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Review Article

The Current Situation of Wind Energy in Turkey

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Wind energy applications and turbine installations at different scales have increased since the beginning of this century. As wind energy is an alternative clean energy source compared to the fossil fuels that pollute the atmosphere, systems that convert wind energy to electricity have developed rapidly. Turkey's domestic fossil fuel resources are extremely limited. In addition, Turkey's geographical location has several advantages for extensive use of wind power. In this context, renewable energy resources appear to be one of the most efficient and effective solutions for sustainable energy development and environmental pollution prevention in Turkey. Among the renewable sources, Turkey has very high wind energy potential. According to the Organization for Economic Cooperation and Development (OECD) Turkey theoretically has 166 TWh a year of wind potential. However the installed wind power capacity is approximately 14% of total economical wind potential. In this study, Turkey's installed electric power capacity and electric energy production are investigated and also the current situation of wind energy in Turkey is examined. The wind data used in this study were taken from Turkish Wind Energy Association (TUREB) for the year 2012. This paper reviews the assessment of wind energy in Turkey as of the end of July 2012 including wind energy applications.

1. Introduction

During recent years according to global environmental pollutions, trends towards the sustainable energy and green power sources such as solar, wind, biomass, and geothermal energy were largely increased. It is now widely accepted that the renewable energy sources are very important for the future of the countries. Wind energy is one of the economic renewable sources and a valuable supplement to conventional energy sources. The wind technology was gradually improved since the early 1970s. By the end of the 1990s, wind energy has re-emerged as one of the most important renewable energy resources [1]. The cost of wind electricity production cost has been gradually decreasing with improving technology. At present, wind energy has been widely used to produce electricity in many countries in America, Asia, and especially Europe. For instance, while the world established wind power is 24,322 MW in 2001, it has increased to 237,016 MW in the end of 2011 [2].

Our country, just as the majority of all world countries, faces some short and long term problems in energy procurement. Turkey should at first attempt to increase the amount of energy acquired from new and renewable energy sources to cover basic requirements of society and realize economic expansion, refrain as much as possible from local and global environmental problems caused by energy consumption and production, and especially reduce foreign-dependency in energy. This is valid for not only our country but also other countries of the world [3].

Especially in the last decade, many scientific studies were presented about the development of wind energy. A general review about wind energy development in Turkey is considered by Sahin [4]. Some authors have researched the developments in wind engineering and turbines, for example, Ackerman and Söder [5], Sahin [6], Thresher et al. [7], and Joselin Herbert et al. [8]. In [9–11] authors presented control techniques for composite wind turbine blades. Many authors have studied the status of wind energy, the wind energy potential of Turkey's different geographical regions [12–33]. A general review about wind energy status, renewable energy potential, and development in Turkey is considered by researchers in [34–41]. In these studies, Turkey's installed wind power capacity and electric energy production are investigated and also Turkey current wind energy status is examined by researchers. Ozgener and Hepbasli [42]

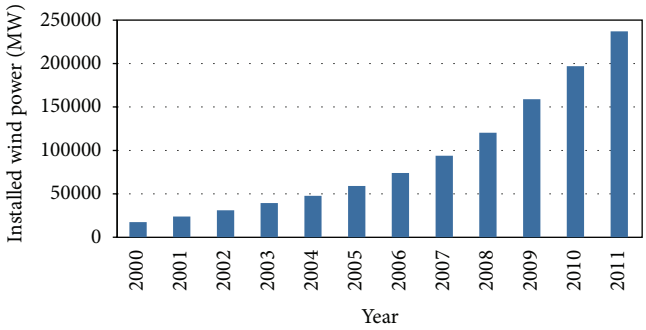

Figure 1: Installed wind power capacity of the world.

