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RESEARCH ARTICLE

TRANSIENT SIMULATION OF WIND ENERGY PRODUCTION FOR ELECTRIC MARKET STABILITY

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Abstract

Today, energy sustainability, which is one of the most significant concerns in the energy industry, is of utmost importance. In this context, investments and interest in renewable energy sources are growing. As a nation with vast wind energy potential, Türkiye is at the forefront of expanding investments in this sector. This study highlights the significance of wind power plants in electricity market and the relevance of wind energy forecasts, as well as the significance of ensuring the imbalance in energy supply and enhancing electricity market stability. Parallel to this, the transient system simulation (TRNSYS) model was used to determine annual energy generation of a wind power plant in Izmir with a capacity of 18 MW, and the obtained results were compared with the real-time generation data from EPİAŞ transparency platform. The model had two approaches, one based on standard data from the second generation of a typical meteorological year (Plan (1)), and the other on actual field data collected in the plant (Plan (2)).

The numerical findings indicate that the annual energy generation values for Plan (1) and Plan (2) are 24,018.1 MWh and 61,699.1 MWh, respectively. Additionally, the real-time production yields a total of 60,176.2 MWh. In a meantime, Plan (1) generated a positive imbalance value of 45,726.7 MWh, whereas Plan (2) has 6,651.3 MWh over the course of one year. In contrast, the annual sum of negative imbalance values was determined to be 9,475.9 MWh for Plan (1) and 8,368.6 MWh for Plan (2). The analysis yielded annual figures of 2,379,110.4 TL and 351,318.3 TL for positive and negative imbalance penalties, respectively, for Plan (1). For Plan (2), the corresponding amounts were 310,875.9 TL and 337,186.4 TL. Consequently, the total penalty payments for Plan (1) amounted to 2,730,428.8 TL, while for Plan (2) it reached 648,062.3 TL.

Keywords

Energy sustainability,
Wind power,
Electricity market stability,
Numerical study

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1. INTRODUCTION

Due to its geographical location and climatic conditions, Türkiye possesses a substantial wind energy potential. According to the Electricity Affairs Survey Administration, there is 131,756.0 MW of onshore wind potential at 50.0 m altitude across the nation. Based on the wind energy potential atlas provided by Republic of Türkiye Ministry of Energy and Natural Resources, the average wind speed in Türkiye is 5.5 m/s in the northwest and 7.5 m/s in the southeast at a height of 50.0 meters. Wind speeds range from 7.0 to 8.5 m/s along the coasts and from 6.5 to 7.0 m/s in the interior areas between the western and northeastern parts of the country, with the greatest potential in the west [1]. This provides a good opportunity for the construction of wind farms and the production of energy. According to the Turkish Wind Energy Association, the country's wind power facilities have a combined installed capacity of 11.1 GWm as of 2021, allowing them to produce 30.9 TWh of electricity, or 9.8% of total electricity production [2].

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Presently, all wind energy plants in Türkiye are located onshore, and studies of the nation's wind energy potential have focused on onshore installations. Gönül et al. [1] conducted a comprehensive analysis of the existing status of wind energy in Türkiye in 2019 relative to 2023 goals. At the conclusion of the study, a number of recommendations were made, such as providing improved credit options, forming partnerships with well-established companies, fixing the feed-in tariff for an extended period, and considering mini-YEKAs (renewable energy resource areas). Arslan et al. [3] examined wind energy potential over Türkiye using wind speed data from 1980 to 2013 based on 335 stations. According to the results by Weibull distribution, Çatalca has the greatest wind energy potential in Türkiye, not only because it has the highest average wind speed with a rate of 7.1 m/s but also because it has vast rural districts for the possible installation of wind farms. Kılıç [4] analyzed the wind energy potential in Türkiye's Burdur province using weather data collected from four distinct nearby stations. The 2009-2016 data was used to train an artificial neural network methodology, which was then used to predict 2030 data for use in a geographic information system. The applied stages revealed that the regions of Burdur, Çeltikci, Ağlasun, and Bucak have greater potential. Kaytez [5] assessed strategies for expanding Türkiye's wind power capacity using a hybrid fuzzy analytic network process analysis. Priority strategies with the highest scores include "development of domestic and efficient technologies" and "sustaining support mechanisms in investments and technical research" among others. Ma and Mei [6] used a hybrid attention-based deep learning approach to predict wind power, and actual data collected from the Yalova farm in Türkiye indicates that the developed model achieves substantially superior prediction accuracy. On the basis of measured wind data, Yaniktepe et al. [7], Akpınar [8], and Bilir et al. [9] statistically investigated the wind energy potential in Türkiye's Osmaniye province, northeastern coast, and Ankara province, respectively. The average wind energy potentials were determined to be 24.5 W/m^2 at 10.0 meters, 64.3 W/m^2 at 10.0 meters, and 40.5 W/m^2 at 20.0 meters.

