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RESEARCH ARTICLE

Comparison of Success Rates of Artificial Intelligence and Classical Methods in Estimation of Photovoltaic Energy Production: Study of İzmir Bakırçay University

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Abstract

Global solar energy has become a popular investment choice for investors, with installed power reaching 940GW according to 2021 data. Investors are interested in profit margin estimations based on energy production, which are provided through feasibility studies conducted before building solar power plants (SPP). While classical mathematical algorithms are typically used to calculate energy production, advances in technology offer opportunities to achieve better results. In our energy production estimation studies conducted at İzmir Bakırçay University SPP, we achieved a 70.24% success rate using classical estimation algorithms based on past production and meteorological data. However, by developing an artificial neural network, we achieved a 98.23% success rate, making it a more beneficial option for investors. Our aim was to create a reliable feasibility environment.

Keywords: photovoltaic energy; energy estimation methods; artificial neural networks

1. Introduction

As technology has advanced, energy production methods have diversified, and renewable energy methods have become a necessity due to the rapid pollution of the world. They do not pollute the environment and provide sustainability. Many global agreements encourage the use of renewable energy sources to prevent global pollution [2]. Renewable energy methods provide unlimited and free resources and prevent the unconscious consumption of existing reserves, ensuring more conscious use of resources that humanity may need in the future [3].

Solar energy is one of the renewable energy sources that has various applications. Photovoltaic (PV) technology, which allows for the conversion of solar energy into electrical energy using semiconductor technology, is one of these applications. PV cells are the building blocks that convert light into electrical energy using the PV effect [4]. Although PV cells were first discovered in 1839 with low efficiency and requiring a high cost, they have gained the advantages of higher efficiency and lower cost through years

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of work [4]. In recent years, PV energy has constantly increased its share in the energy market, making it a remarkable energy source [5].

PV energy attracts investors with features such as unlimited and free renewable energy resources, low post-installation maintenance and operating costs, and the ability to be used as a passive income source after the depreciation period. However, feasibility studies are needed to use investments in PV energy more efficiently [6]. The correct estimation of energy production is the most important factor in feasibility studies because the source of income in solar power plants (SPP) depends directly on the electricity produced [7].

Computer software based on classical mathematical methods is commonly used in feasibility studies to forecast energy production [8-10]. These software packages typically estimate annual energy production by processing past meteorological data on a monthly basis using classical linear mathematical algorithms. While the estimation results from these simple algorithms can be used when there are no alternatives in the market, they require significant processing power as they take into account many parameters. Excluding parameters from the algorithms can also lead to deviation of estimation results from actual values.

Advances in computing technology have enabled the solution of non-linear problems [11]. In this context, artificial neural network technology, which mimics biological neurons in the computing environment and can provide predictive results using learning-based algorithms, can be trained for use in feasibility studies of solar power plants (SPPs).

In this study, an artificial neural network was designed, trained with measurement data from the past years of production at the İzmir Bakırçay University SPP and local meteorological stations, and used in estimation studies. Forecasting studies were also conducted using the PVSOL software, which employs classical mathematical algorithms. By comparing success rates, the aim of this study was to present more reliable new-generation methods to investors.

2. Material and Method

In this study, the energy production data from the İzmir Bakırçay University SPP between 2018-2020, as well as meteorological measurements from 5 different stations in İzmir during the same period, were used. The PVSOL software, frequently used in the market, was employed to estimate energy production using classical calculation methods. Additionally, one of the most popular and comprehensive mathematical software programs, MATLAB, was used to train and test artificial neural networks.

2.1. İzmir Bakırçay University

İzmir Bakırçay University was established in the Menemen district of İzmir, which has a coast on the Aegean Sea, in the west of Anatolia. The University aims to produce its own energy by using its own resources and to protect its national capital. The university, which turns to renewable energy sources for the purpose of producing its own energy, has a wind turbine and a SPP in its main campus.

The province of İzmir, where the university is established, is under the influence of the Mediterranean climate. Summers are hot and dry, and winters are warm and rainy [12]. As shown in Figure 1, the geographical region where Türkiye is located has solar radiation in the range of 1095-1826 kWh/m^2. İzmir province has a good solar potential with solar radiation in the range of 1534-1680 kWh/m^2 annually [13].

