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SELECTION OF A SUITABLE WIND POWER PLANT WITH ECONOMICAL ANALYSIS FOR AMASRA CITY, TURKEY

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Abstract

Today, wind energy is a popular energy source because it is an alternative to fossil sources. However, various analyzes must be done to use wind energy efficiently. In this study, the wind energy potential of the city of Amasra in Turkey was analyzed. Data from the General Directorate of Turkish Meteorology for the years of 2012-2013 were taken. The data had been recorded for a height of 10 m by the Directorate. In the analyses, annual average wind speed of the city was found as 5.77 m/sec. In order to calculate the annual wind energy generation and capacity factor of the city, a 600-kW turbine belonging to Nordex Company and 900 kW and 2300 kW turbines belonging to Enercon Company were used. Thus, investment feasibility with 3 different turbines was analyzed. In the economic analysis, payback and net present value methods were used. In conclusion, it became clear that the use of 2300 kW turbine in the region would be more profitable.

Key words: *Wind energy, Wind turbines, Capacity factor, Cost analysis*

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1. Introduction

The energy demand is increasing in parallel with the increasing population, social and economic development and improved living standards in Turkey. The total installed power of Turkey's electricity is about 78 GW in March 2017. The hydraulic energy has the largest share (about 7.15 GW with 36%) in electric consumption. The natural gas (2%8), coal (22%), wind (7.5%), solar (1.1%) and the other renewable sources constitute the remaining part of energy consumption [1]. Most of energy demand is supplied from foreign countries, this leads to important concerns in the matter. Therefore, Turkey's energy policy aims to increase the share of renewable energy in the total energy, to improve energy efficiency, to increase the diversity of energy sources.

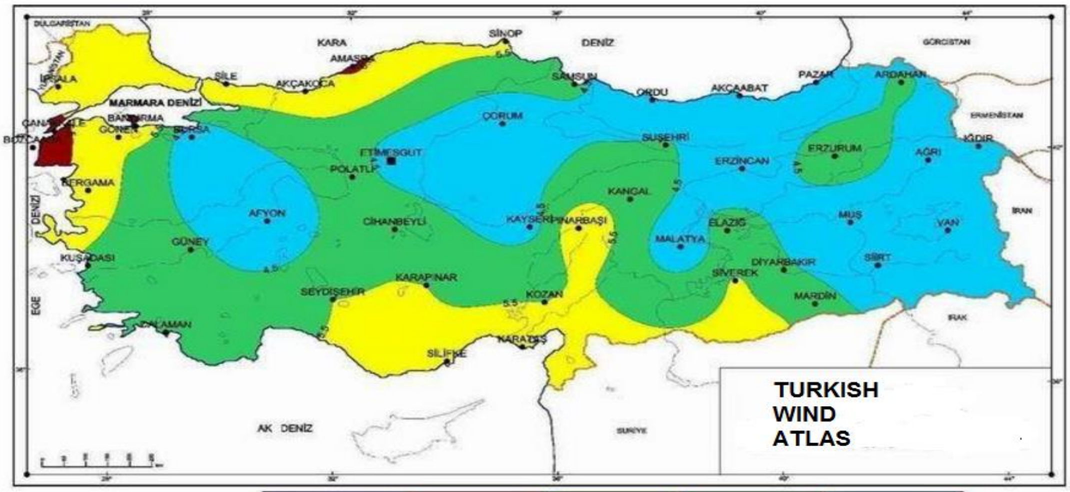
Our country has high potential in terms of renewable energy sources such as wind, solar and geothermal. Turkey is ranked 23rd within 111 countries for sustainable energy because of its geographical position and high potential [2]. It is expected that the share of these sources in electricity generation will increase over 30% until 2023 [3]. The theoretical wind potential of Turkey is about 48000 MW. 38000 MW of this potential is on terrestrial regions, the rest of it is above sea. The total wind installed power is 5,789.39 MW and the number of active power plant is 167. So a very small part of the potential is used. For this reason, wind energy investments are increasingly popular with government incentive and purchase guarantee [4]. These was generated 15,669.548 kWh electricity generation in 2016. Soma wind power plant in Manisa, Dinar wind power plant in Afyonkarahisar and Geycek wind power plant in Kırşehir are between the highest installed wind powered power plants [5].