Numerous investigations on determining wind energy production have been conducted worldwide as well. Examining the most recent ones, Qian and Ishihara [10] proposed a novel probabilistic power curve model for wind farms, and the derived results were compared with the measured one over complex terrain in the northern region of Japan using a variety of statistical indicators. With consideration of wake effects, the proposed model reduces the weighted mean absolute percentage error in mean value from 18.1% to 7.2% and that in standard deviation from 100.0% to 15.6%. Kim and Kim [11] examined the association between atmospheric stability and wind energy production. According to a case study of a 30 MW onshore wind farm in South Korea, the effects of the atmospheric regimes (unstable, neutral, and stable) result in a 5.0–7.0 percent variation in production. Hassanian et al. [12] evaluated the energy production of wind farm in Iceland using 5 years of empirical data and the Jensen-Katic model in deep learning training for wake loss. According to their findings, the optimal capacity factor is 26.1%, and the turbines produce an average of less than 30.0% of their rated power. Cuevas-Figueroa et al. [13] analyzed the precision of weather prediction models and the influence of neighboring wind farms on the energy output of a wind farm operating in complex terrain in Mexico. According to the Rapid Update Cycle and Pleim-Xu models, the measured energy production of the considered wind farm was between 2.0 and 5.3 percent. In a meantime, the ripples of nearby wind farms extend over 12 kilometers downwind, with 5 MW turbines having a larger wake footprint. These farm wakes resulted in a 1.3–1.7% annual energy loss. Moradian et al. [14] estimated the wind resource's potential by calculating the annual energy production based on future climate change scenarios and global circulation models in Ireland. At the conclusion of the investigation, wind speed was predicted to decrease by 7.0% (1981-2010) – 2.0% (2021-2050). Paraschiv et al. [15] assessed the wind energy potential in the south-east of Romania using the Weibull distribution function. At the conclusion of the study, the annual values of the shape and scale parameters were determined to be 1.1 and 5.6 m/s, respectively, indicating that the chosen location is adequate with a monthly average power density of 113.0 and 768.0 W/m^2 at a height of 80.0 meters. Daoudi et al. [16] also used the Weibull distribution function to determine the wind energy potential in Morocco using 24 years of wind data at 10.0 m height. Based on the results obtained, the shape and scale factors are 1.5-1.8 and 2.8-3.6 m/s, respectively, yielding a power density of 16.0-40.5 W/m^2.

In addition to the feasibility analyses provided below, wind energy studies conducted recently have placed a greater emphasis on the energy market both in Türkiye and throughout the globe. Ağbulut [17] proposed a variance sensitive exponential smoothing model to determine wind energy in short term ranges of 30 min, 1-hour, and 3-hour for intraday market in İzmir Province. On the basis of statistical assessment criteria (mean absolute deviation, the mean squared error, the mean absolute percentage error and the root mean square error), the suggested model provides competitive and satisfactory outcomes compared to the regularly used stochastic models (Trigg & Leach, Pantazopoulos & Pappis and optimized simple exponential smoothing) in the literature. Dinler [18] utilized a method of deep learning to reduce electricity market balancing costs. Regarding four tested wind power plants in Türkiye, the proposed methodology allowed for a reduction in balancing cost from 6.2 to 11.2%. Sirin and Yilmaz [19] analyzed Turkish balancing market with the impact of wind and run-of-river hydro energy technologies based on quantile regression. The researchers found that Türkiye's current market structure needed to be revised to account for the geographical and temporal peculiarities of the creation of these technologies. The real value of energy production may be reflected in the balancing market if settlement durations were shorter and there was more than one market zone. Quint and Dahlke [20] examined the impact of wind energy production on the electricity market using Midcontinent Independent System Operator, the second largest competitive wholesale electricity market in the United States. The results indicated that the wholesale price of electricity decreases by $0.01 to $0.03 per MWh for every 100 MWh of additional wind generation. Hu et al. [21] studied the impact of wind power on the intraday market price of electricity in Sweden. The results indicated that wind energy forecast errors have a substantial impact on prices in the country's central and southern regions, but not in the north, where wind energy capacity is low. Liu and Xu [22] evaluated integration of wind power in spot electricity markets in China and found that relaxing bidding regulations can allow wind power producers to develop more profitable bidding strategies and the rise in wind power capacity can decrease the market clearing price.