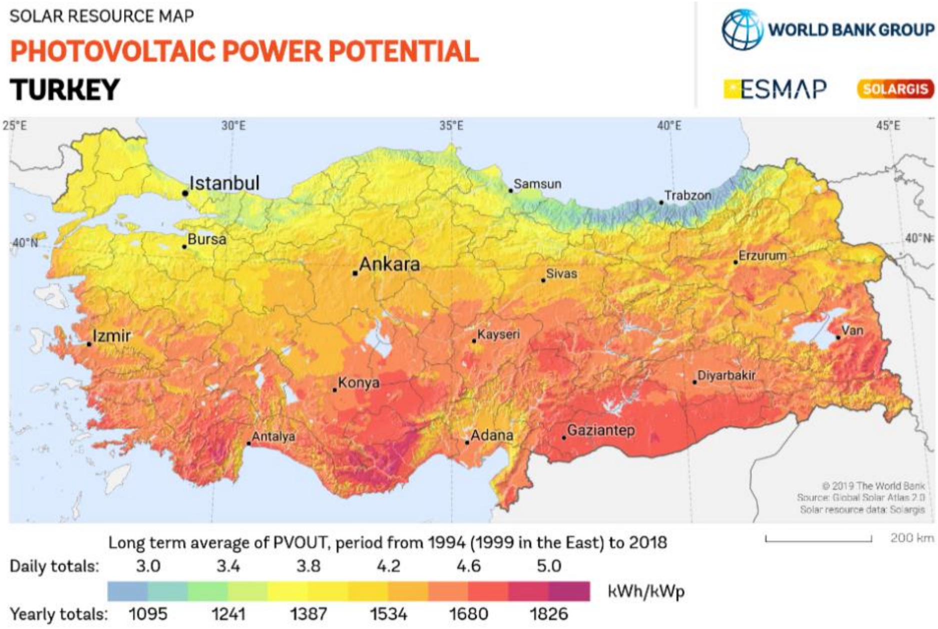


Figure 1. PV power potential of Türkiye with Solar Radiation Map [13].

2.2. SPP of İzmir Bakırçay University

The student parking lot located in the northwest of the main campus of İzmir Bakırçay University is designed to provide shade to the vehicles and at the same time generate electricity from solar energy. The satellite image of the campus is shown in Figure 2.

Figure 2. Satellite image of İzmir Bakırçay University main Campus.

There are a total of 1600 solar panels, 265 in 4 rows and 270 in 2 rows, in the parking lot located in the northwest of the campus, built on 6 rows of steel construction. The panels, one of which has a power of 250W, have a total power of 400kW. The technical specifications of the panels used are shown in Table 1.

Table 1. Used specifications panels.

Specification of the Panels	
Producer	PERLIGHT SOLAR
Model Number	PLM-250P-60
Cell Type	Polycrystalline Silicone
Maximum Power (W)	250
Maximum Voltage (V)	31.73
Maximum Current (A)	7.88
Open Circuit Voltage (V)	37.58
Short Circuit Current (A)	8.49
Maximum System Voltage (V)	1000
Cell Size (mm)	156×156
Module Size (mm)	1650×992×40

Considering the geographical location of Türkiye, it would be more appropriate to place the solar panels installed on the steel construction at an angle of 30 degrees facing south, in order to achieve the highest annual average efficiency [14]. However, in order to provide more shade for the parked vehicles, the panels were installed at an angle of 12 degrees to the south. Simulations carried out with the PVSOL program determined that the yield decrease due to the angle difference is 1.26%. The angle of the panels with respect to the surface is illustrated in Figure 3.

Figure 3. Angle of PV panels with ground.

A total of 24 inverters are used in the SPP in order to rectify the 400kW power produced in 1600 panels with high efficiency. The inverters are housed in steel cages, shown in Figure 3, placed under the panels to protect them from environmental factors. The technical specifications of the used inverters are given in Table 2.

Table 2. Technical specifications of the inverters used.

Specifications of the inverters	
Producer	SMA SOLAR TECHNOLOGY
Model Number	FLX PRO 17
Rated Power (kVA)	17
Number of Phases	3
Output Voltage (V) (Tolerance)	230-400 (+/- 20%)
Maximum Current (Phase-A)	3-21.7A
Rated DC Input Voltage (V)	715
Maximum DC Input Voltage (V)	1000
Maximum Yield (%)	98
Inverter Size (mm)	500×667×233

Figure 4. Inverters placed in steel cages under PV panels.

2.3. Meteorological Mesaurement Datas

The amount of energy produced in SPPs is directly dependent on the amount of light received by the panels, which can be affected by various meteorological factors. Therefore, using meteorological measurements to estimate the energy produced can be an effective method. In this study, meteorological data was collected from three different meteorological stations, as indicated by their geographical locations in Figure 4.

