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Research Article

Analysis of Wind Data, Calculation of Energy Yield Potential, and Micrositing Application with WAsP

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The parameters required for building a wind power plant have been calculated using the fuzzy logic method by means of Wind Atlas Analysis and Application Program (WAsP) in this study. Overall objectives of the program include analysis of raw data, evaluation of wind and climate, construction of a wind atlas, and estimation of wind power potential. With the analysis performed in the application, the average wind velocity, average power density, energy potential from micrositing, capacity factor, unit cost price, and period of redemption have been calculated, which are needed by the project developer during the decision-making stage and intended to be used as the input unit in the fuzzy logic-based system designed. It is aimed at processing the parameters calculated by the designed fuzzy logic-based decision-making system at the rule base and generating a compatibility factor that will allow for making the final decision in building wind power plants.

1. Introduction

Various methods are being used for the determination of wind power potentials. One of the most important of these is WAsP (Wind Atlas Analysis and Application Program), which is made in the Denmark Riso National Laboratory and used to generate the wind atlas of the European continent (EWA) [1].

WAsP is being used for the determination of regional wind atlas statistics and energy yield potential by using the wind speed and direction information as well as the obstacles around the wind observation station, land surface roughness, and land topographical characteristics.

Fuzzy logic is a multiple-logic system that is developed against the binary-logic system and assigns membership grades to variables used in everyday life and determines the proportions at which events occur. Everything is right or wrong in two-valued logic. In fuzzy logic, everything, including truth, is only a matter of degree.

Wind is formed by heating and cooling different surfaces at different speeds on the earth from the sunrise until sunset. Kinetic energy of the air in motion is called as wind power. Since the humans are being concerned with the environment, the interest in utilisation of renewable power is increasing. Wind power among the renewable energy is being used widely [2]. Due to the fact that Turkey is a country with three sides surrounded by sea, it is in a very important position in terms of wind power potential. The calculated wind power potential of Turkey is around 88000 MW, and a great majority of this potential is located in Aegean, South Mediterranean, and Marmara regions [3].

In this study, analysis of wind measurement data obtained at 10 m height and 10-minute interval has been carried out with WAsP, and the wind speed, average power density, form parameter, scale parameter, dominant wind direction, and the Hellmann coefficient have been calculated in accordance with the Weibull distribution. While planning to install the wind turbines to the plant, the required regional wind atlas has been generated. Meteorological data from weather stations outside urban areas are sometimes used, where wind measurements are not available [4, 5].

In this micrositing study, a wind plant with 12 MW in the region has been planned to be established, and the use of a 2 MW V80-type turbine belonging to the VESTAS company available in the WAsP library has been planned for this establishment. Annual energy generation values of the turbines have been calculated as a result of the micrositing study performed in this way.

The capacity factor, which is the most important parameter during the definition of wind energy potential of one region, is identified as the proportion of energy generated by a wind power plant to the energy that has to be generated at nominal power [6]. With the calculations made, the capacity factor of the region and the annual generation value of the plant in kWh and the amortization period have been found.

2. WAsP Model

WAsP has been used during the analysis of wind data and energy generation potential. WAsP is a computer program developed in the Denmark Riso National Meteorology Laboratory which is performing analysis with the assumption that wind speed data comply with the Weibull distribution with 2 parameters.

2.1. Basic Information Used by WAsP. WAsP carries out some analyses by assessing four various basic data in its submodels. Hourly wind data, roughness data of the region, obstacle data in the near vicinity, and topographical data of the region are the basic information used by the program. For the wind farm location, it is also necessary to enter data such as the power curve, thrust coefficient curve, turbine hub height, and turbine rotor diameter in the program [7].

2.2. General Purposes of WAsP. It is possible to group them under four main titles of general purpose of WAsP so as to analyze the raw data, generate the wind atlas, and assess the wind climate and wind energy potential.

WAsP is performing the time-series analysis by adjusting the raw meteorological data including wind direction and speed data. Weibull parameters are being calculated with the performed analysis [7]. Wind speed histograms may be converted into wind atlas series. Histograms may be generated by the data analysis method or may be directly made with standard climatologic tables [7].

It is possible to carry out wind climate assessment in any region by using the wind atlas generated by WAsP or by using the data series or data from other reliable sources. Wind climate is being assessed with Weibull parameters and regional distribution of the wind [7]. WAsP also calculates the total energy to be obtained from wind. Program may also provide annual average energy to be obtained from a wind turbine and an energy curve of the subject turbine.

3. Submodels Used at the Application

WAsP uses some submodels while determining the wind potential. These submodels are obstacle screening, orographic, and roughness exchange models.