As evidenced by the aforementioned literature, the intermittent nature of wind energy production makes its prediction a difficult task. In the interim, the forecasted quantity of wind energy production influences intraday, day-ahead, and balancing prices on the energy market, which are of importance to producers, regulators, and policymakers. In this study, annual energy generation of a wind power plant in Izmir with a capacity of 18 MW was calculated with a series of TRNSYS simulations. During simulations, two methodologies were utilized: one based on standard data from the second generation of a typical meteorological year, and the other on actual field data collected at the plant. The obtained results were then compared to the real-time generation data from the EPİAŞ transparency platform. The economic equivalence of the simulated outcomes on the energy market has subsequently been determined using two distinct methodologies. The novelty of this study can be summarized as follows:

i. On the basis of two distinct climate data sets, the TRNSYS model, which is primarily employed in practical and energy systems, was evaluated.
ii. In one of the methods, direct measurements from the power plant were employed.
iii. Using a case study, the TRNSYS model's outcomes based on two distinct climate data sets were incorporated into the energy market price.

The structure of this paper is as follows. In section 2, a detailed overview of the Turkish electricity market, a developed numerical model for wind electricity production, and a developed case study in the energy market are provided. In section 3, the energy projections' outcomes are presented, discussed, and contrasted to actual data. In the interim, the incorporation into market prices for energy is presented and discussed. The paper concludes with a discussion of the conclusions in section 4.

2. METERIALS AND METHODS

2.1. An Overview of the Turkish Electricity Market

In the last 30 years, Türkiye's electricity consumption has risen by an average of 6.0% per year, which is about 1.5 times the average growth rate for the rest of the world. As 2019 draws to a close, annual electricity consumption in Türkiye will reach 300.0 TWh. [23]. Despite the fact that the country's renewable potential capacity along a year is quite high (130.0 TWh for wind, 140.0 TWh for hydro, and 380.0 TWh for solar), coal is still the largest source, accounting for 37.0%, followed by hydro, natural gas, and wind, with respective shares of 30.0%, 20.0%, and 7.5%. Since Türkiye must rely on imports for the vast majority of its primary energy needs, its energy strategy centers on ensuring the country's continued access to reliable energy while decreasing its reliance on foreign suppliers. Concurrently, in 2001, Türkiye passed the Energy Market Law, and in 2005, it implemented the Renewable Energy Support Mechanism, both of which are designed to improve the effectiveness of the energy sector by allocating its resources more effectively. These regulations included the liberalization of the market for private investment, the privatization of formerly government-owned electrical producing and distribution firms, and the launch of day-ahead, intra-day and balancing (real-time) electricity markets [23, 24].

In 2011, the day-ahead market (DAM) system was implemented and the Turkish Electricity Market was given a new sense of dynamism and vision, as well as the ethos of a competitive market. In this market, producers declare how much they wish to sell at what price for the next day, with a minimum volume of 0.1 MW for individual hours and blocks, and suppliers declare how much they wish to purchase at what price. Energy Exchange Istanbul (EXIST) combines the proposals for producers and suppliers to determine market clearing price (MCP) for the next day's delivery hour. All EXIST-accepted bids must trade at the derived spot price, regardless of initial price offers or location, and transmission constraints are not taken into account when determining the MCP. There is no requirement for participation in the DAM. Players who do not participate in the DAM can sell the electricity they produce through bilateral agreements and purchase the electricity they consume through bilateral agreements as well. Daily (advance period) and hourly (settlement period) market transactions are conducted in DAM. Each day consists of hourly time periods that begin at 00:00 and conclude the following day at 00:00. To alleviate market imbalances caused by inaccurate forecasts or utility disruptions, the intra-day market (IDM) was introduced in 2016. In contrast to DAM, IDM matches orders based on the offered price. Bids per minute are sorted by hourly price (up-regulation is at the top, down-regulation is at the bottom), and the system marginal price (SMP) is calculated hourly based on the offer volume and price. In balancing market (BM), Turkish Electricity Transmission Company (TEIAS) is the system operator instead of EXIST.

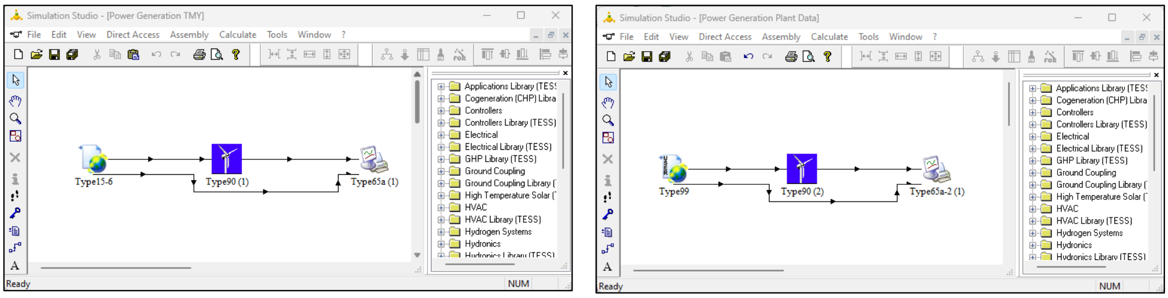
2.2. A Developed Numerical Model for Wind Electricity Production

In this research, an Izmir wind farm with a capacity of 18 MW was chosen. The primary rationale for this selection is that Izmir is the leading city for the installation of wind farms, and that the employed turbine manufacturer and turbine type are the most frequently used, among others. The wind farm is situated at 38.3°N and 26.3°E and is comprised of six 3 MW turbines with the characteristics listed in Table 1.