Although wind energy investments are expensive, their costs have declined in recent years. Hence, many analyses should be carried out like sector legal, technical, financial, and environmental evaluations. Especially, technical and financial evaluation are important for researches and there are various examples in the literature. Ucar and Balo presented a work on statistical analysis of wind energy potential based on the Weibull and Rayleigh distribution for two different regions- Ankara and Polatlı, Turkey [6]. Ojosu worked wind energy potential for power generation in Nigeria, 15 years-monthly average wind speed data were used for six sites with using Weibull distribution [7]. Akdağ and Güler presented an overview of wind energy development in the world and then reviewed related situations in Turkey. Then, wind electricity generation cost analyses were performed at 14 locations in Turkey [8]. Lunney and others worked evolution of the technical and economic viability of deploying high altitude wind power as a resource in Northern Ireland [9]. Arıkan and Çam worked wind energy potential of Elmadağ region in Turkey with using Weibull distribution with two parameters. Maximum likelihood, energy trend factor method and moment methods were used in this distribution [10]. Kostekci, Arıkan and Çam prepared a program by using Profilab-Expert 4.0 software and it was designed as a program that the users can easily make the technical-financial data entrance and take out the calculations results as tables and graphics by a visual screen [11]. Arıkan, Akkaş and Çam worked wind energy potential of Elmadağ region and economic analysis of wind investment in the region was been studied [12].

In this paper, we aim to do technical and economic analysis of the regions where the wind energy plant can be installed in our country. For this reason, we chose Amasra region which has high wind speed according to Fig.1 but no wind power plant as application area. The wind power potential assessment was carried out for Amasra which has believed to have high potential. Firstly, annual average wind speed was calculated with using the data of wind speed that is measured hourly between 2012-1013. Then, the amount of energy generation and capacity factor was calculated with using 3-different wind turbines which have nominal powers 600, 900, 2300 kW respectively. Finally, economic analysis was done to make which one is the most suitable for the region. This study was carried out under the Tübitak-1001 code project titled ''A Web-based Software for Decision Support System in Wind and Solar Power Systems'' [13].

2. The Investigation of Region and Wind Data

The region of Amasra (41º 44ˈ 24ˈˈN and 32º 22ˈ 48ˈˈE) is a province of Bartın which is located in the west black sea of Turkey [14]. According to Turkey wind map (as shown in Fig. 1), the wind speed of this region is between 6.5-7.0 m/sec [15]. Unfortunately, there is no wind power plant in there. It is remarkable situation.



U (m/s)	> 7.5	6.5 – 7.5	5.5 –6.5	4.5 – 5.5	< 4.5
P (W / m^2)	> 500	300 - 500	200 - 300	100 - 200	< 100

Fig. 1. Turkey wind map.

The wind data were taken from the General Directorate of Turkish Meteorology for the years of 2012-2013 [16]. The data had been recorded hourly for a height of 10 m by the Directorate. The weighted average method which is described in Equation 1 was used to calculate the monthly average wind speed [17]. The monthly wind speed data are shown in Fig. 2.

$$V_m = \left(\frac{1}{n} \sum_{i=1}^{n} V_i^3 \right)^{1/3} \quad (1)$$

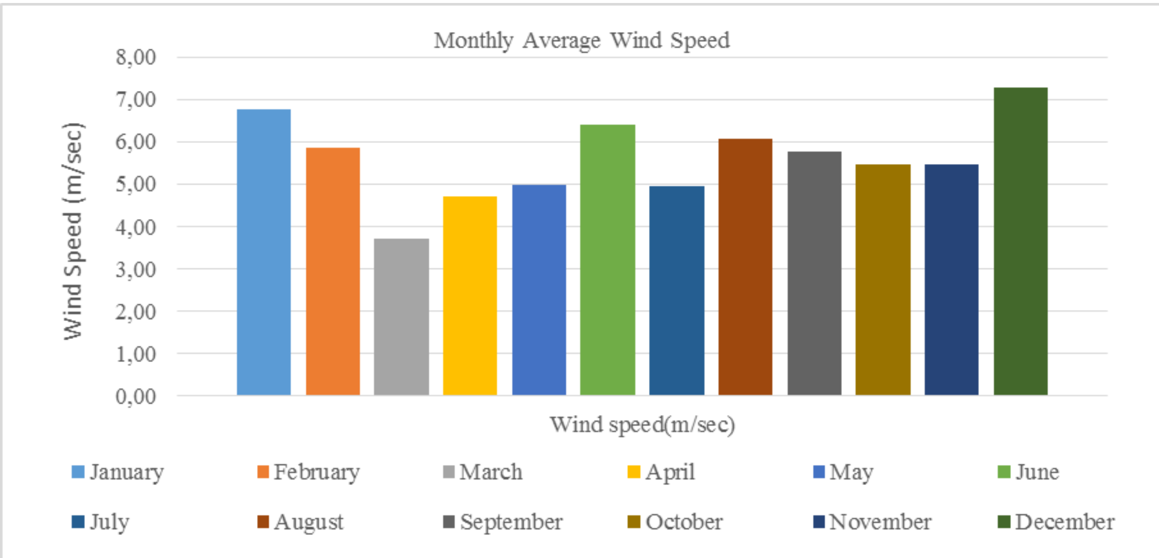


Fig. 2. The monthly average wind speed (m/sec, h=10m).