3.1. Roughness Exchange Model. The logarithmic wind profile is only applicable where the surface is homogeneous. Pressure changes as per the average surface tensions and surface conditions of surface wind speed until where the gradient force is equal to the fraction force. For the roughness length values belonging to two different surfaces, the following equation may be written for the increase of the limit layer height values:

$$\frac{h}{z_0}\left(\ln\frac{h}{z_0}-1\right) = \text{constant}\,\frac{x}{z_0},$$
$$z_0 = \max\left(z_{01}, z_{02}\right), \qquad (1)$$

where h is the boundary layer height value, x is the surface condition distance, and z_0, z_{01}, and z_{02} are the roughness coefficients (constant: 0.9).

The wind profile is deformed below the level h, and the constant value is 0.9. If we accept the neutral wind profile at height h, the difference in the surface friction speed may be modelled empirically, and this can be shown as follows:

$$\frac{U_{*_2}}{U_{*_1}} = \frac{\ln\left(h/z_{01}\right)}{\ln\left(h/z_{02}\right)}, \qquad (2)$$

where U_{*_2} is the friction speed at the considered point and U_{*_1} is the surface friction speed.

In this equation, friction speed at the point taken into consideration is the surface friction speed.

3.2. Shelter Model. The wind profile is deformed at close distances and at lower parts of the flow of wind coming from the turbine. For this, these objects creating an obstacle effect should be separately studied. Generally, there should be a distance of two objects' height on the upper wind part of the obstacle and five objects' height on the lower wind part of the obstacle. Since the meteorological stations are being impacted by the obstacles in the vicinity, this model corrects the fault caused by the obstacle on the data.

The results of wind tunnel studies on simple two-dimensional objects have the following equation:

$$\frac{\Delta_u}{u} = 9.8\left(\frac{z_a}{h}\right)^{0.14}\frac{x}{h}\left(1-P\right)\eta\exp\left(-0.67\eta^{1.5}\right), \qquad (3)$$

where P is the open area/total area, h is the height of the obstacle, z_a is the height of the anemometer, and x is the under wind region distance.

In this equation, η is expressed as follows:

$$\eta = \frac{z_a}{h}\left(\frac{0.32}{\ln\left(h/z_0\right)}\,\frac{x}{h}\right)^{-0.47}, \qquad (4)$$

where z_a is the height of the anemometer, h is the height of the obstacle, x is the under wind region distance, and z_0 is the roughness coefficient.

If there are more than one object, they have been assessed with sectors formed with angles of 30°.

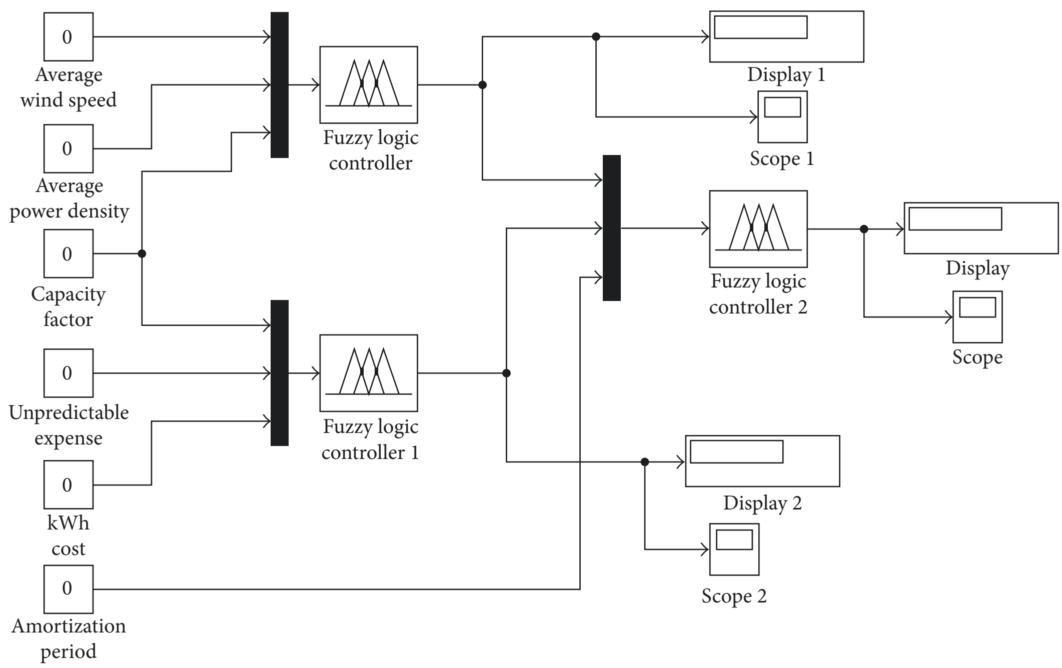

Figure 1: Matlab/Simulink model of the designed system.