Table 1. The main characteristics of wind turbine

Property	Value	Unit
Rated power	3	MW
Rated speed	12	m/s
Cut-in wind speed	3	m/s
Cut-out wind speed	25	m/s
Rotor diameter	116.8	m
Swept area	10,715	m^2
Number of blades	3	-
Hub height	120	m

As shown in Figure 1, a TRNSYS-Type 90 mathematical model for a wind energy conversion system was constructed in the simulation studio based on the properties listed in Table 1. The model computes the output power of a wind energy conversion system using a power versus wind speed characteristic. This model also simulates the effects of air density changes and wind speed increases with altitude. The model's wind speed is derived from an external file that can be serviced by TRNSYS-Type 15-6 (standard format weather data reading and processing) or TRNSYS-Type 99 (user defined weather data reading and processing) models. On the other hand, the TRNSYS-Type 65a online plotter with file model can collect and analyze the model's power output.



a) b)

Figure 1. The developed TRNSYS models for wind energy conversion system based on **a)** standard data from the second generation of a typical meteorological year, **b)** actual field data collected at the plant.

The following describes the work performed to construct a numerical model for wind energy production using two distinct climate data sets (standard data from the second generation of a typical meteorological year and actual field data collected at the plant):

i. TRNSYS-Type 90 (1) and TRNSYS-Type 90 (2) parameters were defined as 5 m, 30 m, 120 m, 0.1, 3, and 31 for site elevation, data collected height, hub height, turbine power loss (from turbine output to transformer center), number of turbines, and logical unit of file containing power curve data, respectively.

ii. TRNSYS-Type 90 (1) and TRNSYS-Type 90 (2) external file was generated based on the employed wind turbine characteristics. Regarding this, the rotor center height, rotor diameter, sensor height for data pairs, power-law exponent, turbulence intensity, air density, rated power, rated speed, and number of pairs were specified as 120 meters, 116.8 meters, 120 meters, 0.3, 0.1, 1.225 kilograms per cubic meter, 3 megawatts, 12 meters per second, and 38, respectively.

iii. The external file "TR-Izmir-Cigli-Airp-172180.tm2" was selected as the TRNSYS-Type 15(6) external file.

iv. An external file for TRNSYS-Type 99 was created using actual field data collected at the plant and the power versus this data taking into account the wind turbine in use.

v. Using the wind velocity parameter, the outputs of TRNSYS-Type 15(6) and TRNSYS-Type 99 were connected to the inputs of TRNSYS-Type 90 (1) and TRNSYS-Type 90 (2), respectively.

vi. Using parameters for power output, turbine working hours, and power coefficient, the outputs of TRNSYS-Type 90 (1) and TRNSYS-Type 90 (2) were connected to the inputs of TRNSYS-Type 65a (1) and TRNSYS-Type 65a (2), respectively.

vii. Using wind velocity, the outputs of TRNSYS-Type 15(6) and TRNSYS-Type 99 were connected to the inputs of TRNSYS-Type 65a (1) and TRNSYS-Type 65a (2), respectively.

2.3. A Developed Case Study in Energy Market

The determination of imbalance penalties in the Turkish energy market relies on the values of market clearing price (MCP) and system marginal price (SMP). The observed disparity indicates a discrepancy between the actual energy production (E_{act}) and the intended quantities as per the plan (E_{plan}). When the level of production exceeds the predetermined plan, it is referred to as a positive imbalance. In such cases, a positive imbalance penalty (PIP) is imposed, which can be determined using the equation (1) given below.

$$PIP = \left(E_{act} - E_{plan}\right) \cdot [MCP - min(MCP, SMP) \cdot 0.97)] \quad (1)$$

In the event that production falls short of the intended target, it is referred to as a negative imbalance. The consequence for this inconsistency is referred to as the negative imbalance penalty (NIP), which may be determined using equation (2) in the following manner.

$$NIP = \left(E_{act} - E_{plan}\right) \cdot [(max(MCP, SMP) \cdot 1.03) - MCP] \quad (2)$$

The determination of the SMP in the aforementioned equations is contingent upon the indication of an energy deficit or surplus in the system's direction within the energy market. In the event of an energy deficit, the system considers all offers within the balancing power market, prioritizing those with the lowest load purchase bid prices. The price at which the net order volume is determined is referred to as the SMP. In the event that the system exhibits surplus energy, a comparable computation is initiated, commencing with the load shedding bid price that is the greatest.

