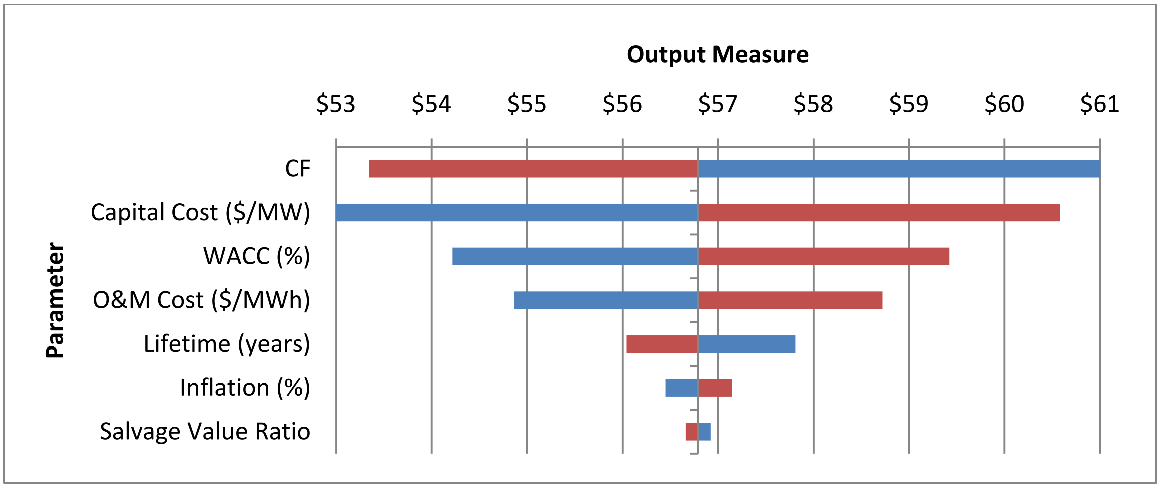
positively and negatively is given in Table 93. In this analysis, only seven parameters are included because other parameters do not affect the level of LCE. Contrary to the situation in NPV, there is not any parameter which can change LCE more than 10%. Even the parameters having the highest effect on LCE can only change the level of LCE by 7%.

Table 93: The results of static sensitivity analysis for LCE for onshore wind

DATA TABLE					PARAMETER INFO			
Parameter	-10 Pct	+10 Pct	Range	Base Case	Base Case	% Sensitivity	-%	+%
CF	$61	$54	$8	$57	31%	10	28%	34%
Capital Cost ($/MW)	$53	$61	$8	$57	$951,833	10	$856,650	$ 1,047,016
WACC (%)	$55	$60	$5	$57	$0.09	10	$0.08	$0.10
O&M Cost ($/MWh)	$55	$59	$4	$57	$16.24	10	$14.62	$17.87
Lifetime (years)	$58	$56	$2	$57	20	10	18	22
Inflation (%)	$57	$58	$1	$57	3%	10	2%	3%
Salvage Value Ratio	$57	$57	$0	$57	20%	10	18%	22%

The result of the static sensitivity analysis is also used to construct Tornado chart which is given in Figure 36. The most important factors are the same as the NPV analysis: capacity factor and capital cost, each has a potential to make around 7% changes in LCE if the base case value is increased or decreased by 10%.