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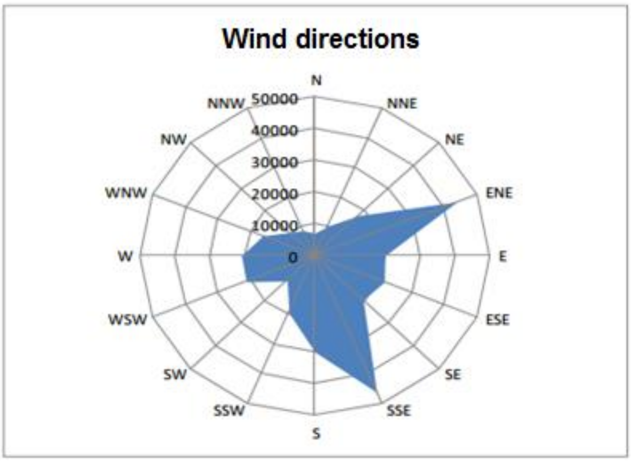

Fig. 3. Wind directions of the region.

The annual wind speed data was found to be about 5.77 m/sec and the highest wind speed was 7.28 m/sec in December and the lowest wind speed data was 3.708 m/sec in March. When it was considered that these values were calculated at 10 meters, it can be said that the region had the appropriate potential for investment in wind energy. According to records in the meteorological station, the dominant wind directions in the region were in South-South East, East-North East and South respectively. These are shown in Fig. 3.

3. The Evaluation of Wind Power

Table 1. Technical characteristics of wind turbines

Wind Turbine	Nominal Power (kW)	Hub Height (m)
Nordex N-43	600	40/50/60/78
Enercon-44	900	45/55/65
Enercon-70	2300	57/64/85/98/113

Wind turbines convert kinetic energy of the wind into mechanical energy and electrical energy respectively. Today, wind turbines are produced with different nominal powers. In this study, three different wind turbines that have been rated power 600, 900 and 2300 kW were used to evaluation of wind power for the region. Their necessary technical characteristics of these turbines are shown in Table 1 and power curves of the turbines are shown in Fig. 4 [18-19].

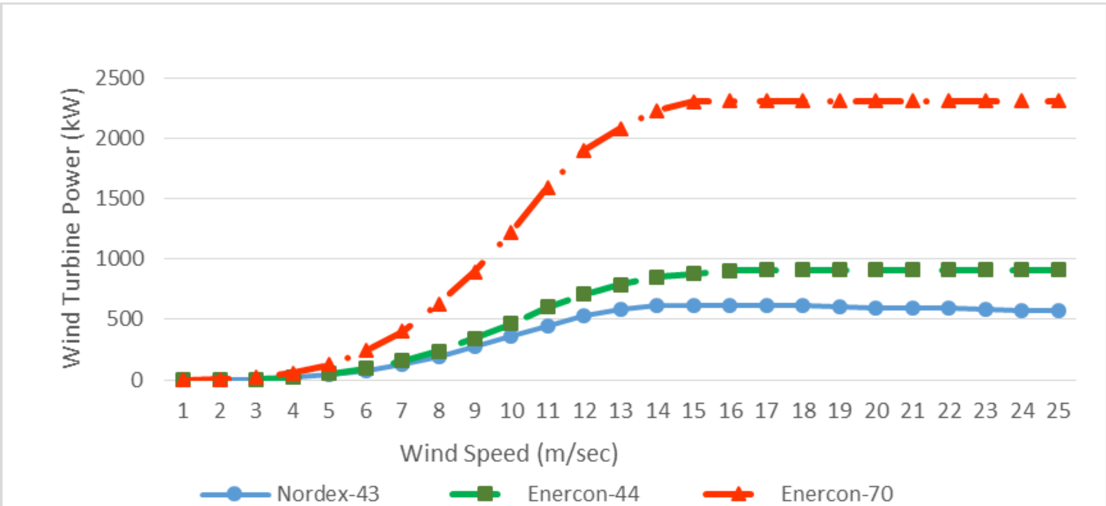

Fig. 4 Power curve of turbines.

