

Evaluation of wind energy investment interest and electricity generation cost analysis for Turkey

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ABSTRACT

Turkey has remarkable wind energy potential, but its utilisation rate is very low. However, in 2007, energy investors applied to the Energy Market Regulatory Authority (EMRA) with 751 wind projects to obtain a 78180.2 MW wind power plant license. This paper first presents an overview of wind energy development in the world and then reviews related situations in Turkey. Second, to motivate the interest in wind energy investment, new wind power plant license applications in Turkey are analysed. Finally, wind electricity generation cost analyses were performed at 14 locations in Turkey. Capacity factors of investigated locations were calculated between 19.7% and 56.8%, and the production cost of electrical energy was between 1.73 and 4.99 \$cent/kWh for two different wind shear coefficients.

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1. Introduction

Wind power is becoming the fastest growing renewable energy source in the world. The strong growth in wind power capacity is attributable to the promotion of models of renewable energy sources, energy supply security, fuel diversity concerns, ecological awareness and economic reasons. By the end of 2008, global installed wind power capacity reached 121,188 MW and an annual output of approximately 260 TW h. At present, wind generated electricity contributes more than 1.5% to global electricity consumption [1], and five countries meet more than 6% of their electricity demand with wind energy [2,3].

Wind electricity has a significant impact on decreases in the electricity market price, especially during peak periods [4]. Thus, in some countries and regions, installed wind capacity grew more than other power plant types, including hydropower, nuclear and coal plants [5]. Over the last decade, interest in wind power has increased dramatically in many countries. The installed wind power capacity development of the top 10 countries is shown in Table 1 [2,6–8]. The speed of wind power development across countries can be explained by various reasons, such as different wind characteristics, promotion policies, economic factors, technical reasons and energy security problems.

Several papers were published, in the last three decades in Turkey and abroad, to determine wind characteristics, and electricity generation cost [9–35]. The goal of this paper is to investigate the wind energy development, wind power plant license applications and wind electricity generation cost for 14 locations in Turkey. This paper first presents an overview of wind energy development and the situation in Turkey. Second, new wind power plant license applications of Turkey are analysed to comprehend the interest in wind energy investment. Then, a brief review of wind energy resource assessment studies in Turkey is presented. The last section is devoted to wind electricity generation cost analysis for 14 locations in Turkey using the determined Weibull distribution parameters in the literature.

2. Wind energy situation in Turkey

Turkey is located in the northern hemisphere between the 36° and 42° northern parallels and the 26° and 45° eastern meridians. Turkey borders the Black Sea, the Mediterranean, the Aegean and the Marmara Sea and has a total coastline of 8333 km. Turkey lacks large natural gas, coal and oil reserves: over 75% of energy demand is imported and indigenous sources only meet 40% of Turkey's electricity production [36]. The development of installed capacity and electrical energy production in Turkey are presented in Fig. 1 [37,38]. The average annual increase in the rate of electricity production was approximately 8.7% for 1970–2008. Therefore, meeting the rapid increase in electrical energy demand and finding solutions for energy security problems are the main dilemma in

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Nomenclature

k	Weibull shape parameter	a_2	regression constants of wind turbine
c	Weibull scale parameter (m/s)	a_3	regression constants of wind turbine
C_f	capacity factor	a_4	regression constant of wind turbine
$f(v)$	Weibull probability density function	v	wind speed (m/s)
P_R	wind turbine rated power	v_o	cut-out speed (m/s)
$P_T(v)$	wind turbine power curve as a function of wind speed	v_1	cut-in speed (m/s)
a_1	regression constants of wind turbine	v_R	rated wind speed (m/s)

Table 1

Top 10 installed wind power capacities (MW).

	Country	2000	2001	2002	2003	2004	2005	2006	2007	2008
1	USA	2554	4275	4685	6374	6740	9149.0	11603.0	16818.8	25,170
2	Germany	6113	8754	12,001	14,609	16628.8	18427.5	20622.0	22247.4	23,903
3	Spain	2235	3337	4830	6202	8263	10027.9	11630.0	15145.1	16,754
4	China	340	401	468	566	764	1266.0	2599.0	5912.0	12,210
5	India	1167	1407	1702	2110	2985	4430.0	6270.0	7850.0	9645
6	Italy	427	682	788	904	1265	1718.3	2123.4	2726.1	3736
7	France	79	85	147	198	390	757.2	1567.0	2455.0	3404
8	UK	408	464	552	647.6	900.8	1353.0	1962.9	2389.0	3241
9	Denmark	2300	2417	2880	3110	3117	3128.0	3136.0	3125.0	3180
10	Portugal	100	127	193.8	288.6	562	1022.0	1716.0	2130.0	2862

Turkey. To overcome this problem, it is crucial to increase the rate of indigenous and renewable sources in electrical energy production.