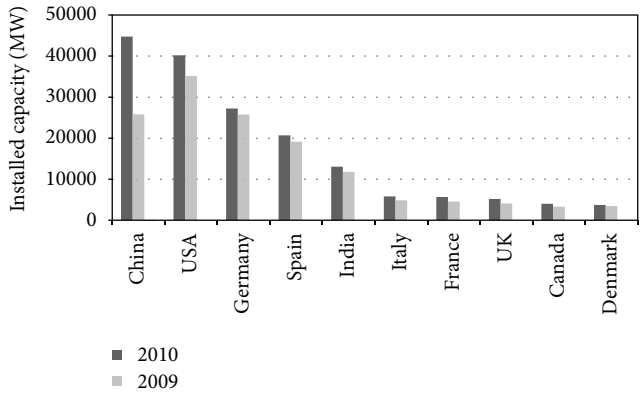

Figure 2: Top ten countries in terms of total installed wind power capacity in the world.

presented future directions of wind energy applications in Turkey. Many authors have researched the status, potential, utilization, environmental pollution, and future perspectives of renewable energy sourches, for example, Evrendilek and Ertekin [43], Ocak et al. [44], Yüksel [45], Oğulata [46], Keleş and Bilgen [47], Çapik et al. [48], Yuksel and Kaygusuz [49], Volkan and Ediger [50], Kaya [51], Kaygusuz and Sari [52], and Akpinar et al. [53]. In addition, Kenisarin et al. [54] has discussed wind power engineering in the world and its development in Turkey.

In this paper, wind energy and its importance are discussed firstly, and then the current status and development of Turkey's wind power plants are investigated in detail.

2. Situation of Wind Energy in the World

Wind energy is the most advanced and widespread renewable energy source being the most convenient in commercial terms. Being a clean energy source, wind energy is environment friendly having no possibility of extinction as long as the sun exists. It is an ever growing energy source despite being continuous and despite the fact that it is not exactly known whether available amount will be at hand when required. For instance, while the world established wind power is 24,322 MW in 2001, it has increased to 215,000 MW in June 2011 [2]. Figure 1 shows installed wind power capacity in the world between 2000 and 1st half 2011 [2, 55]. There is an increasing trend in installed wind energy and average increasing rate is 25% over this period. It is estimated that installed wind power will be reached in 24,500 MW by the end of 2011 [2].

Approximately 43.7% of the installed wind capacity of the world is in Europe, 22.5% in North America, and 31.1% in Asia. However, China has the highest installed wind capacity with 44,733 MW which is equal to 52% of Europe's and 22.7% of world installed capacity. The top ten wind energy markets are shown in Figure 2 between 2009 and 2010 [56].

As it is seen from Figure 2 China shows the highest development in installed wind energy capacity with 73% between 2009 and 2010. USA has also high development with 14.2%. The increasing rate of installed wind capacity in this term for Germany, Spain, and India is 5.5, 7.9, 10.6%, respectively. Although the established power of wind energy has recently increased in the countries in the Asian continent, 43.7% of the established power of world wind energy is in the European continent, according to 2010 data.

According to 2010 data of Balkan countries being under the influence of almost similar wind systems to Turkey, our bordering neighbor Greece has 1208 MW of wind energy established power, while Bulgaria has above 375 MW of established wind power. Based on a comparison with our neighbors, the significance of the potential of our country is blatant, only when we consider the great surface area of our country.

3. Turkey's Electrical Energy Status

The main purpose of energy policy in Turkey is to supply the sufficient energy to the utilization taking environmental and economic aspects into account by supporting the economical growing and social development [57]. The trend of growing has been calculated to be continuing in future. Turkey's total installed power capacity obtained from hydraulic, thermal (natural gas, coal, lignite, fuel-oil, LPG, etc.), and wind sources is 49,524 MW at the end of the 2010, an increase of 10.6% over 2009. From 2000 to 2010 total capacity increased by 74.6%. This was one of the largest increases in IEA member countries, reflecting a significant build-up in CCGTs but also coal and hydro capacity [58]. Together, natural gas, hydropower, oil, and coal plants account for 97%. Distribution of the installed power capacity of Turkey according to the sources is given in Figure 3 [59]. As it is seen from Figure 3, the rate of thermal source power plants is very high and approximately 75% of these are natural gas plants.