Figure 36: Tornado analysis chart for LCE for onshore wind



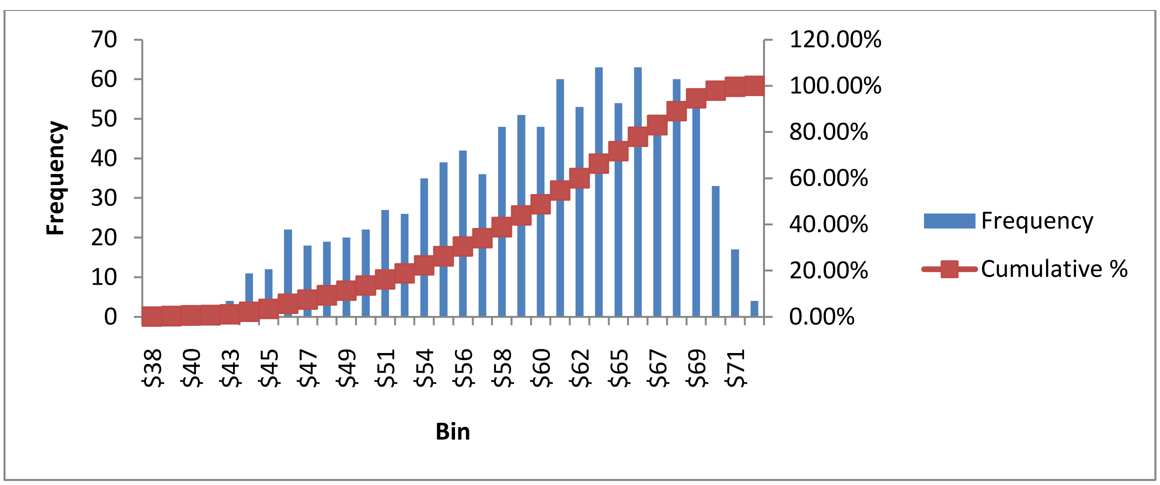
The two important factors diagnosed by the Tornado chart are used to do a partially dynamic sensitivity analysis by changing two parameters at a time to see the effect of the simultaneous changes on LCE and the results are given in Table 94. In this analysis, the highest capacity factor and the lowest capital cost generate a LCE of $47/MWh, while the worst case level of LCE is $79/MWh. The number of LCE which are higher than the minimum current regulated price is only five which exist only if capacity factor is lower than 28% and capital cost is higher than $1,171/kW. As a result, it is obvious that the risk of onshore wind energy projects deployed a site having equal to or more than 7.25 m/s annual average wind speed is very low. The probability of having a LCE higher than the regulated price is very close to zero.

Table 94: Two-way data sensitivity analysis for LCE for onshore wind

Capacity Factor	Capital Cost ($1,000/kW)											
	584	649	714	780	845	910	975	1,040	1,106	1,171	1,236	1,236
26%	$47	$50	$54	$57	$60	$63	$66	$69	$72	$75	$79	$79
27%	$46	$49	$52	$55	$58	$61	$64	$67	$70	$73	$76	$76
28%	$45	$48	$51	$54	$57	$60	$63	$66	$69	$71	$74	$74
29%	$44	$47	$50	$53	$56	$58	$61	$64	$67	$70	$72	$72
30%	$44	$46	$49	$52	$54	$57	$60	$63	$65	$68	$71	$71
31%	$43	$45	$48	$51	$53	$56	$59	$61	$64	$66	$69	$69
32%	$42	$45	$47	$50	$52	$55	$57	$60	$62	$65	$67	$67
33%	$41	$44	$46	$49	$51	$54	$56	$59	$61	$64	$66	$66
34%	$41	$43	$46	$48	$50	$53	$55	$57	$60	$62	$65	$65
35%	$40	$42	$45	$47	$49	$52	$54	$56	$59	$61	$63	$63

Lastly, a Monte Carlo analysis is also done to visualize the probabilistic distributions of possible LCE values, which is very helpful to understand the level of the risk of an investment. For this analysis, the same parameters and assumptions are used as the ones used in the analysis of NPV. Again, 1,000 LCE values are calculated and the results are summarized on the histogram in Figure 37.

Figure 37: The histogram for LCE values for onshore wind



When the calculated values of LCE and the histogram are analyzed, it can be concluded that:

- The distribution of LCE values is very close to triangular distribution with a most probable value of about $67.
- The average LCE value is $59.
- The lowest LCE value is $38 and the highest LCE value is $72.
- The standard deviation for these 1,000 values is $7.
- All values are lower than the regulated price. Even in the highest probable case, LCE is still lower than $73 which is the minimum value of the regulated price.
- Based on the current regulatory framework and current cost structure, to invest in the wind energy in Turkey with an average wind speed of 7.25 m/s and over is very attractive.

4.4.2. Solar Tower Technology

Like onshore wind energy, three different methods which are static sensitivity, partially dynamic sensitivity, and Monte Carlo analysis are used to conduct uncertainty analysis for solar energy. Tower technology is chosen for the uncertainty analysis because this technology has the most favorable NPV and LCE values which are still insufficient for base case scenario to make investment on solar energy in Turkey. In this section, I try to reveal under what circumstances a solar energy investment can generate zero or positive NPV, if there are some and to find out what the possibility of positive NPV for solar energy is by carrying out the mentioned three uncertainty analysis methods.

I start with the analysis of NPV per kW which is used instead of total NPV to provide intuition about the relative magnitude of NPV to capital cost. First, static sensitivity analysis is done by changing each parameter at a time by increasing or decreasing the value of each parameter by 10% to find out the effect of the relevant parameter on the level of NPV. The summary of the results and the base case and sensitivity values of each parameter are given in Table 95.