3.3. Orographic Model. In this model, on the measured wind, data faults of local impacts caused by the topographical structure are being corrected [8]. For the remedial of these impacts, a horizontal scale of 20–30 km shall be taken into account. Primarily, potential current deformations caused by the land topography shall be calculated. The speed perturbation is

$$\overline{u} = \Delta X, \tag{5}$$

where X is the potential and $\overline{u}$ is the three-dimensional speed deformation vector.

For a given radius R, for the potential flow at polar coordinates, the following equation shall be written:

$$X_j = K_{nj} J_n\left(C_j^n \frac{r}{R}\right) \exp(\ln \Phi) \exp\left(-C_j^n \frac{z}{R}\right), \tag{6}$$

where K_{nj} is the random coefficient, J_n, n is the level Bessel function, r is the radius, Φ is the azimuth, z is the height, and $C_j^n = j_n'$ s i, which is zero.

For the specific problems, coefficients shall be calculated from surface kinematical limit conditions:

$$J_n\left(C_j^n \frac{r}{R}\right), \tag{7}$$

where J_n, n is the level Bessel function; $C_j^n = j_n'$ s i, which is zero; and r is the radius.

Functions are as Fourier–Bessel series. K_{nj} coefficients may be defined independently. The model forms the gray data on the contour lines on the topographical map. Sensitivity of the model depends on the density of contours.

4. Wind Atlas Analysis and Program Application

In order to make the wind power more competitive against other power generation methods, bigger wind turbines are being designed and established on the clusters especially on the overseas regions called as the wind plant [9].

To be able to establish a wind power plant, both meteorological and financial parameters are needed. This also shows that one wind plant establishment actually requires to think and use more than one discipline at the same time. For this reason, during the analysis, WAsP has been used which has been already used for the preparation of the European Wind Atlas and Turkish Wind Atlas.

This study is aimed at finding out the average wind speed, average power density, energy yield potential obtained as a result of micrositing, capacity factor, amortization period, and unit cost price required for the establishment of the wind power plant as a result of the performed analysis. These obtained values are being planned to be used to generate a compliance factor for the establishment of the wind power plant by scaling in the rule basis prepared in the fuzzy logic method. In Figure 1, Matlab/Simulink design of the inspection system is seen, which is planned to be used as an input unit of obtained parameters.

4.1. Geographical Status of Arapgir Province Selected for This Study. Mathematical location is between 39°05′ N latitude and 38°30′ E longitude. We can examine the province in three parts in terms of surface features:

(i) Mountainous areas in the western and northern parts of the province

(ii) The section east of the district center

(iii) Medium-height and slightly rugged Arapgir rubble forming the southern part [10, 11].

As a result of continental climate, most part of the areas of the province are coated with steppe. This means that forest

Figure 2: Satellite view of Arapgir Province.

Table 1: Monthly average wind speed measured at 10 m height.

Month	Average wind speed at 10 m height (m/s)
January	1.6
February	2
March	2.6
April	2.8
May	3.1
June	3.8
July	4.1
August	3.6
September	2.9
October	1.9
November	2.5
December	2.2

Table 2: Average wind severity and average power density of the region.

	Calculated values
Average wind severity (m/s)	2.75
Average power density (W/m^2)	53

land is very small. Existing forest lands are not in good quality. These are mostly very small oak forests. Satellite view taken from Google Earth of Arapgir Province is shown in Figure 2. In this study, topographical obstacles have been taken into consideration [10, 11].

4.2. Assessment of Wind Measurement Data. In this study, wind speed and wind direction data belonging to 10 m of the height taken from OMGI (Automatic Meteorological Observation Station) are being used between January 2014 and December 2015.

Monthly average of the measurements taken at 10 m of the height in the region is shown in Table 1. When the table is examined, the highest average wind speed is obtained as

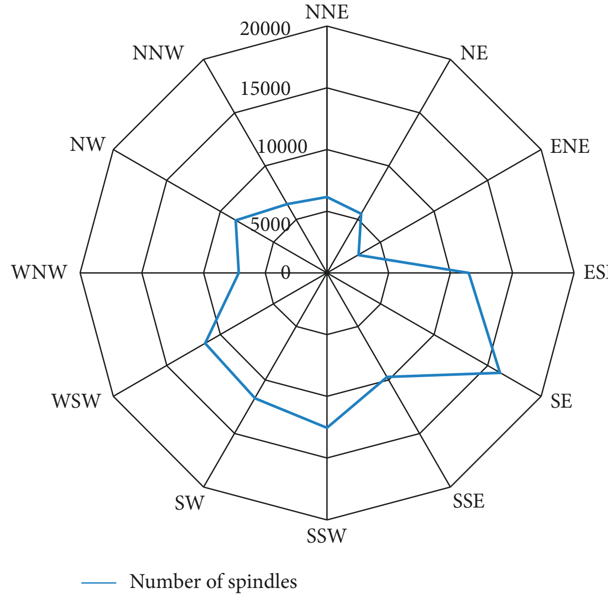

Figure 3: Wind rose belonging to Arapgir Province.