The total gross electrical energy production in 2010 was 211,207.7 GWh and changes in the production rate depended on the economic situations and technological developments. Average increasing rate was approximately 8.4% in this term [59]. Turkey's electrical energy production from 2005 to 2010 is shown in Figure 4 [59]. Although electrical energy production has increased gradually, there was a decrease in electrical energy production in 2009. Electricity production was realized as 194,812 GWh with a decrease about 2% in 2009 when compared to the values of 2008, that is, 198,418 GWh.

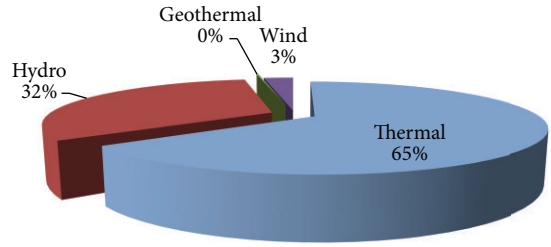

Figure 3: Distribution of installed power capacity of Turkey.

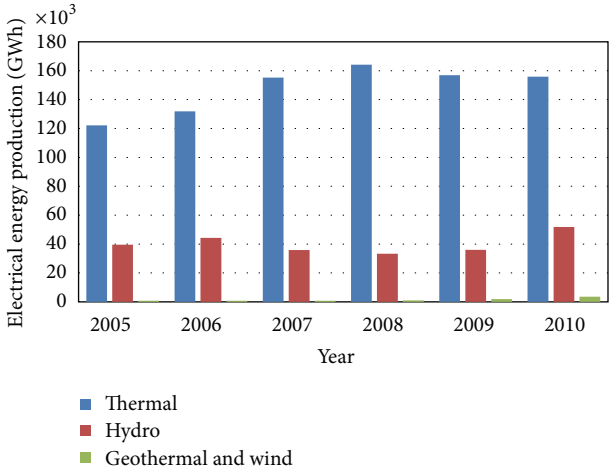

Figure 4: Turkey's gross electrical energy production for the years 2005–2010.

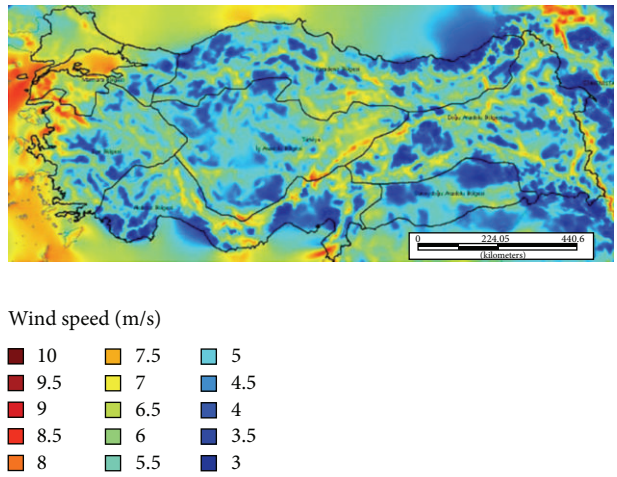

Figure 5: Scattering of average wind speed at 50 m high in Turkey.

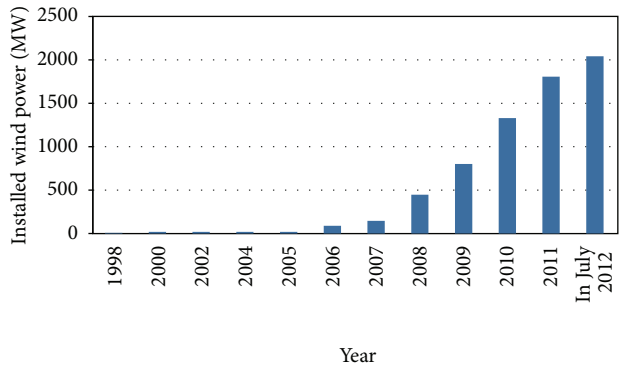

Figure 6: Installed wind power capacity in Turkey.