This simple sensitivity analysis shows that the most important factors affecting the level of NPV are capacity factor, capital cost, WACC, price, and O&M cost each of which generates more than 70% change on NPV when the value of one of these inputs is changed by 10% positively or negatively. In addition, storage efficiency, heat to electricity efficiency, storage capacity, and tax rate generate more than 30% change in NPV. Contrary to wind energy project, each parameter has a big effect on the level of NPV.A 10% increase in capacity factor or price or a 10% decrease in capital cost or WACC will create a positive NPV. This situation may be interpreted as an opportunity for solar projects in that a slight change in a major input may result in a positive NPV value, but it also increases the risk because the unexpected negative slight change in one parameter may ruin the profitability of the project.

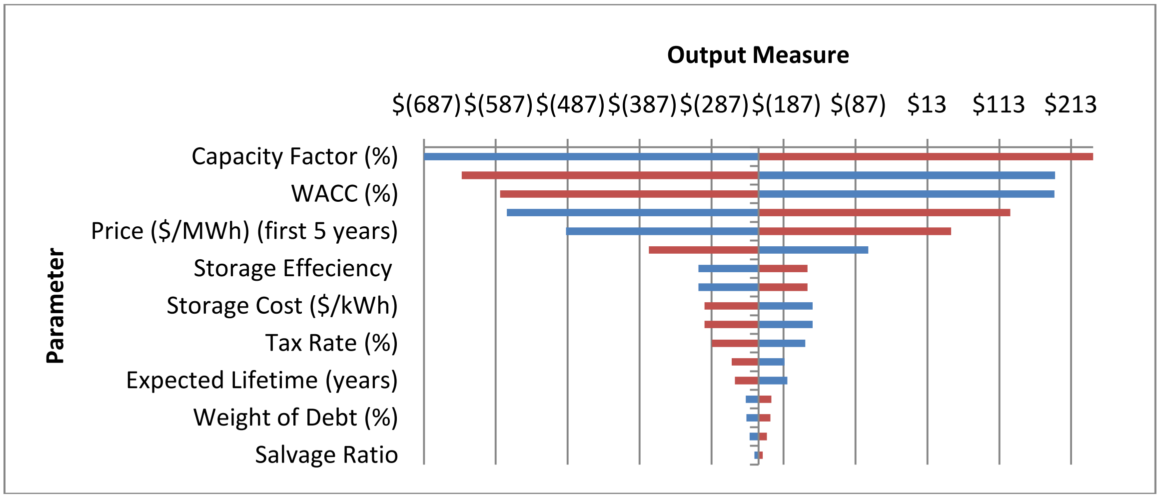
Table 95: The results of static sensitivity analysis for NPV per kW for solar tower

DATA TABLE					PARAMETER INFO			
Parameter	-10 Pct	+10 Pct	Range	Base Case Result	Base Case	% Sensitivity	-%	+%
Capacity Factor (%)	$(687)	$243	$931	$(222)	62.08%	10.00	55.87%	68.29%
Capital Cost ($/kW)	$191	$(634)	$825	$(222)	$4,619.89	10.00	$4,157.90	$5,081.88
WACC (%)	$190	$(581)	$771	$(222)	9.43%	10.00	8.48%	10.37%
Price ($/MWh) (after 5 years)	$(572)	$128	$700	$(222)	$133.00	10.00	$119.70	$146.30
Price ($/MWh) (first 5 years)	$(490)	$46	$536	$(222)	$160.00	10.00	$144.00	$176.00
O&M ($/MWh)	$(69)	$(375)	$305	$(222)	$28.27	10.00	$25.45	$31.10
Storage Efficiency	$(305)	$(154)	$152	$(222)	95.00%	10.00	85.50%	104.50%
Efficiency Rate (Heat to electricity)	$(305)	$(154)	$152	$(222)	39.63%	10.00	35.66%	43.59%
Storage Cost ($/kWh)	$(147)	$(297)	$150	$(222)	$19.78	10.00	$17.80	$21.75
Storage Capacity (hour)	$(147)	$(297)	$150	$(222)	16.00	10.00	14.40	17.60
Tax Rate (%)	$(157)	$(287)	$130	$(222)	20.00%	10.00	18.00%	22.00%
Inflation (%)	$(186)	$(259)	$74	$(222)	2.50%	10.00	2.25%	2.75%
Expected Lifetime (years)	$(182)	$(255)	$73	$(222)	30.00	10.00	27.00	33.00
Cost of Debt (%)	$(240)	$(204)	$36	$(222)	7.17%	10.00	6.45%	7.89%
Weight of Debt (%)	$(239)	$(205)	$33	$(222)	50.00%	10.00	45.00%	55.00%
Debt Payment Period (years)	$(234)	$(210)	$24	$(222)	10.00	10.00	9.00	11.00
Salvage Ratio	$(228)	$(216)	$12	$(222)	20.00%	10.00	18.00%	22.00%