4.1 m/s in July and the lowest average wind speed is obtained as 1.6 m/s in January.

In Table 2, average wind severity and average power density values belonging to the region obtained as a result of the analysis made in WAsP are being shown.

Twelve sectors have been used in Figure 3 as a result of the calculations made in WAsP, and the dominant wind direction has been observed as SE at 120° sector.

Most frequently, the distribution used for the calculation of wind power potential is the Weibull distribution. This distribution has been found by the Swedish physicist Waloddi Weibull. This distribution is considerably flexible and simple and also complies with the real data. In other words, since the Weibull distribution is in compliance with wind speed data, it is generally accepted in wind power analysis [12]. The Weibull distribution function is as follows [13]:

$$hw(V) = \frac{k}{c} X \left(\frac{V}{c}\right)^{k-1} X e^{\left[-(V/c)^k\right]}, \quad (8)$$

where k is the figure parameter (parameter showing the wind speed distribution form), c is the scale parameter (relative cumulative frequency for wind speed), and $hw(V)$ is the possibility density function of wind speed.

In order to find Weibull parameters (k and c), wind data of the land are required. Analytical and experimental equations used to find Weibull parameters are written as follows [14]:

$$k = \left(\frac{a_u}{U}\right)^{-1.086},$$
$$c = UX\left(0.568 + \frac{0.433}{k}\right)^{-1/k}, \quad (9)$$

where a_u is the standard deviation and U is the average speed.

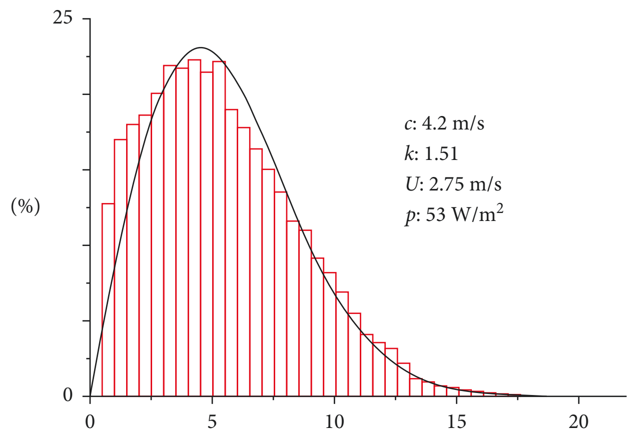

Figure 4: The Weibull distribution belonging to Arapgir Province.

After examining the wind data in detail and performing the above-given calculations, according to the Weibull distribution in Figure 4, the average wind speed is found as 2.75 m/s, the average power density is found as 53 W/m^2, the figure parameter is found as 1.51, and the scale parameter is found as 4.2 m/s.

Wind speed measurements are generally being made at different heights than at the tower heights of wind turbines. For this reason, these measured wind speeds are being extrapolated to turbine tower heights by using the formula known as 1/7 wind power law [14]. As known, by using the Hellmann coefficient, estimated wind speed values at a requested height may be calculated from the wind speed values measured at a specific height. Wind speed data measured at a specific height may be transferred to other heights by using the following equation:

$$U = U_{\text{rref}} \left(\frac{h}{h_{\text{ref}}} \right)^{\mu}, \tag{10}$$

where U is the wind speed at the height to be calculated, U_{rref} is the wind speed at the height where the measurement results are known, h is the height of the point to be calculated from the surface, h_{ref} is the height of the point where the measurement results are known from the surface, and μ is the Hellmann coefficient.

In this study, wind speed values obtained at 10 m in Arapgir with ten minutes of interval have been moved to 80 m which is the turbine hub height with the calculated Hellmann coefficient.

The Hellmann coefficient can be taken as 1/7 in the most general case. However, the other ways can be used to determine it more accurately [15].

