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Technoeconomic analysis of electricity generation from wind energy in Kutahya, Turkey

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ABSTRACT

Conventional energy usage has various environmental effects that cause global warming. Renewable energy sources are thus more favorable because they have nearly zero emission. Wind energy, among the various renewable sources, finds increasing usage, concurrent with developing technology. In addition, wind is an infinite energy source. In this study, the electricity-generation ability of Kutahya has been investigated. With this aim, wind data, from the measurement station located on Bunelek Hill, Kutahya, have been collected for a period of 36 months (July 2001–June 2004). From the collected data, the electricity generated has been calculated for different types of wind turbines. The calculations have been based on the electricity requirement of the main campus of the Dumlupinar University. Finally, the economic evaluation has been analyzed using life-cycle cost analysis. For the analysis of the economical aspects, the social and CO_2 costs have also been taken into account.

1. Introduction

According to the estimation of the International Energy Agency, by the year 2030, the global energy demand will increase at a rate of 1.6%, and approximately 65% of this increase will be expended by the developing countries. In 2007, the global oil consumption increased at a rate of 1.1%, this increase being approximately 3.1% and 4.5% for the consumption of natural gas and coal, respectively [1]. By the end of 2006, the installed power capacity was recorded as 4300 GW, and only 207 GW of this capacity (excluding large hydropower plants) belonged to renewables [2]. As inferred from these numbers, the demand on fossil fuels showed an increasing tendency, causing gradual increases in greenhouse-gas emissions.

Of the total emissions of greenhouse gases, which constitute the primary parameter for global warming, 85% can be attributed to the energy sector [3,4]. CO_2 emissions reached 27,136 million tonnes (Mt) in the year 2005, from the level of 15,661 Mt in 1973. Of the total quantity in 1973, the CO_2 emissions produced in the Organization for Economic Co-operation and Development (OECD) countries was 65.9%. This value decreased to 47.6% in 2005, but the reason for this decrease was not the reduction in emission; it resulted from the increase of the share of developing countries such as Turkey in this emission [5]. In Table 1, the changes in the greenhouse-gas emission in Turkey are shown on an annual basis. According to this table, the CO_2 emission was 273.70 Mt in 2006, whereas it was 139.59 Mt in 1990. The total greenhouse-gas emissions increased at a rate of 95% between 1990 and 2006 [6].

In literature, the wind-energy potential has been determined in several studies. Akpinar and Akpinar [7] have calculated the wind-energy potential for Maden-Elazıg using Weibull density functions. This study is based on the theoretical power generation and does not include a realistic wind turbine. Rehman et al. [8] presented the methodology for the calculation of unit cost of electricity in Saudi Arabia. The authors developed wind-duration curves and used them to calculate the electricity generation for different types of wind turbines, with sizes such as 600, 1300, and 2500 kW. Rehman and Ahmad [9], in their study, have calculated the energy output for wind machines of different sizes ranging from 150 to 2500 kW. In this study, a case study has been conducted, in which electricity generation from wind for meeting the needs of a university campus has been calculated. Wind turbines with different sizes have been taken into consideration, and the optimum case has been determined from the economical point of view. In the economic analysis, the socioeconomic aspects have also been taken into account.

2. Turkey's wind energy potential and utilization

Turkey has significant wind-energy potential because of its geographical characteristics, such as its shoreline and mountain-