Based on the results of the static sensitivity analysis in Table 95, a Tornado chart is also constructed to visualize how each parameter affects the level of NPV by changing only one parameter at a time (Figure 38). When we look at the chart, we can see that the most important parameter is capacity factor with a potential of around 200% change in

NPV as it is increased or decreased by 10%. The second factor is capital cost which generates about 185% change in NPV per kW slightly higher than the effect of WACC.

Figure 38: Tornado analysis chart for NPV per kW for solar tower



After the static analysis, a partially dynamic sensitivity analysis is done by changing two parameters at a time to see the effect of the simultaneous changes on NPV. For this aim, capacity factor and capital cost per kW values are used because these two parameters are the most important factors affecting the level of NPV as seen from Tornado chart in Figure 38. For capital cost, minimum and maximum values are taken as $3,727/kW and $5,542/kW with an increment of $202/kW; and for the capacity factor, minimum, maximum and increment are taken as 58%, 67%, and 1%, respectively. The result of this analysis is given in Table 96.

Table 96: Two-way data sensitivity analysis for NPV per kW for solar tower

Capacity Factor	Capital Cost ($/kW)									
	$3,727	$3,929	$4,130	$4,332	$4,534	$4,735	$4,937	$5,139	$5,340	$5,542
58%	$270	$90	$(90)	$(271)	$(451)	$(631)	$(811)	$(991)	$(1,171)	$(1,351)
59%	$345	$165	$(16)	$(196)	$(376)	$(556)	$(736)	$(916)	$(1,096)	$(1,276)
60%	$420	$239	$59	$(121)	$(301)	$(481)	$(661)	$(841)	$(1,021)	$(1,201)
61%	$494	$314	$134	$(46)	$(226)	$(406)	$(586)	$(766)	$(946)	$(1,126)
62%	$569	$389	$209	$29	$(151)	$(331)	$(511)	$(691)	$(871)	$(1,051)
63%	$644	$464	$284	$104	$(76)	$(256)	$(436)	$(616)	$(796)	$(976)
64%	$719	$539	$359	$179	$(1)	$(181)	$(361)	$(541)	$(721)	$(901)
65%	$794	$614	$434	$254	$74	$(106)	$(286)	$(466)	$(646)	$(826)
66%	$869	$689	$509	$329	$149	$(31)	$(211)	$(391)	$(571)	$(751)
67%	$944	$764	$584	$404	$224	$44	$(136)	$(316)	$(496)	$(676)

The two-way data sensitivity analysis show that in the best case where CF is maximum (67%) and capital cost is minimum ($3,727/kW), NPV per kW becomes $994 while in the worst case it becomes -$1,351. Among a hundred values, there are 38 values which are higher than zero. As a result, it can be concluded that solar tower projects constructed in an area having a DNI of 2,227kWh/m^2-y or more has an important probability of having positive NPV.

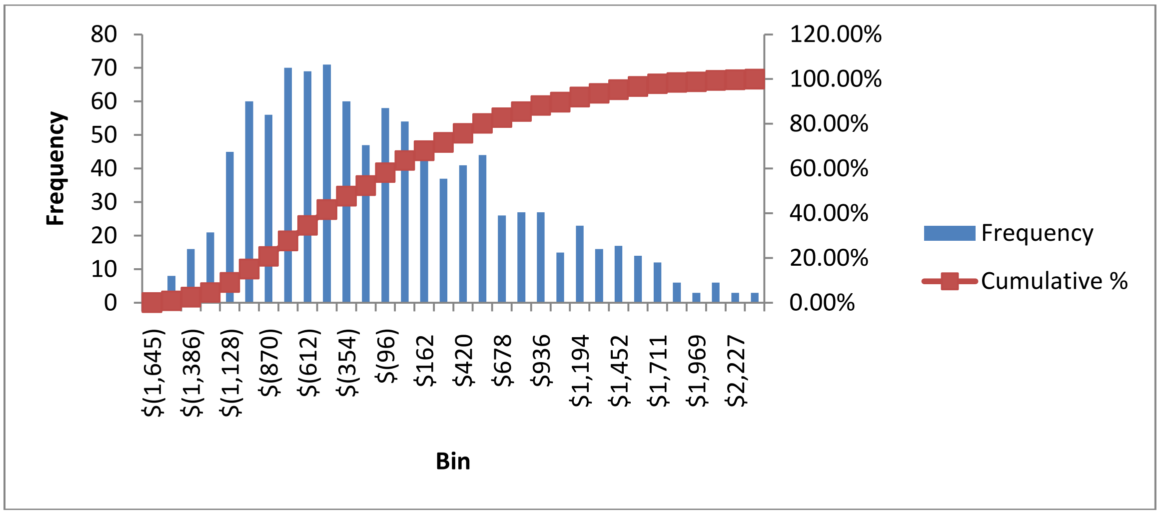
Lastly, a Monte Carlo analysis is conducted to see the probabilistic distribution of NPV values, which also provide us the probability of having a positive NPV. In this analysis, some parameters are considered as fix, some of them are assumed as probabilistic, and some are calculated from other parameters. The assumptions about the parameters are given in Table 97.