The concept of MCP pertains to the established electricity price that arises from the equilibrium between supply and demand in day ahead power markets. The maintenance of equilibrium between production and consumption within the energy sector holds significant importance. Insufficient fulfillment of consumption demand results in the occurrence of shortages and disruptions in the provision of power. MCP is the price at which the most costly power plant in the system supplies energy, ensuring that the balance between generation and consumption is attained. The determination of this pricing in Türkiye is conducted by the utilization of the merit order approach. The objective of this approach is to efficiently incorporate manufacturing facilities that can effectively satisfy the consumption requirements inside the system. The merit order model is utilized to forecast the quantity of electrical energy for a given day, considering the hourly consumption demands, using a one-day advance estimation. Based on this assessment, the power plants responsible for meeting the hourly electricity demand are arranged and commissioned in ascending order of cost. The market clearing price is determined by the cost of the most recent power plant that satisfies the demand for electricity. Market players inform EPİAŞ with their demand projections for the subsequent day. The offers are assessed by EPİAŞ, and afterwards, the indeterminate MCP for the following day is announced. Subsequently, any objections, if present, are assessed and the ultimate decision about the MCP is made [25].

The values of the 1.03 and 0.97 coefficients utilized in the computation of the energy imbalance amount have been established in 01 May 2015. Furthermore, individuals who fail to disclose unfulfilled orders within a 4-hour timeframe, resulting in a modification of the SMP, are required to bear the financial burden associated with the resulting price discrepancy. The objective of this endeavor is to ensure the effective administration of the instruction reconciliation function and the SMF decision process.

3. RESULTS AND DISCUSSION

The present study involved the estimation of the yearly energy production of an 18 MW wind power facility located in Izmir through a sequence of TRNSYS simulations using one-hour data. In the course of the simulations, two distinct techniques were employed: one relied on standard wind data derived from the second generation of a representative meteorological year, while the other drew upon real-world wind data obtained on-site at the facility. In a meantime, the real-time generation data was gathered from the EPİAŞ transparency platform. Figure 2 depicts the wind data in a monthly format, whereas Figure 3 shows the simulated results for annual energy generation together with real-time production at the facility from the EPİAŞ transparency platform. Table 2 displays the outcomes of the economic assessment carried out in this study, with respect to the quantities of energy produced.

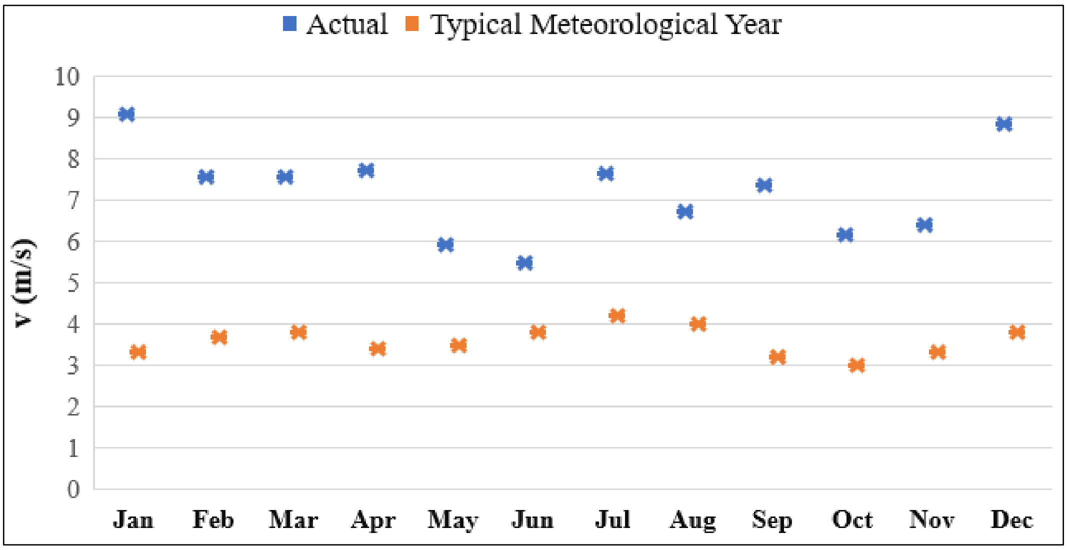


Figure 2. The wind velocity amounts on the side based on plant readings and TRNSYS simulations.