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Nomenclature

a	Regression constant
A	Area swept by the rotor, m^2
A_F	Availability factor
c	Scale parameter of Weibull distribution, m/s
C_F	Capacity factor
E	Wind energy, Wh
E_c	Electricity need, Wh
E_{TA}	Actual energy derived from a wind turbine, Wh
E_{TR}	Nominal energy achieved from an ideal turbine, Wh
E_{TW}	Energy achieved from an ideal turbine, Wh
$f(V)$	Probability density function of wind speed
$F(V)$	Cumulative distribution function of wind speed
g	Inflation rate
i	Interest rate
i^*	Adapted interest rate
k	Shape parameter of Weibull distribution
L	Lifetime, year
m	Air mass flow rate, kg/s
m_b	Unit electricity purchase price, US$/MWh
m_{inv}	Unit investment cost, US$/kW
$m_{O\&M}$	Unit operating and maintenance cost, US$/MWh
m_s	Unit electricity sale price, US$/MWh
$m_{s,c}$	unit social cost for coal based electricity generation, USCent/kWh
$m_{s,w}$	unit social cost for wind-based electricity generation, USCent/kWh
m_{CO_2}	Unit cost of greenhouse gas, US$/MWh
M_b	Electricity price bought from the grid, million $
M_{inv}	Investment cost, million $
$M_{O\&M}$	Operating and maintenance cost, million $
M_{plant}	Plant cost, million $
M^*_{plant}	Plant cost including social and greenhouse gas costs, million $
M_s	Electricity price sold to grid, million $
$M_{salvage}$	Salvage cost, million $
n	Number of constants
N	Number of observations
$P(V)$	Power, W
P_R	Nominal power generation, W
P_T	Actual power achieved from the turbine, W
R^2	Correlation coefficient
T	Time period
V	Wind speed, m/s
$\overline{V}$	Mean wind speed, m/s
V_0	Cutout Wind speed, m/s
V_1	Cut-in wind speed, m/s
V_R	Wind speed at which nominal power generation is obtained, m/s
x_i	ith predicted data
y_i	ith experimental data

Greek letters

χ^2	Chi-square
$\Gamma(\ldots)$	Gamma function of $(\ldots)$
η	Turbine efficiency (%)
ρ	Air density, kg/m^3
σ	Standard deviation

Abbreviations

EWEA	European Wind Energy Agency
OECD	Organization for economic co-operation and development
PWF	Present worth factor
PDF	Probability density function
RMSE	Root mean square error

valley structures [10]. Dundar et al. [11], in their wind atlas, have noted that Turkey's wind-energy potential is approximately 88 GW. Ogualata [12] has evaluated Turkey's wind-energy potential in terms of the technical aspects and determined an available technical potential of 83 GW for Turkey. The actual information is included in the wind atlas (Fig. 1) prepared by the General Directorate of Electrical Power Resources Survey and Development Administration of Turkey (EIE) using the data obtained from the Turkish State Meteorological Service (DMI) and neighbour countries in 2006 [13]. According to this atlas, the sea fronts of the Agean, Marmara, Mediterranean, and Black Seas, and some places of the Southeast Anatolian belt have a high wind potential, with an average speed of 4.5–10 m/s. In this atlas, it is also observed that the wind speed in Kutahya is in the range of 5–5.5 m/s in the common and 6.5–7 m/s in the partial areas.

In Turkey, the first wind-based power plant started operation in the Izmir-Cesme-Germiyan region in February 1998 with an installed capacity of 1.5 MW. By the year 2008, the total installed capacity recorded was 333.35 MW, as seen in Table 2 [14–18].

3. Materials and methods

In this study, a wind measurement station was installed, and the data for 36 months from July 2001 to June 2004 were collected. These data were later evaluated by considering the Weibull and Rayleigh distributions, and the available electricity, which was generated from the wind energy to meet the needs of the Dumlupinar University, was determined for the several types of wind turbines present in the market.

3.1. Materials

The suitable location for the measurement station was determined as Bunelek Hill, considering the wind and solar measurements in the region [19]. Bunelek Hill, with an altitude of 1094 m, is located in the campus area of the Dumlupinar University (29°54′4.04″ longitude and 39°29′6.34″ latitude). In Fig. 2, the measurement setup and location are shown.

The wind measurements are frequently carried out for periods in the range of 10–60 min; therefore, it can be configured to many standard software types that evaluate the wind data. In this study, the CallAlog 02 software, which collects the signals from the

Table 1
Greenhouse-gas emissions in Turkey (million tonnes CO_2 equivalent) [6].

	1990	1995	2000	2001	2002	2003	2004	2005	2006
CO_2	139.59	171.85	223.81	207.38	216.43	230.99	241.88	256.43	273.70
CH_4	29.21	42.54	49.27	48.70	46.87	47.76	46.29	49.32	50.33
N_20	1.26	6.33	5.74	4.84	5.41	5.25	5.49	3.43	4.59
F Gases[a]	0.00	0.00	1.14	1.18	1.90	2.29	2.93	3.24	3.13
Total	170.06	220.72	279.96	262.10	270.61	286.29	296.59	312.42	331.75

[a] F gases as known; Chloroflourocarbons, Hydroflourocarbons, Perfluorocarbons, etc.