Annual developments of the gross electrical energy production according to sources between 2005 and 2010 are given in Table 1 [59]. As it is seen from Table 1, 73% of the electrical energy is supplied from thermal sources. It can be seen that the proportion of natural gas in the electrical energy production increased approximately 33.6% in this term. In electrical energy production, consumption of natural gas reached 46% in 2010 whereas it was 37% in 2000 [39]. However, the natural gas share of the world in production of electrical energy is 21.4% [60]. Since Turkey imports almost all required natural gas, this high rate usage in producing electricity than the world is an important point to be examined economically [39]. On the other hand, electrical energy production from the wind has grown rapidly in recent years.

4. The Current Situation of Wind Energy in Turkey and Its Future

A wind atlas of Turkey published by the Turkish Energy Market Regulatory Agency (EPDK) in May 2002 indicates that the regions with the highest potential for wind speeds at height of 50 m are the Aegean, Marmara, and Eastern Mediterranean regions of Turkey, as well as some mountainous regions of central Anatolia [61]. Figure 5 shows scattering of average wind speed in 50 m high in Turkey [3]. In addition to this, meteorological data by the USA space studies have shown that Turkey has high wind capacity [39].

Power intensity in 50 m of elevation above ground, which is significant to establish turbines, in places with 4-5 m/s of average annual wind speed at 50 m of elevation above ground mostly exceed annual average of 500 w/m^2. Estimated figures resulting from the researcher conducted in the field, technical wind energy potential of Turkey, established power, and average efficiencies are available in Table 2 [3]. In this table, the land of Turkey has been classified by means of wind energy resource degree. It can be seen from this table that approximately 37% of the land of Turkey has capacity above medium.

First small-scale application to generate electrical energy in Turkey was started with a plant that has 55 kW installed power in Izmir-Çeşme in the Aegean region in 1986. The first power plant in large-scale was also installed in 1998, Çeşme-Germiyan with 1.74 MW capacity. In 1998, the ARES wind farm was built in Çeşme-Alaçatı and included 12 × 600 kW wind turbines. The biggest wind energy power plant in Turkey has 140.1 MW capacity constructed in Manisa-Soma in 2012. Current wind power plants under operation in Turkey are listed in Table 3 [62]. Installed wind power capacity for electrical production is shown in Figure 6 [62].

Table 1: Distribution of resources of the Turkey's gross electrical energy production (GWh).

Resources	2005	2006	2007	2008	2009	2010
Hard coal + Imp. coal	13246.2	14216.6	15236.2	15857.5	16595.6	19104.3
Lignite	29946.3	32432.9	38294.7	41858.1	39089.5	35942.1
Fuel-oil	5120.7	4232.4	6469.6	7208.6	4439.8	2143.8
Diesel	2.5	57.7	13.3	266.3	345.3	4.3
Natural gas	73444.9	80691.2	95024.8	98685.3	96094.7	98143.7
Renew. and wastes	122.4	154.0	213.7	219.9	340.1	457.5
Others	359.3	50.3	43.9	43.6	18.0	31.9
Total thermal	122242.3	131835.1	155196.2	164139.3	156923.4	155827.6
Hydro	39560.5	44244.2	35850.8	33269.8	35958.4	51795.5
Geothermal + wind	153.4	220.5	511.1	1008.9	1931.1	3584.6
Total	161956.2	176299.8	191558.1	198418.0	194812.9	211207.7

Table 2: Areal distribution of wind speed, power and potential energy amount in Turkey.

Wind source degree	Wind class	Wind power at 50 m. (W/m^2)	Wind speed at 50 m. (m/s)	Overall area (km^2)	Windy land (%)	Potential capacity (MW)
Medium	3	300–400	6.8–7.5	16781.39	2.27	83906.96
Good	4	400–500	7.5–8.1	5851.87	0.79	29259.36
Perfect	5	500–600	8.1–8.6	2598.86	0.35	12994.32
Perfect	6	600–800	8.6–9.5	1079.98	0.15	5399.92
Perfect	7	>800	>9.5	39.17	0.01	195.84
Total				26351.28	3.57	131756.40

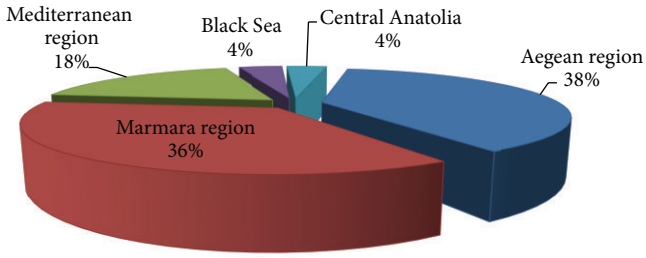

Figure 7: Distribution of wind energy power stations according to the regions in Turkey.