The figure 2 illustrates that the collected wind velocity readings throughout the year exceeded the average values often observed in meteorological records. The observed velocity readings from the plant range from 5.48 m/s (in June) to 9.08 m/s (in January), with an average of 7.20 m/s over the course of a year. However, typical meteorological velocities vary between 2.99 m/s (in October) and 4.20 m/s (in July), with an annual average of 3.58 m/s. The variability observed in the actual wind data is significantly more than that often observed in meteorological wind data.

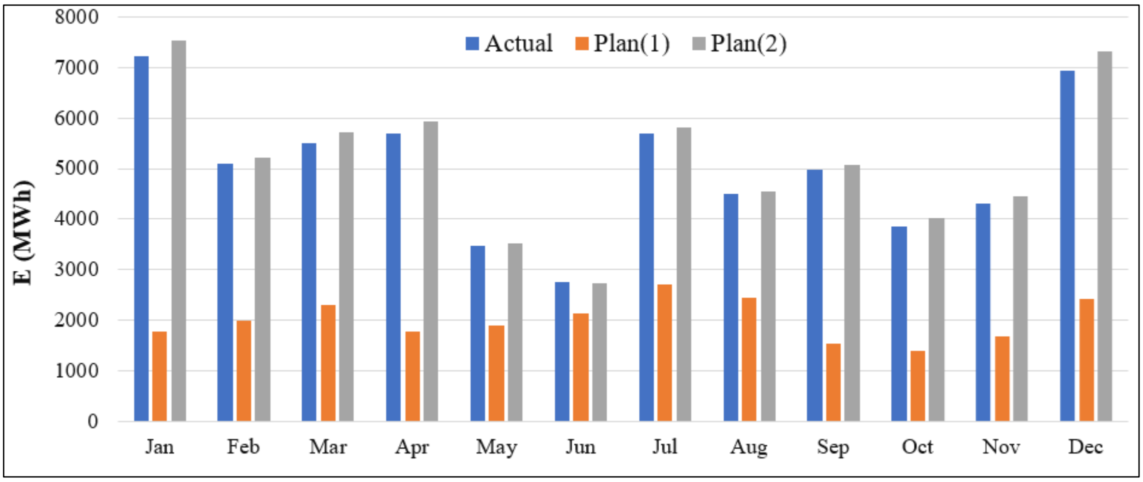


Figure 3. The energy generation amounts on the side based on EPİAŞ transparency platform and TRNSYS simulations.

According to Figure 3, it can be observed that the annual energy generation values for Plan (1) consistently exhibit their lowest values across all months, which was based on standard wind data derived from the second generation of a representative meteorological year. It is evident from Figure 2 that the recorded velocity readings exhibit the lowest values in this particular scenario. The minimum and maximum values were simulated on a monthly basis, with the minimum value of 1,391.9 MWh occurring in October and the maximum value of 2,697.8 MWh occurring in July. Meanwhile, it was determined that the annual energy production, derived from standard wind data, amounted to 24,018.1 MWh. In accordance with Plan (1), several researchers have studied electricity generation using the TRNSYS-Type 90 model for wind energy conversion systems with meteorological year data [26-30]. Bakić et al. [26] conducted a dynamic simulation of a PV/wind hybrid system in the city of Belgrade, Serbia, where the average annual wind speed is 3.54 m/s. The simulation included wind turbines with capacities of 1 kW, 3 kW, and 5 kW, all modeled at a hub height of 20 m. The total annual energy production for the aforementioned capacities was computed as 983 kWh, 1,840 kWh, and 3,930 kWh, respectively, at the end of the simulations. In a numerical study done by Żołądek et al. [27] assessed energy and economic performances of a PV/wind/wood gasifier with battery/hydrogen energy storage system for the city of Agkistro, Greece. The simulation findings indicate that the annual total energy generation from the 110-kW wind turbine is 151,000 kWh. Yesilyurt et al. [28] performed conventional exergy analysis on a hybrid energy generation system that includes a vanadium redox flow battery and an air source heat pump. The system was analyzed specifically for the city of Istanbul. The annual energy production of a 2.5-kW wind turbine was calculated to be 5,827.9 kWh, considering a yearly average wind velocity of 4.5 m/s. Anaune et al. [29] applied a study to determine the appropriate size for a PV/wind system in Rabat, Morocco. They used the second generation of a typical meteorological year for their analysis. The annual electricity production of a 1-kW wind turbine was simulated to be 1,404 kWh, based on the average wind speed of 4.14 m/s at a hub height of 10 m. Panayiotou et. al [30] did a numerical study to analyse the technical and economic performances of two stand-alone systems (PV and PV/wind) in two distinct locations (Nicosia, Cyprus and Nice, France). According to data, wind turbines with 1-5 kW and 2.4-kW capacities produce 2,077 kWh and 2,353 kWh respectively in the city of Nice, which as a more favorable wind profile. The energy output per unit of capacity varied between 920 1/h and 2,331.16 1/h as a result of the wind turbine type and the weather data. The study produced a value of 1,334.3 1/h, which indicates that the result is within the allowed range for this value.