Calculation in terms of roughness length:

$$\mu = 0.096 \log_{10} z_0 + 0.016 \left(\log_{10} z_0 \right)^2 + 0.24. \tag{11}$$

Calculation in terms of speed and height:

$$\mu = \frac{0.37 - 0.088 \ln \left(U_{\text{rref}} \right)}{1 - 0.088 \ln \left(U_{\text{ref}} / 10 \right)}. \tag{12}$$

Calculation of roughness length and speed:

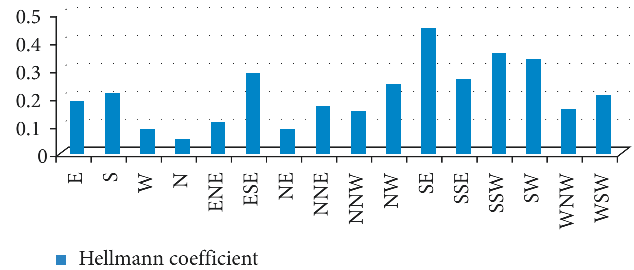

Figure 5: Change of the Hellmann coefficient as per wind direction.

$$\mu = k_0 \left[1 - 0.55 \log \left(U_{\text{ref}} \right) \right]. \tag{13}$$

Equation (13) is proposed by the NASA for the Hellmann coefficient. By using the existing data, the change of the Hellmann coefficient as per the direction has been examined in addition to the analysis made according to the wind flow direction. The average of the Hellmann coefficient has been calculated as 0.21 with the analysis of 61,293 data in total for all sectors. As shown in Figure 5, the highest Hellmann coefficient has been found in SE which is the dominant wind direction.

4.3. Generation of the Wind Atlas. In this study, wind atlas statistics have been prepared belonging to the plant area with the help of WAsP software by using the frequency distribution table obtained from wind speed and direction data belonging to 10 m of the height, obstacles in near vicinity, roughness data, and digitized map with a scale of 1/25.000 representing the region topography.

Data imported into WAsP are being analyzed, and the average wind severity map of the region in Figure 6 and power density map of the area in Figure 7 have been visually obtained. The wind turbine-locating process shall be carried out on the points where the wind severity is high by using the average wind speed calculated in the region.

While planning the installation of wind turbines in the site, wind atlas is being used. By using WAsP and wind atlas statistics, locations where the power generation amount will be high on the digital map may be defined from colour distribution.

4.4. Micrositing and Turbine Selection. In this study, it has been planned to establish a wind plant of 12 MW in the area, and for this establishment, it has been planned to use 2 MW of the V80-type turbine belonging to the VESTAS company within the WAsP library. In order to minimize the interference of turbines with each other, the micrositing study has been performed.

During this micrositing study, design has been made so as to keep the track area losses of the turbines on each other in the minimum level. Furthermore, while designing the optimum turbine placement so as to obtain a maximum yield, wind turbines have been placed on the dominant wind direction not only taking into consideration the generation amount but also the operability limits of the

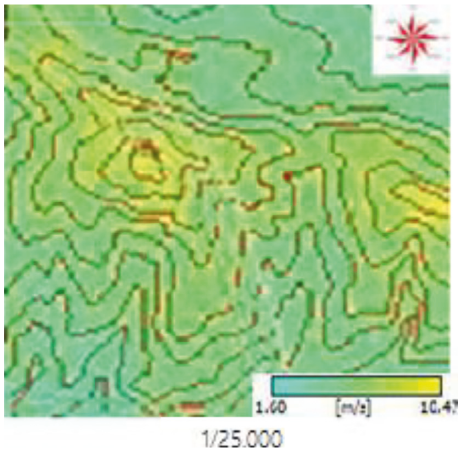

Figure 6: Average wind severity map calculated in the area.

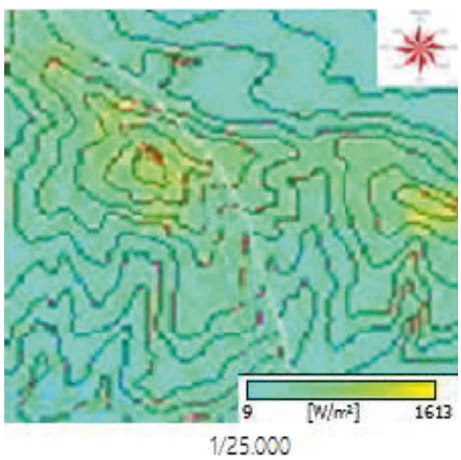

Figure 7: Power density map of the area.

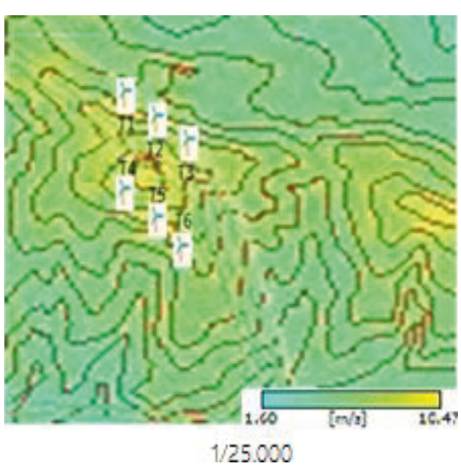

Figure 8: Micrositing process of turbines.

turbines in technical terms. In Figure 8, the micrositing study has been shown where six 2 MW VESTAS V80 wind turbines are used.