Having a look at Table 3, the existing wind power stations are active only in the five of the seven geographical regions of the country, being Aegean, Marmara, Mediterranean, Black Sea, and Central Anatolia regions. While Aegean ranks first with 786.2 MW of established power, Marmara region with 730.65 MW of established power ranks second to be followed by the Mediterranean region with 372.5 MW of established wind power energy station capacity. Distribution of wind energy power stations according to the regions in Turkey is shown in Figure 7.

Considering the distribution of installed power according to provinces, Balıkesir ranks first, as is seen in Table 4, having almost 20% of the overall capacity. Manisa ranks second with 17% of share, İzmir, again a city from the Aegean region, ranks third with 16% of the total capacity, then the other provinces listed. In the near future, the number of provinces with active wind power stations is expected to be further augmented.

In 2010, 528 MW of new wind energy capacity was added in Turkey, bringing the total up to 1329 MW. This represents a year-on-year growth rate of 66%. According to TEIAS (the state-owned transmission company and system operator) it is projected that up to 415.8 MW of wind projects might be added in 2011 [61].

Installed wind capacity is expected to grow between 500–1,000 MW per year reaching more than 5 GW by 2015. Turkey hopes to install up to 20 GW by 2023, helping the country to source 30% of its electricity generation from renewable sources by that date. In order to reach this target, however, the transmission infrastructure will require substantial upgrades to allow such large scale developments to be connected to the power grid. This issue will need to be addressed in the near future [61].

The predicted wind power development capacity in Turkey can be seen in Table 5 [54]. Two different assumptions have been made in this table. According to both predictions, the power obtained from wind will increase and exceed 10,000 MWs by 2030.

The new renewable energy law introduced fairly attractive incentives for wind power plants in Turkey. In early 2007, the Turkish government updated the renewable energy law that guarantees wind generators with 10 year agreements involving a fixed tariff between 50/MWh and 55/MWh. Although somewhat lower than tariffs in other developing markets, for example, 73/MWh in Brazil or the 66/MWh set in Portugal, the tariff, coupled with the high wind potential,

Table 3: Wind power plants under operation in Turkey (July 2012).