Table 97: The assumptions about parameters of Monte Carlo analysis for solar tower

Parameter	Distribution	Minimum	Maximum	Most Probable
Capital Cost ($/kW)	Uniform	3,727	5,542	
Storage Cost ($/kWh)	Uniform	18.56	22.11	
O&M Cost ($/MWh)	Uniform	26	31.82	
Capacity Factor (%)	Uniform	59	65	
Salvage Value Ratio	Triangular	5%	20%	20%
Lifetime (years)	Triangular	25	30	30
Price ($/MWh) (5 years)	Triangular	133	188	160
Price ($/MWh) (after 5 years)	Triangular	133	188	133
Debt Payment Period (years)	Uniform	5	25	
Inflation (%)	Uniform	1	4	
Cost of Debt (%)	Triangular	5.17%	9.17%	7.17%
Cost of Equity (%)	Triangular	10.50%	24.03%	13.11%
Weight of Debt (%)	Uniform	0%	100%	
Weight of Equity (%)	Calculated			
WACC (%)	Calculated			
Capacity (MW)	Calculated			
Tax Rate (%)	Fixed			20
Needed Land Area (m^2/kW)	Triangular	36	75	68
Needed Field Area (m^2/kW)	Triangular	6	14	14
Storage Capacity (h)	Fixed			16
Storage Efficiency (%)	Uniform	90	99	
Heat to electricity efficiency (%)	Uniform	38	41	
DNI (kWh/m^2-y)	Fixed			2,277
Suitable Land Area (km^2)	Fixed			879
Solar Field Area (km^2)	Calculated			
Storage Capacity (kWh/kW)	Calculated			

I do not have enough data to predict the distribution of each parameter, so I assume uniform distribution if I cannot prefer one value to another in terms of the probability; and I assume triangular distribution if there is a most probable value. Excel is used to generate random numbers for the variables having uniform distribution, but the random numbers for the variables having triangular distribution cannot be generated in Excel. Therefore, Easyfit program is used to generate random numbers for these parameters. I generate 1,000 random numbers for each variable and calculated 1,000 NPV by using Excel. The histogram of NPV per kW values is given in Figure 39.

Figure 39: The histogram for NPV per MW values for solar tower



When the data and the histogram are analyzed, it can be concluded that:

- The distribution of NPV values which are is fitted by Easyfit is very close to gamma distribution.
- The average NPV value is -$153/kW.
- The lowest NPV value is -$1,645/kW and the highest NPV value is about $2,356/kW.
- The standard deviation of these 1,000 values is $825. Like the results of the partial sensitivity analysis, there is a high deviation. For example the standard deviation is eight-fold of the standard deviation of NPV in the onshore case.

- The probability of getting a negative NPV is high with a cumulative probability of 58%. If the high risk (large deviation) and negative average NPV are considered, it can be concluded that solar energy projects in Turkey are very risky with a negative expected value.
- Based on the current regulatory framework and current cost structure, to invest in the solar energy in Turkey is not attractive even in a good site having a DNI of 2,277kWh/m^2-y.
- To make solar energy projects attractive in short run, the regulated price should be increased to the level that makes expected NPV positive. Otherwise, these projects can only be realized in the long run if the technology gets mature and the capital cost of solar power plants decreases enough.