Following this micrositing study with 12 MW installed power where 6 VESTAS V80 wind turbines are

Table 3: Annual generation values of 6 V80 wind turbines.

Parameter	Total	Min	Max
Net annual generation (GWh)	38.352	5.713	7.082
Gross annual generation (GWh)	41.316	6.034	7.897
Wake (track) loss (%)	7.173	—	—

Table 4: Annual generation and loss values of 6 V80 wind turbines.

Turbine number	Hub height (m)	Net annual generation (GWh)	Wake (track) loss
Turbine 1	80	6.789	7.09
Turbine 2	80	6.145	6.18
Turbine 3	80	5.824	9.62
Turbine 4	80	7.082	5.34
Turbine 5	80	6.799	8.29
Turbine 6	80	5.713	9.79

used, electricity generation of annual gross 4.1316 GWh and net 38.352 GWh has been calculated. As a result of the interference of turbines with each other, it has been understood that there will be a 7.17% loss. Annual generation values have been shown in Table 3 in the micrositing study where 6 VESTAS V80 wind turbines are used.

In Table 4, generation and loss values for each turbine are given for the micrositing study where 6 V80 wind turbines have been used.

As can be shown in Table 4, when annual net power generation values are being considered, the maximum generation amount 7.082 GWh was at turbine number 4 and the minimum generation amount 5.713 GWh was at turbine 6. During the micrositing study, it has been calculated that the maximum wake loss 9.79% was at turbine 6 and the minimum wake loss 5.34% was at turbine number 4.

4.5. Capacity Factor of the Area. The capacity factor, which is an important parameter and has to be known both by the generators and consumers, is the division of energy generated in a specific time frame to the maximum energy that can be generated at that specific time frame [16, 17].

In this study, the capacity factor has been calculated for the turbine used during micrositing and turbine selection studies and generated micrositings:

$$C_F = \frac{E_T}{T * P_R}, \tag{14}$$

where C_F is the capacity factor, E_T is the generated total power, P_R is the nominal power value, and T is the time.

In the micrositing study, the annual calculated generation amount for six 2 MW V80 wind turbines, maximum amount that can be generated from turbines, and capacity factor are shown in Table 5.

In case of operation under nominal power of six 2 MW turbines during 8760 hours in one year, they may generate maximum $8760 \times 12 = 105.120$ GWh power in one year. As

Table 5: Capacity factor of the area.

Turbine model	Turbine number	Installed power	Annual calculated production amount (GWh)	Nominal power to be produced (GWh)	Capacity factor (%)
VESTAS V80	6	12	38.352	105.12	36.48

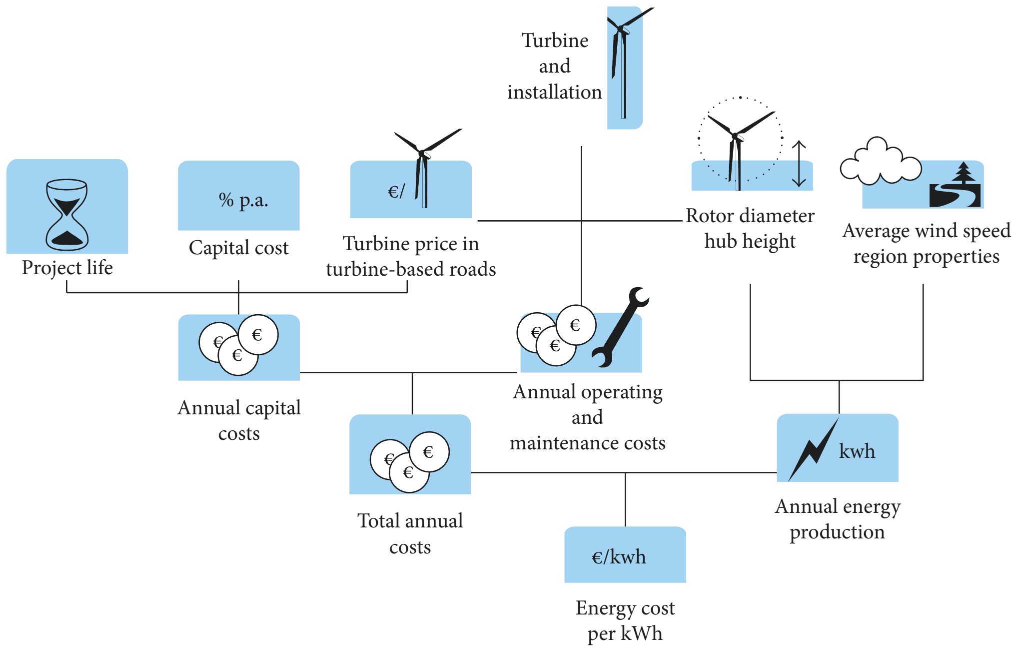

Figure 9: Cost structure per kWh for wind power projects.

a result of the calculations made in WAsP, it has been determined that the wind power generated by the wind power plant formed by six 2 MW turbines shall generate 38.352 GWh power in one year, and the capacity factor shall be realized as 38.352/105.120 = 0.3648, in other words 36.48%. The capacity factor which is calculated at and above 25% for the wind turbines deemed appropriate for the investment in Turkey [18].