On the contrary, Figure 3 demonstrates that Plan (2) consistently exhibits the highest levels of annual energy production throughout various months, namely January (7,527.0 MWh), February (5,206.9 MWh), March (5,720.8 MWh), April (5,928.2 MWh), May (3,523.4 MWh), July (5,810.1 MWh), August (4,539.5 MWh), September (5,067.4 MWh), October (4,028.3 MWh), and December (7,155.2 MWh), with the exception of June (2,728.4 MWh). In this particular case, the wind data utilized in the analysis was derived from actual wind measurements collected on-site at the plant. Simulated work based on Plan (2) was successfully found the real-time production amounts. While the cumulative energy generation over the course of a year was determined to be 61,699.1 MWh based on Plan (2), it was obtained to be 60,176.2 MWh for the actual readings.

Table 2 presents the economic implications, specifically the associated imbalance fines, resulting from the differences seen between the energy output estimated using the TRNSYS model and the real-time generation data obtained from the EPİAŞ transparency platform.

Table 2. Imbalance penalties based on production estimation for Plan (1) and Plan (2), respectively

Mounts	Positive Imbalance (MWh)	Negative Imbalance (MWh)	PIP (TL)	NIP (TL)
Jan	5,904.7/516.5	430.8/819.2	181,895.9/13,828.4	11,566.1/24,839.6
Feb	3,674.7/396.1	577.1/513.7	91,516.1/11,039.4	10,890.1/10,348.3
Mar	4,376.5/602.6	1,180.9/809.4	144,361.6/17,778.1	53,818.3/28,882.7
Apr	4,512.4/487.4	584.1/711.7	176,191.9/13,263.0	21,988.2/24,296.4
May	2,739.7/549.4	1,179.1/608.6	132,136.0/19,939.3	53,873.8/22,142.0
Jun	1,608.3/570.8	986.6/540.7	43,627.5/15,601.3	30,742.3/17,776.4
Jul	3,847.3/643.0	832.0/751.2	177,451.7/25,052.1	15,858.9/19,110.1
Aug	3,000.9/643.4	961.5/694.7	211,819.8/44,737.8	24,577.9/16,315.8
Sep	3,999.3/678.2	545.0/773.2	359,123.7/44,861.0	10,522.5/19,726.3
Oct	3,193.0/581.5	725.4/735.5	175,102.7/33,050.7	28,575.3/39,118.2
Nov	3,417.6/473.4	773.2/635.9	229,754.7/23,782.0	56,610.5/61,311.0
Dec	5,452.4/509.0	700.2/774.9	456,128.8/47,942.9	32,294.6/53,319.7

Table 2 illustrates a notable disparity in positive imbalances between Plan (1) and Plan (2), with Plan (1) exhibiting much higher levels. The positive imbalance for Plan (1) ranges from 1,608.3 MWh in June to 5,904.7 MWh in January, resulting in an annual total of 45,726.7 MWh. In contrast, Plan (2) exhibits a monthly positive imbalance range of 396.1 MWh in February to 678.2 MWh in September, with a yearly sum of 6,651.3 MWh. The data presented in Figure 3 clearly demonstrates that the observed energy production levels exceed the estimated energy generation based on Plan (1) by a substantial margin. In the case of Plan (2), the actual energy generation amounts and the anticipated energy production amounts exhibit a high degree of similarity. Accordingly, the PIP for Plan (1) demonstrates a fluctuation from 43,627.5 TL in June to 456,128.8 TL in December. The economic assessments were undertaken on an hourly basis, resulting in the highest PIP observed in December, despite the presence of a maximum positive imbalance in January. In contrast, the PIP values for Plan (2) were found to be much lower compared to the PIP quantities for Plan (1). The recorded amounts vary from 11,039.4 TL in February to 47,942.9 TL in December. In accordance with PIP for Plan (1), the highest cost was achieved during the month of December. The annual PIP amounts for Plan (1) and Plan (2) were observed to be 2,379,110.4 TL and 310,875.9 TL, respectively. Table 2 also demonstrates that the negative imbalance amounts on a monthly basis for Plan (1) and Plan (2) are similar to each other. In February, March, May, June, July, August, and November, Plan (1) exhibits higher values compared to Plan (2), specifically 577.1 MWh to 513.7 MWh, 1,180.9 MWh to 809.4 MWh, 1,179.1 MWh to 608.6 MWh, 986.6 MWh to 540.7 MWh, 832.0 MWh to 751.2 MWh, 961.5 MWh to 694.7 MWh, and 773.2 MWh to 635.9 MWh, respectively. Conversely, for the remaining months, namely January (819.2 MWh to 430.8 MWh), April (711.7 MWh to 584.1 MWh), September (773.2 MWh to 545.0 MWh), October (735.5 MWh to 725.4 MWh), and December (774.9 MWh to 700.2 MWh), Plan (2) demonstrates higher values than Plan (1). Annual total negative imbalance amounts were found to be 9,475.9 MWh and 8,368.6 MWh for Plan (1) and Plan (2), respectively. The NIP for Plan (1) and Plan (2) exhibits a variation from 10,522.5 TL in September to 56,610.5 TL in November, and from 10,348.3 TL in February to 61,311.0 TL in November. The economic evaluations were conducted on an hourly basis, revealing that the largest NIP was seen in November for both Plan (1) and Plan (2). It is worth noting that despite experiencing a maximum negative imbalance in March for Plan (1) and in January for Plan (2), the NIP remained highest in November. The annual NIP amounts for Plan (1) and Plan (2) were recorded as 351,318.3 TL and 337,186.4 TL, respectively.