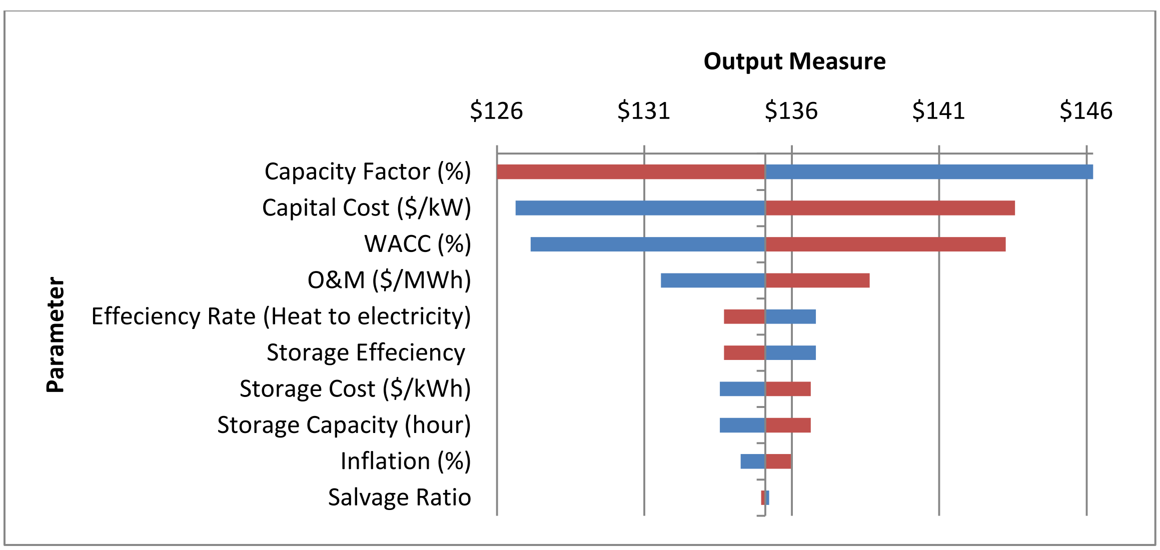
The same analyses are carried out for LCE of the chosen technology with a DNI value of 2,277kWh/m^2-y. The results for static sensitivity analysis that is done by changing each parameter by 10% positively and negatively is given in Table 98. In this analysis, only ten parameters are included because other parameters do not affect the level of LCE. Contrary to the situation in NPV, the effect of the change in the value of a parameter is very limited. Even the first ranked parameter (capacity factor) can only change LCE by about 7% which is lower than 10% change in the parameter itself. On the other hand, this result is very compatible with the situation on the onshore wind analysis.

Table 98: The result of sensitivity analysis for LCE for solar tower

DATA TABLE					PARAMETER INFO			
Parameter	-10 Pct	+10 Pct	Range	Base Case Result	Base Case	% Sensitivity	-%	+%
Capacity Factor (%)	$147	$126	$20	$136	62%	10	56%	68%
Capital Cost ($/kW)	$127	$144	$17	$136	$4,620	10	$4,158	$5,082
WACC (%)	$128	$144	$16	$136	9%	10	8%	10%
O&M ($/MWh)	$132	$139	$7	$136	$28.27	10	$25.45	$31.10
Efficiency Rate (Heat to electricity)	$137	$134	$3	$136	40%	10	36%	44%
Storage Efficiency	$137	$134	$3	$136	95%	10	86%	105%
Storage Cost ($/kWh)	$134	$137	$3	$136	$19.78	10	$17.80	$21.75
Storage Capacity (hour)	$134	$137	$3	$136	16	10	14	18
Inflation (%)	$135	$136	$2	$136	2.5%	10	2.3%	2.8%
Salvage Ratio	$136	$135	$0	$136	20%	10	18%	22%

The result of the static sensitivity analysis is also used to construct Tornado chart which is given in Figure 40. The most important factors are the same as the NPV analysis: capacity factor and capital cost, each has a potential to make around 7% changes in NPV if the base case value is increased or decreased by 10%.