4.6. Economical Analysis of the Data. One of the most important studies that have to be carried out while establishing a wind turbine to a region is the calculation of kWh power cost. Generally, the cost of one wind power project per kWh is found by proportioning the annual total cost to the annual power generation amount.

The annual power generation amount changes depending on the parameters such as the hub height of turbine, rotor diameter, average wind severity of the area, and annual cost may be correlated with turbine price, turbine foundations, inner site road construction costs, investment costs, and project lifetime. In Figure 9, the cost structure is shown per kWh for wind power projects [19].

In this study, within the first establishment, turbine cost, network connection, foundation and establishment costs, electricity installation, and road construction and control

Table 6: Turbine establishment cost [20–26].

Establishment parameters	Cost (€)
Turbine and installation	9.000.000
Project preparation costs (permission and licences)	650.000
Land rental cost	100.000
Network connections (cable, transformer, and communication)	1.800.000
Foundation and installation (foundation, road, and site)	1.200.000
Finance (consultancy, insurance, and bank)	450.000
Total	13.200.000

Table 7: Annual income-expense table [20–26].

	€/year
Electricity sales income	2.109.360
Emission sales income	82.608
Annual operational income (€/year)	**2.191.168**
Rental amount	100.000
Maintenance-repair insurance	130.000
Labour	30.000
Annual licence cost	1.000
General administrative costs	5.000
Annual operational expenses (€/year)	**266.000**
Annual operational margin (€/year)	**1.925.168**

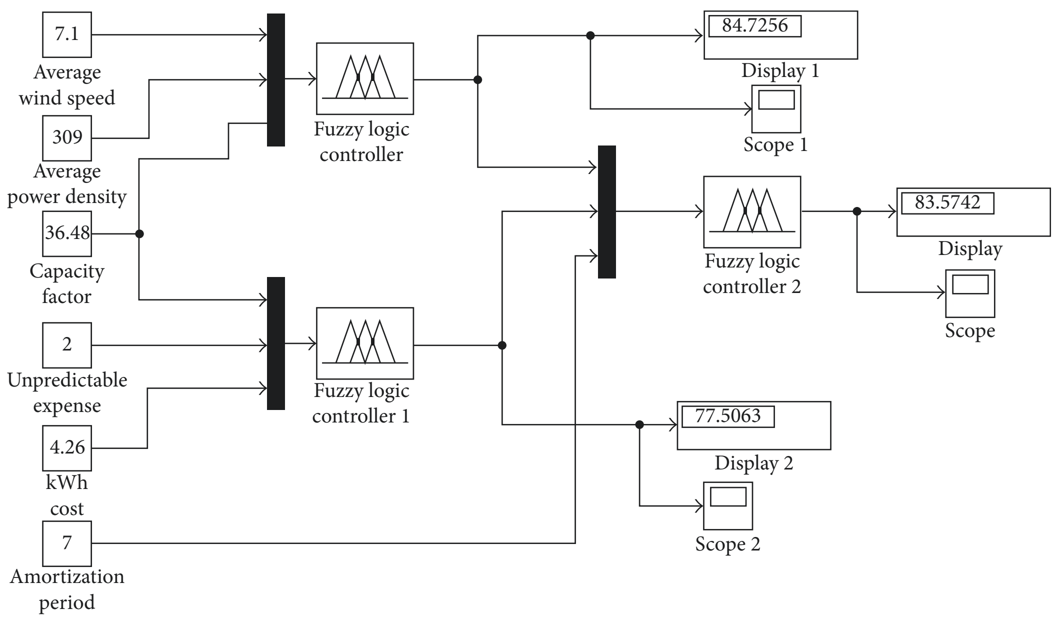

Figure 10: Display of the result values generated by the fuzzy-based decision-making system designed according to the input values calculated by the WAsP.

systems have been considered as mentioned in the report of the European Wind Power Union, and land rental, consultancy, maintenance and repair, and yearly licence costs have been included into the analysis as permanently paid costs within years (Table 6).