4. CONCLUSION

This study aimed to quantify the degree of disparity between the energy output estimated using the TRNSYS models and the real-time generation data from the EPİAŞ transparency platform. Additionally, the associated penalties resulting from this disparity were computed. Accurate assessment of energy generation has been demonstrated to be crucial in mitigating disparities. By employing accurate calculations, it is possible to mitigate the potential for imbalance and the associated expenses that may arise from such imbalances. In conclusion, these calculations enhance the stability and long-term viability of the energy market. Within the present context, the study's findings are presented as follows.

- The collected wind velocity readings throughout the year 2021 (from 5.48 m/s to 9.08 m/s with an annual average of 7.20 m/s) exceeded the average values often observed in meteorological records (from 2.99 m/s to 4.20 m/s with an annual average of 3.58 m/s).
- The energy generation values for Plan (1) were simulated to range from 1,391.9 MWh to 2,697.8 MWh, with a total annual sum of 24,018.1 MWh. According to the literature studies conducted in accordance with Plan (1), The energy production per unit of capacity exhibited a yearly variation ranging from 920 1/h to 2,331.16 1/h. For this study, the energy output per unit of capacity was found to be 1,334.3 1/h, which falls within the acceptable range.
- The energy production values for Plan (2) were found to be between 2,728.4 MWh and 7,527.0 MWh having a yearly sum of 61,699.1 MWh. Therefore, simulated work based on Plan (2) was successfully found the real-time production amounts which was obtained to be 60,176.2 MWh along a year.
- The simulated energy generation values yielded positive imbalance values ranging from 1,608.3 MWh to 5,904.7 MWh, with a total annual sum of 45,726.7 MWh for Plan (1). For Plan (2), the positive imbalance values ranged from 396.1 MWh to 678.2 MWh, with a yearly total of 6,651.3 MWh. On the other hand, negative imbalance values ranging from 430.8 MWh to 1,180.9 MWh, with a total annual sum of 9,475.9 MWh for Plan (1). For Plan (2), the negative imbalance values ranged from 513.7 MWh to 819.2 MWh, with a yearly total of 8,368.6 MWh.
- The simulated positive imbalance amounts yielded PIP ranging from 43,627.5 TL to 456,128.8 TL, with a total annual sum of 2,379,110.4 TL for Plan (1). For Plan (2), the PIP values ranged from 11,039.4 TL to 47,942.9 TL, with a yearly total of 310,875.9 TL. On the other hand, the simulated negative imbalance amounts yielded NIP ranging from 10,522.5 TL to 56,610.5 TL, with a total annual sum of 351,318.3 TL for Plan (1). For Plan (2), the NIP values ranged from 10,348.3 TL to 61,311.0 TL, with a yearly total of 337,186.4 TL. The combined penalty payments (PIP and NIP) were found to be 2,730,428.8 TL for Plan (1) and 648.062,3 TL for Plan (2), respectively.

In future research, the impact of various parameters on energy generation can be investigated using the TRNSYS model. These characteristics may include turbulance intensity, shear exponent, turbine power loss, and others. Meanwhile, certain machine learning models can be utilized to do energy assessments with more precision. Hence, energy producers have the potential to receive economic rewards.

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CONFLICT OF INTEREST

The author stated that there are no conflicts of interest regarding the publication of this article.

CRediT AUTHOR STATEMENT

Huseyin Gunhan Ozcan: Conceptualization, Methodology, Software, Validation, Formal analysis, Writing – Original Draft, Visualization.

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