Name of windfarm	Installed capacity (MW)	Turbine power	Turbine brand	Location	Production date
Çeşme	1.50	0.5 MW	Enercon	İzmir-Çeşme	1998
Ares	7.20	0.6 MW	Vestas	İzmir-Çeşme	1998
Bozcaada	10.20	0.6 MW	Enercon	Çanakkale-Bozcaada	2000
Intepe	30.40	0.8 MW	Enercon	Çanakkale-İntepe	2007
Karakurt	10.80	1.8 MW	Vestas	Manisa-Akhisar	2007
Burgaz	14.90	0.8 MW + 0.9 MW	Enercon	Çanakkale-Gelibolu	2007
Sayalar	34.20	0.9 MW	Enercon	Manisa-Sayalar	2008
Çatalca	60.00	3 MW	Vestas	İstanbul-Çatalca	2008
Yuntdağ	57.50	2.5 MW	Nordex	İzmir-Aliağa	2008
Kemerburgaz	24.00	2 MW	Enercon	İstanbul-Gaziosmanpaşa	2008
Mare manastır	39.20	0.9 MW + 0.8 MW	Enercon	İzmir-Çeşme	2006/2007
Sunjut	1.20	0.6 MW	Enercon	İstanbul-Hadımköy	2003
Teperes	0.85	0.85 MW	Vestas	İstanbul-Silivri	2006
Bandırma	35.00	1.5 MW	GE + Nordex	Balıkesir-Bandırma	2006
Şamlı	114.00	3 MW	Vestas	Balıkesir-Şamlı	2008
Datça	29.60	0.8 MW + 0.9 MW	Enercon	Muğla-Datça	2008
Sebenoba	30.00	2 MW	Vestas	Hatay-Samandağ	2008
Akbuk	31.50	2.1 MW	Suzlon	Aydın-Didim	2009
Çamseki	20.80	2 MW + 0.8 MW	Enercon	Çanakkale-Ezine	2009
Keltepe	20.70	0.9 MW	Enercon	Balıkesir-Susurluk	2009
Gökçedağ	135.00	2.5 MW	GE	Osmaniye-Bahçe	2009/2010
Düzova	30.00	2.5 MW	GE	İzmir-Bergama	2009/2010
Mazı-3	30.00	2.5 MW	Nordex	İzmir-Çeşme	2009/2010
Ayyıldız	15.00	3 MW	Vestas	Balıkesir-Bandırma	2009
Bandırma	60.00	3 MW	Vestas	Balıkesir-Bandırma	2009/2010
Soma	140.10	2 MW + 0.9 MW	Enercon	Manisa-Soma	2011/2012
Belen	36.00	3 MW	Vestas	Hatay-Belen	2009/2010
Sarıkaya	28.80	2 MW + 0.8 MW	Enercon	Tekirdağ-Şarköy	2009
Kocadağ-2	17.50	2.5 MW	Nordex	İzmir-Urla	2010
Bandırma-3	25.00	2.5 MW	Nordex	Balıkesir-Bandırma	2010
Mersin	33.00	3 MW	Vestas	Mersin-Mut	2010
Boreas-1	15.00	2.5 MW	Nordex	Edirne-Enez	2010
Aliağa	90.00	2.5 MW	Nordex	İzmir-Aliağa	2010
Şenbuk	15.00	3 MW	Vestas	Hatay-Belen	2010
Ziyaret	57.50	2.5 MW	GE	Hatay-Samandağ	2010/2011
Soma	90.00	2.5 MW	Nordex	Manisa-Soma	2010
Kuyucak	25.60	2 MW + 0.8 MW	Enercon	Manisa-Kırkağaç	2010
Sares	22.50	2.5 MW	GE	Çanakkale-Ezine	2010/2011
Turguttepe	24.00	2 MW	Vestas	Aydın-Çine	2010
Çataltepe res	16.00	2 MW	Enercon	Balıkesir	2010
Çanakkale	29.90	2.3 MW	Siemens	Çanakkale-Ezine	2011
Susurluk	45.00	2.5 MW	Nordex	Balıkesir-Susurluk	2011
Seyitali res	30.00	2 MW	Enercon	İzmir	2011
Söke-Çatalbük	30.00	2 MW	Gamesa	Aydın	2012
Aksu	72.00	2 MW	Vestas	Kayseri	2012
Amasya	40.00	2.5 MW	Nordex	Amasya	2012
Metristepe	40.00	2.5 MW	Nordex	Bilecik	2012
Dağpazarı	39.00	3 MW	Siemems	Mersin	2012
Şenköy	27.00	3 MW	Alstom W.	Hatay	2012
Şahres	93.00	3 MW	Vestas	Balıkesir	2011

Table 3: Continued.

Name of windfarm	Installed capacity (MW)	Turbine power	Turbine brand	Location	Production date
Ayres	5.00	1.8 MW	Vestas	Çanakkale	2011
Akres	45.00	2.5 MW	Nordex	Manisa	2011
Karadağ	10.00	2.5 MW	GE	İzmir	2012
Bozyaka	12.50	2.5 MW	Nordex	İzmir	2011
Killik	40.00	2.5 MW	Nordex	Tokat	2012
Saray	4.00	2 MW	Enercon	İstanbul	2012
Total	2041.35				

Table 4: Distribution of installed capacity according to Provinces of Turkey.

Provinces	Installed capacity (MW)
Balıkesir	423.10
Manisa	345.70
İzmir	325.40
Hatay	165.50
Osmaniye	135.00
Çanakkale	133.70
İstanbul	90.05
Aydın	85.50
Mersin	72.00
Kayseri	72.00
Tokat	40.00
Amasya	40.00
Bilecik	40.00
Muğla	29.60
Tekirdağ	28.80
Edirne	15.00

Table 5: Prediction of wind power development capacity in Turkey.