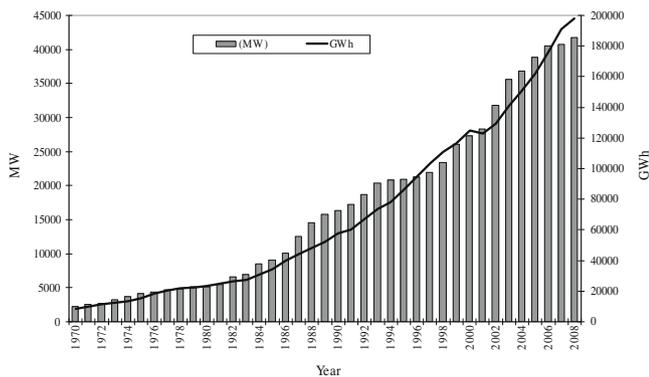
Among the renewable energy sources, wind energy has considerable economic potential, but its utilisation rate is very low. Wijk and Coelingh reported that Turkey's technical and economical wind energy potentials were 83,000 MW and 10,000 MW, respectively [39]. In 2002, a Turkey Wind Map was prepared from Turkish State Meteorological Service data. The results of the wind map showed that the economic potential was 10,000 MW and the technical potential was 88,000 MW. Further research to determine the technical wind potential of Turkey was carried out in 2006 by the General Directorate of Electrical Power Resources and Development Administration. The Wind Energy Potential Atlas (REPA) was prepared by numerical weather prediction methodology at 200×200 m resolution for different heights [40]. Wind energy potential at 50 m above ground level in land regions was calculated as 131,756 MW, which is equivalent to a wind power density greater than 300 W/m^2 [41]. Fig. 2 illustrates the annual wind power density at a height of 50 m [42]. From the figure, it can be easily seen that wind sources in Turkey are concentrated in the western and southern regions of Turkey.

Wind power may have a meaningful contribution to Turkish electricity generation as in some European countries. Turkey has 28 operating wind power plants with 727.45 MW installed capacity. As listed in Table 2, capacities vary between 0.85 and 90 MW [43]. At the end of 2005, the cumulative installed wind power capacity was 20.1 MW; wind power then experienced dramatic growth and now represents more than 1% of the total installed power capacity.

Turkey's annual wind electrical energy production is shown in Fig. 3. Wind electricity production has been increasing rapidly in recent years. In 2008, the generation of electricity from wind power in Turkey reached 797 GW h, which is equivalent to 0.4% of Turkey's total electrical energy consumption [38]. The mean capacity factor of wind power plants ranged from 30% to 45% between 1998 and 2008. On the other hand, the mean realised capacity factor for wind power plant in European countries was below 21% between 2003 and 2007 [44]. The mean capacity factor of wind power plants in Turkey is significantly higher compared to European countries. This difference is a result of higher average wind speeds and the low utilisation ratio of suitable and viable sites for wind energy generation in the Turkey.

3. Investigation of new wind energy license applications

In Turkey, prior to the installation of power plants, investors must apply to EMRA to obtain a license. In January 2005, 36 wind power plant projects had been licensed by EMRA. The capacity of these power plants ranges from 0.66 MW to 135 MW. The total capacity of all plants was 1406.92 MW, and the average capacity factor of these projects was 37.5% [45]. In November 2007, energy investors applied to EMRA with 751 wind projects to obtain a 78180.2 MW power plant license [46]. This capacity was equal to 64.5% of global installed wind power capacity in 2008, and it was almost two times greater than Turkey's installed capacity. According to Şahin [40], the major driving force of these booming applications is REPA. The regional distribution of the applications, number of turbines, average turbine powers, estimated production, project periods, and capacity factors are shown in Table 3.

**Fig. 1.** Turkey installed electrical power capacity and generation (1970–2008).

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