Figure 40: Tornado analysis chart for LCE for solar tower



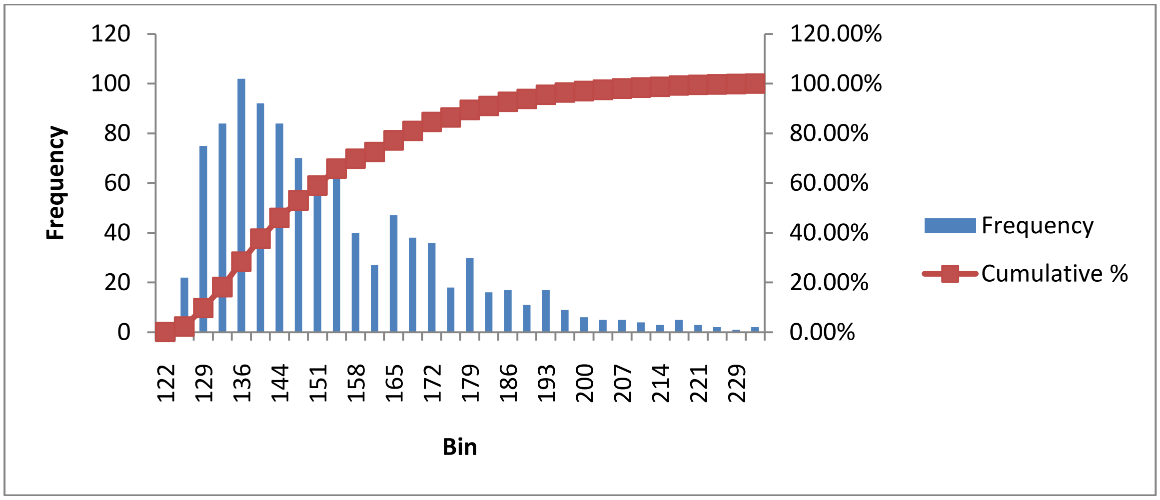
The two important factors diagnosed by the Tornado chart are used to do a partially dynamic sensitivity analysis by changing two parameters at a time to see the effect of the simultaneous changes on LCE and the results are given in Table 99. In this analysis, the highest capacity factor and the lowest capital cost generate a LCE of $112/MWh which is lower than the current regulated price, while the worst case level of LCE is $159/MWh. The number of LCE which are low than the minimum current regulated price ($133/MWh) is forty seven which is big number if we consider the regulated price are not escalated with the inflation. As a result, it can be said that the risk of a solar tower project deployed a site having equal to or more than a DNI of 2,277kWh/m^2-y is high.

Table 99: Two-way data sensitivity analysis for LCE for solar tower

Capacity Factor	Capital Cost ($/kW)									
	$3,727	$3,929	$4,131	$4,333	$4,534	$4,736	$4,938	$5,139	$5,341	$5,543
59%	$124	$127	$131	$135	$139	$143	$147	$151	$155	$159
60%	$122	$126	$130	$134	$137	$141	$145	$149	$153	$156
61%	$121	$124	$128	$132	$136	$139	$143	$147	$151	$155
62%	$119	$123	$127	$130	$134	$138	$141	$145	$149	$153
63%	$118	$122	$125	$129	$133	$136	$140	$143	$147	$151
64%	$117	$120	$124	$127	$131	$135	$138	$142	$145	$149
65%	$115	$119	$122	$126	$130	$133	$137	$140	$144	$147
66%	$114	$118	$121	$125	$128	$132	$135	$139	$142	$145
67%	$113	$116	$120	$123	$127	$130	$134	$137	$140	$144
68%	$112	$115	$119	$122	$125	$129	$132	$136	$139	$142

Lastly, a Monte Carlo analysis is also done to visualize the probabilistic distributions of possible LCE values, which is very helpful to understand the level of the risk of an investment. For this analysis, the same parameters and assumptions are used as the ones used in the analysis of NPV. Again, 1,000 LCE values are calculated and the results are summarized on the histogram in Figure 41.

Figure 41: The histogram for LCE for solar tower



When the calculated values of LCE and the histogram are calculated, it can be concluded that:

- The distribution of LCE values is very close to triangular distribution with a most probable value of $136.
- The average LCE value is $151 higher than the minimum regulated price.
- The lowest LCE value is $122 and the highest LCE value is $232.
- The standard deviation for these 1,000 values is $21 which is three-fold of the standard deviation in an onshore wind project investigated in Section 4.4.1.
- Some values are lower than the regulated price, but the majority is higher. In fact, 82% of all LCE values are higher than the regulated price.
- Based on the current regulatory framework and current cost structure, to invest in the solar energy in Turkey is risky and not attractive.

Chapter 5: Conclusion

Renewable energy has become very popular in the last years due to the environmental concerns and the increase of fossil fuels prices both in the world and Turkey. In this study, I analyze wind and solar energy potential of Turkey to find out whether these sources can be utilized economically based on the current regulated prices and the current wind and solar power plant costs collected from the literature. For this aim, firstly, I give background information about wind and solar energy technologies and costs. Then, the structure of Turkish electricity market and her wind and solar energy potential are explained. After giving background information about technology, cost and the potential of Turkey, I construct five different models for five technologies which are onshore wind, offshore wind, solar PV, solar trough and solar tower to conduct economic analysis.