Years	Wind energy, MW* [35]	Wind energy, MW* [54]
2000**	19	19
2010**	1329	1329
2015	5142	7230
2020	7849	10620
2025	9733	13160
2030	11200	15885

*Calculation of the authors assuming a wind turbine utilization factor.
**Statistical data.

Table 6: Electricity generation costs by fuel type (cent/kWh).

Power source	Minimum	Maximum
Large hydro	3.0	13.0
Small hydro	4.0	14.0
Municipal solid wastes	4.2	6.3
Bio mass	4.2	7.9
Natural gas	4.3	5.4
Coal	4.5	7.0
Agricultural residues	4.5	9.8
Wind	4.7	7.2
Geothermal	4.7	7.8
Hydraulic	5.2	18.9
Nuclear	5.3	9.3
Solar thermal hybrid	6.0	7.8
Wave/tidal	6.7	17.2
Energy crops	10.0	20.0
Solar PV	28.7	31.0

Table 7: Cost structure of a typical 2 MW wind turbine installed in Europe (€2006).

	Investment (€1,000/MW)	Share of total cost %
Turbine (ex works)	928	75.6
Grid connection	109	8.9
Foundation	80	6.5
Land rent	48	3.9
Electric installation	18	1.5
Consultancy	15	1.2

provides good market prospects. The law also guarantees reduced costs for land access, generation, and licenses, as well as no VAT or custom taxes for wind equipment [4]. It is seen that this law has encouraged many investors for making investments given below regarding renewable energies in Turkey and especially wind energy.

5. Wind Energy Economics

The economics of wind power plants is influenced by a number of factors. These include the quality of the wind resource, technology efficiency and reliability, the availability of long-term power contracts, and the ability to forecast at least several hours ahead. By far the most significant factors that contribute to wind energy value are related to the wind resource and the characteristics of the grid and the evolving market rules. As additional wind capacity is developed, these variables will be quantified more precisely. A cost comparison between wind energy and other energy production methods was shown in Table 6 [40]. It can be seen that wind energy is as economically usable as other common energy sources.

Approximately 75% of the total cost of energy for a wind turbine is related to upfront costs such as the cost of the turbine, foundation, electrical equipment, and grid-connection.

Obviously, fluctuating fuel costs have no impact on power generation costs. Thus a wind turbine is *capital-intensive* compared to conventional fossil fuel fired technologies such as a natural gas power plant, where as much as 40–70% of costs are related to fuel and operation and maintenance. Table 7 gives the price structure of a typical 2 MW wind turbine [63].

6. Conclusions

Under global climate change conditions, all countries have trended towards renewable energy sources to reduce carbon dioxide emissions into the atmosphere. Wind energy is the most suitable energy source among renewable sources because wind energy has great potential throughout the world, including Turkey, and it is sustainable and does not pollute the environment. So, it has become crucial for electricity production. In general, potential wind energy areas in Turkey lie in northern and the north-western parts, at locations along the Aegean Sea and Marmara Sea coast. Aegean, Marmara, East-Mediterranean, and South East Anatolia regions of Turkey are generally seen as promising of higher wind power potential compared to other part of Turkey. In Turkey the available wind power was 801 MW by the end of the year 2009. This capacity reached 1329 MW at the end of 2010. This capacity became 2041.35 MW at the end of July 2012. The installed wind capacity of Turkey is approximately 14% of Turkey's total economical wind potential. However this rate will be increased after installing the licensed projects.

Turkey is facing serious challenges in satisfying its growing energy demand. To fuel a rapidly growing economy, the country's electricity consumption is increasing by an average of 8-9% every year, and significant investments are needed in generation, transmission, and distribution facilities to balance the power system's supply and demand. Finally, Turkey is an energy-importing country. In order to be less dependent on other countries, Turkey needs to use its sustainable sources. From this point of view, wind power is a very attractive choice, since it is economical, sustainable, environment friendly, and a familiar energy source in Turkey.

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