In the analysis, 40, 45 and 57 meters were used for Nordex-43, Enercon-44 and Enercon-70 turbines respectively and these values are the most frequently used values today. According to these values, mean wind speed data in the measurement height was converted to the new values with using Hellman Equation that expresses the relation between height and wind speed and this is given in Equation 2:

$$\left(\frac{v}{v_0}\right) = \left(\frac{H}{H_0}\right)^{\propto} \tag{2}$$

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where Ho is the measurement height, H is height of wind speed to be changed, Vo is wind speed at Ho height. V is the wind speed at the H height and α is roughness coefficient which varies with region (0.1-0.4). According to regional characteristics, this value was taken as 0.15, that is, the area with long grass [20].

In order to calculate the amount of energy generated from the turbines, it is necessary to calculate the frequency of wind speed. The frequency of wind speed can be found with using Equation 3. The blowing time (Bt) of wind speed data during a year can be calculated with using Equation 4:

$$f_R(v) = \frac{\pi v}{2v_m^2} \exp\left[-\frac{\pi}{4}\left(\frac{v}{v_m}\right)^2\right] \quad (3)$$

$$B\_t=f\_R\ (v)*8760 \quad (4)$$

where Vm is average wind speed [16]. The frequency of wind speed data according to hub heights of three different turbines is shown in Fig 5.

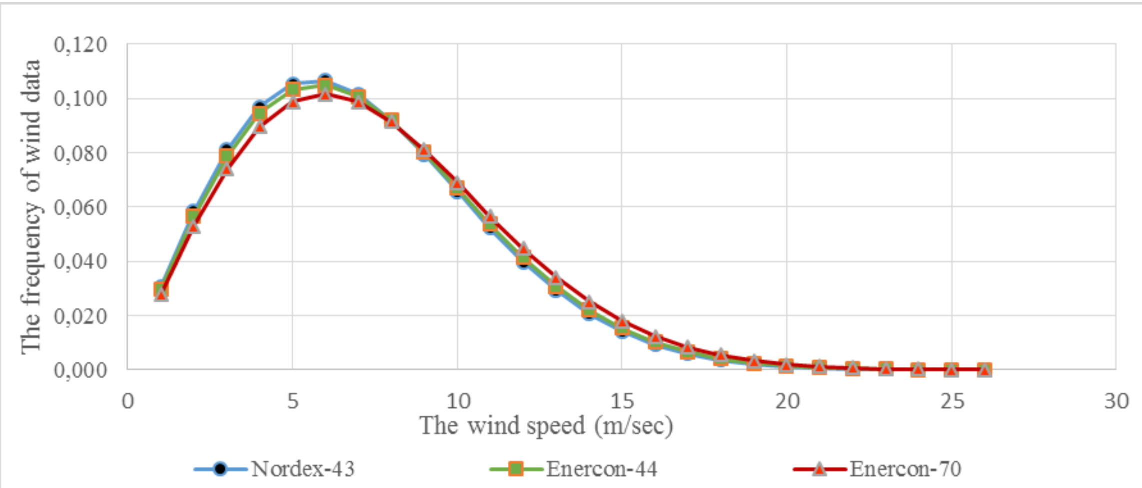

Fig. 5. The frequency of wind.

The amount of energy generated from turbine is found by multiplying blowing time with power value that corresponds to the wind speed at power curve. Then, these values are summed by using the Equation 5[21],

$$E_T = \sum_{i=1}^{25} B_i * P_{turbine,i} \quad (5)$$

where i is the values of power curve. According to the Equation 5, the amount of generated energy (kWh) at specific wind speed is shown in Fig. 6.

The capacity factor that indicates the performance of wind turbine can be found with using Equation 6:

$$CF = \frac{\text{The amount of generated energy}}{P_R * 8760} \quad (6)$$

Table 2. Recalculated wind speed, amount of energy and capacity factor

Wind Turbine	Wind Speed at Hub Height (m/sec)	The Amount of Energy (MWh)	Capacity Factor (%)
N-43	7.11 (h=40)	1647.84	31.35
E-44	7.23 (h=45)	2244.4	28.47
E-70	7.49 (h=57)	6310.2	31.32

where PR is nominal power of wind turbine. The capacity factor is generally between 0.25 and 0.40 [17]. As the value of the capacity factor increased, it may be considered that the region is convenient for the energy

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generation. According to Equations 5 and 6, wind speed at hub height, the amount of generated energy and capacity factor were calculated for three wind turbines. These results can be seen from Table 2.