The cost data, the technical parameters and the financial factors constitute the inputs of the models. By using these models I conduct two different economic analyses which are static analysis (base case scenario) and uncertainty analysis. The former one is carried out for five wind classes of onshore and offshore wind power plant projects and for two solar sources of solar PV, solar trough and solar tower power plant projects while the latter one was done for the most promising technologies which are onshore wind and solar tower. First, three financial analysis measures which are payback period, NPV and IRR and two market analysis measures which are levelized cost of electricity and shut-down price are calculated based on the cash flows generated by the models. When these five measures are analyzed, it can be concluded that:

- In terms of simple payback periods, all projects can return initial investment back, but this period is very long for all technologies except onshore. On the other hand, discounted payback period is lower than the expected lifetime only for onshore wind projects.

- Only wind onshore technology has positive NPV values which increase as the wind quality increases. Among the remaining technologies, solar tower technology generates the highest NPV which is -$221,892/MW when the DNI equals to 2,277kWh/m2.
- IRR values range from 1.34% belonging to solar PV to 22.74% belonging to onshore wind and only IRR values of onshore project are higher than discount rate. The most promising technology among the remaining technologies is solar tower technology whose IRR is very close to the discount rate.
- The levelized cost of electricity is lower than the regulated price for onshore wind projects and it is in the range of feed-in tariffs for solar tower projects and some offshore projects. All other projects' LCE is higher than the feed-in tariffs.
- Shut-down price of all technologies are low, especially for solar PV and onshore wind technologies. Therefore, these power plants will not be shut down unless the price decreases very much.

Based on the results of static analysis, two most promising technologies which are onshore wind technology and solar tower technology are chosen to conduct uncertainty analysis. In this context, three different uncertainty analyses methods including static sensitivity, partially dynamic sensitivity and Monte Carlo analysis are used to evaluate two important economic analysis measures which are NPV and LCE for onshore wind power plant projects having a wind speed of 7.25 m/s and solar tower plant projects having a DNI of 2,277 kWh/m^2-y. The analysis of the results of uncertainty analysis for onshore wind energy shows that:

- This simple sensitivity analyses show that the most important factors affecting the level of NPV and LCE are capacity factor and capital cost.
- The two-way data sensitivity analyses show that there is only one NPV value that is lower than zero among a hundred values and five LCE values which are higher than the minimum regulated price among a hundred values.
- Monte Carlo analyses show that: (1) The distribution of one thousand NPVs is very close to normal distribution with a mean of $440/kW, standard deviation of $103/kW, minimum value of $239/kW and maximum value of $937/kW. Based on the capital cost of $951/kW, these values are very sufficient. (2) The distribution of one thousand LCEs is very close to triangular distribution with a most probable value of about $67, minimum value of $59, maximum value of $72 and average value of $59. Even the maximum value is lower than the minimum regulated price.

On the other hand, the main findings of the uncertainty analysis of solar tower projects in Turkey are listed below:

- Like onshore projects, the simple sensitivity analyses shows that the NPV and LCE of the solar tower project are also affected mainly by the capacity factor and capital cost.
- The two-way data sensitivity analyses show that there are 38 NPVs higher than zero and 47 LCEs lower than the minimum regulated price among 100 values.
- Monte Carlo analyses show that:
    - (1) the distribution of one thousand NPVs is skewed to the left and very close to gamma distribution with a mean of -$153/kW, standard deviation of $825/kW, minimum value of -$1,645/kW and maximum value of $2,356/kW. Based on the high risk (large deviation), negative average

NPV and 58% probability of getting a negative NPV, it can be concluded that investing in the solar energy in Turkey is not attractive even in a good site having a DNI of 2,277kWh/m^2-y under the current cost structure. To make solar energy projects attractive in short run, the regulated price should be increased to the level that makes expected NPV positive. Otherwise, these projects can only be realized in the long run if the technology gets mature and the capital cost of solar power plants decreases enough.

- (2) The distribution of one thousand LCEs is very close to triangular distribution with a most probable value of about $136, minimum value of $122, maximum value of $232 and average value of $151. Both most probable and average LCE are in the range of feed-in tariffs, but 18% is lower than the minimum regulated price.

To sum up, under the current technological structure, the costs of wind and solar energy technologies and the feed-in tariffs for renewables in Turkey, only onshore wind projects are attractive among five alternatives. However, with a minor increase in the regulated price for solar thermal electricity, tower plant projects will also attract investments in the future. Otherwise, to utilize solar energy potential, Turkey has to wait the decrease in the construction cost of tower power plants.

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