Annual 38.352 GWh power generation has been calculated for the wind power plant formed with six 2 MW VESTAS V80 wind turbines. In this case, annual income has been calculated as 2.109.360 € with 5.5 €cent/kWh electricity sales price. Emission sales income for the 38.352 GWh power generation has been calculated as 82.608 € annually. As a result of the calculations made, annual income and expenses as well as the annual margin are shown in Table 7.

In this study, operational expenses, maintenance, repair, insurance, rental, and licence costs, and some values changing as per year such as interest have been reflected as average values in the income-expense table by taking into consideration the project lifetime. In case of selling the electricity at 5.5 €cent/kWh at the wind power plant formed by 6 VESTAS V80 wind turbines, it is seen that the cash flow will pass to the positive state at 7 years and the project returns at year 7.

In this study, cost per kWh for the capacity factor obtained from selected turbines has been calculated. By using the capacity factor as 36.48% calculated for the VESTAS V80 turbine used in the established system, the annual generation amount of the plant in kWh has been found.

In order to calculate the unit cost of electricity power obtained from wind turbines, it is necessary to know the regaining factor of investment. The regaining factor of capital (C) is calculated with the following formula:

$$C = \frac{i(1+i)^n}{(1+i)^n - 1}, \tag{15}$$

where i is the interest rate (%) and n is the turbine lifetime (years).

Generation cost is as follows:

$$\ddot{U} = \frac{C_T (C + I)}{E}, \tag{16}$$

where Ü is the generation cost (€/kWh), I is the service, maintenance, and insurance (operational) expenses (%), C_T is the total establishment cost of the wind turbine (€), and E is the annual generated power amount (kWh).

The power to be generated by the wind turbine (kWh/year) in the region (E) where the establishment of the wind turbine is planned is defined with the following formula:

$$E = \eta_{\text{kay}} \cdot C_p \cdot \frac{1}{2} \cdot \rho_h \cdot S \cdot \sum_{i=1}^{k} \Delta t_i \cdot U_r^3, \tag{17}$$

where Δt_i is the time interval (h), U is the wind speed (m/s), ρ_h is the air density (kg/m^3), r is the radius, S is the scanned area by the wind turbine (m^2), C_p is the power coefficient, η_{kay} is the fraction losses at bearings (e.g., 0.996), losses at the gear box (e.g., 0.972), and losses at the electricity generator (e.g., 0.94) and general total coefficient (may be considered as approximately $\eta_{\text{kay}} = 0.9$ at calculations):

$$\begin{aligned} C &= \frac{0.075(1+0.075)^{25}}{(1+0.075)^{25} - 1} = 0.08971, \\ \ddot{U} &= \frac{13.200.000\,(0.08971 + 0.02)}{33.955.200} = 0.0426 \text{ €/KWh} \\ &= 4.26 \text{ €c/KWh}. \end{aligned} \tag{18}$$

In the calculations made, unit cost values to be used as the input unit in the fuzzy logic system are found as 4.26 €c/kWh.

5. Conclusion

In this study, average wind speed and wind direction data of Arapgir province measured at 10 m height and 10-minute intervals and taken from OMGI (Automatic Meteorological Observation Station) were analyzed by WAsP software. In the analysis made, the average wind speed is found as 2.75 m/s, the average power density is found as 53 W/m^2, the figure parameter is found as 1.51, and the scale parameter is found as 4.2 m/s obtained at 10 m according to the Weibull distribution.

As a result of the calculations made in WAsP, 12 sectors have been used in the wind mill and dominant wind direction has been observed as SE at 120° sector. The change of the Hellmann coefficient as per the direction by using existing data in addition to the analysis made as per the wind blowing has been examined, and the average Hellmann coefficient has been calculated as 0.34.

As a result of this micrositing study with 12 MW installed power where 6 VESTAS V80 wind turbines are used, with the wind power plant to be established in the region, it has been calculated that annual gross 41.316 GWh and net 38.352 GWh electricity shall be generated. It has been understood that 7.17% loss shall occur as a result of the interference of wind turbines with each other.

In case six 2 MW turbines operate under nominal power during 8760 hours, a maximum of 105.120 GWh energy may be generated. As a result of the calculations made in WAsP, it has been determined that the wind power plant formed by six 2 MW turbines shall generate 38.352 GWh energy in one year, and the capacity factor shall be realized as 36.48%.

Annual generation values of the plant have been found as 4.26 €c/kWh by using 36.48% capacity factor calculated for the VESTAS V80 turbine used in the established system. The amortization period is calculated as 7 years. Unpredictable expenditure was selected as 2% of the initial installation cost. The height of the tower of the wind turbine was determined as 80 m. The wind speed at 80 m height was calculated as 7.1 m/s. The power density at the height of 80 m was calculated as 309. In Figure 10, the final relevance factor of running the system in the Matlab/Simulink model is 83.57.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors certify that there are no actual or potential conflicts of interest in relation to this article.

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