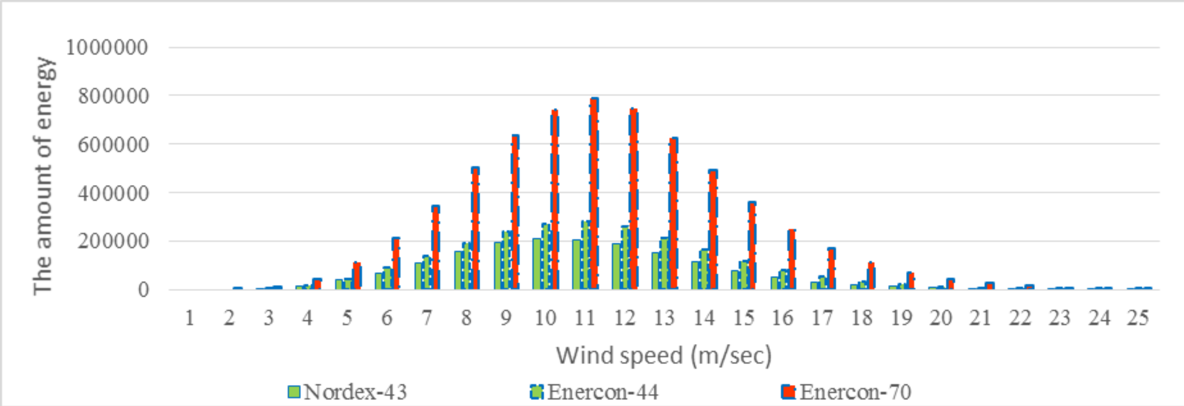

Fig. 6. The amount of generated energy at specific wind speed.

4. Economic Analysis with Various Methods

Economic analysis that is one of the most important issues in any investment, is the most serious and challenging part for wind energy investors because of variability and high cost of the wind. The economic analysis process begins after analysis of data and energy generation. If the economic analysis results are calculated as profitable, the investment can be applied.

Table 3. The cost of wind energy systems.

	Nordex-43	Enercon-44	Enercon-70
Turbine Cost (₺)	2.190.000,0	3.650.000,0	8.050.000,0
Const.- install. (₺)	600.000,0	1.000.000,0	2.300.000,0
Project and consultation (₺)	60.000,0	100.000,0	230.000,0
Maintenance (₺)	60.000,0	100.000,0	230.000,0
Other (₺)	90.000,0	150.000,0	345.000,0
Total cost (₺)	3.000,000,0	5.000.000,0	11.500.000,0

In wind energy investment, wind turbine has the largest share in total cost. The construction and installation cost, project and consultation cost and maintenance cost consist remaining of total cost. The cost of wind turbine varies according to the nominal power. While determining the costs of wind turbines, the market research was done. The cost of wind energy systems which used in this study are given in Table 3.

4.1. Payback Period

This method is calculated by counting the number of the years it will take to recover the cash invested in a project. For example, an investor invests 10.000 $ and the cash saving from investment is expected to be 2000 $ per years. In this case, the payback period is five years. In this method, interest rate is 0% [17].

4.2. Net Present Value

This method is the difference between the present value of cash inflows and the present value of cash outflows. It is used in capital budgeting to analyse the profitability of a projected investment. Net present value can be found with Equation 7:

$$Pv = \sum_{t=0}^{h} At(1+i)^{-t} \qquad (7)$$

where Pv is the present value of the investment, A is the cash savings, t is the time, h is the investment time and i is the interest rate [17].

In this paper, economic analysis was carried out according to the following: 1 kWh electricity will be sold to the market at the 7.5 cents. The economic life of the investment is 20 years and interest rate is

8%. The dollar is traded as 3.65 (₺) on 23.03.2017. 30% of the investment cost is met by equity. According to these item, the results of economic analysis are given in Table 4.

Table 4. The results of economic analysis.

	Nordex-43	Enercon-44	Enercon-70
Payback period (i=0)	5	6	6
Payback period (i=8%)	8	8	7
Profit (₺)	20.246.790, 0	16.389.194, 0	68.504.202, 0

5. Conclusions

In this paper, the wind energy potential of Amasra region was analysed. For this purpose, a program was designed and supported in the "1001" project named "A Web-based Software for Decision Support System in Wind and Solar Power Systems" supported by Tübitak. Feasibility studies of wind, solar and hybrid energy systems can be done in the program designed in Matlab. In this study, only the Wind Energy System was analyzed. For the city, the annual wind speed for recorded data (h=10 meters) was found as 5.77 m/sec. After determining the potential of the city is suitable for investment, the amount of generated energy and capacity factor were calculated with using three different turbines their nominal power ranging from 600 kW to 2300 kW. According to the results, as the hub height increased, the wind speed and energy amount increased while the capacity factor did not increase. Moreover, in the study, economic analysis was also carried out using the payback period and the net present value method. According to the analyses made, the most suitable wind turbine for the region was proposed as the Enercon-70.

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