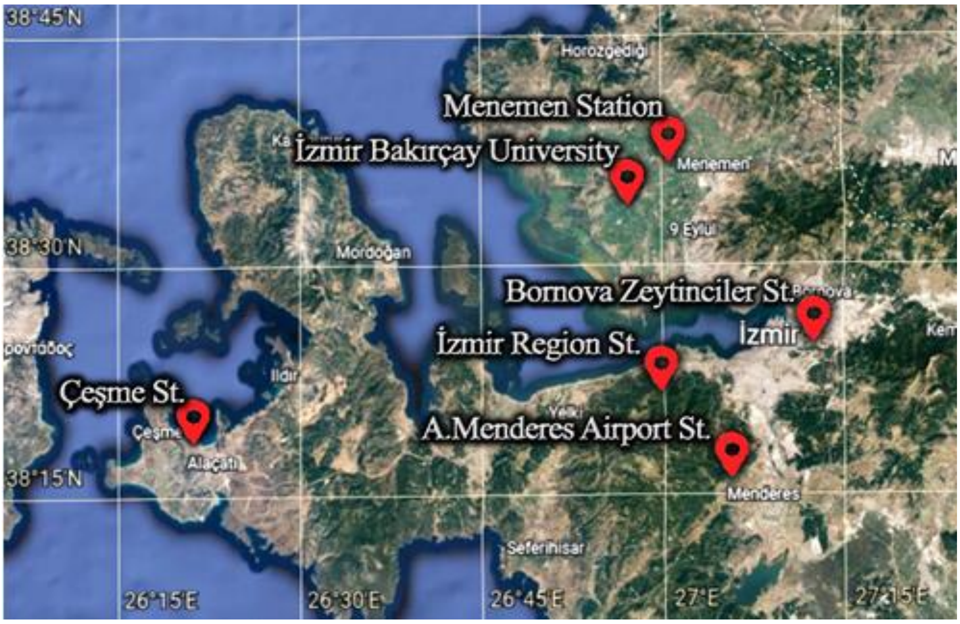


Figure 4. Geographical locations of İzmir Bakırçay University and meteorological measurement stations.

As shown in Figure 4, the closest meteorological measurement station to İzmir Bakırçay University SPP *(N38.58208, E26.96403)* is Menemen Station *(N38.62539°, E27.04255°)*. Other meteorological measurement stations located in the south and west of the region, the measurement data obtained from a total of 4 different meteorological stations, namely Çeşme Station *(N38.30408°, E26.37264°)*, İzmir Regional Station *(N38.39438°, E27.08137)*, Adnan Menderes Airport Station *(N38.29378°, E27.15173°)*, were used [16].

The main meteorological data used in the study consist of the number of cloudy days, solar radiation, average ambient temperature and minimum relative humidity measured between 2018 and 2020 by the relevant meteorology stations.

3. Estimation of Solar Energy Production

PVSOL software is one of the most popular programs for simulating and reporting on the feasibility of solar photovoltaic power plants (SPPs). The program allows users to design an SPP from scratch and generate cost analyses by estimating energy production. It uses meteorological data from previous years in its database to make energy production forecasts based on classical mathematical methods.

3.1. Estimation with PVSOL

PVSOL software is one of the most popular SPP simulation and feasibility reporting programs. The program generally allows you to design an SPP from scratch and then generate cost analysis by generating energy production estimates. Using the meteorological data of the previous years in the database, it makes energy production forecasts based on classical mathematical methods. The interface of the PVSOL program is shown in Figure 5.

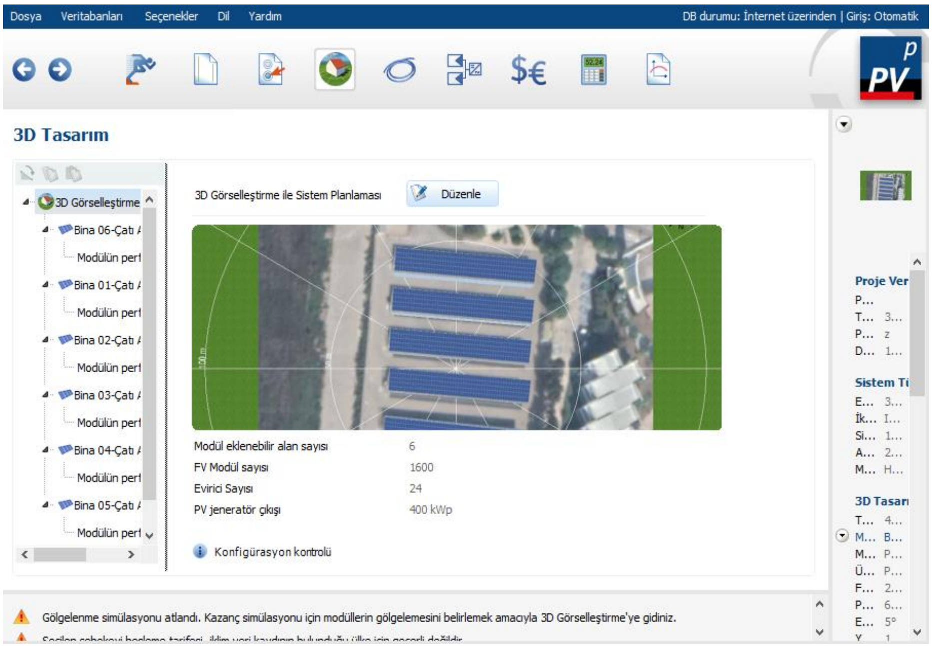


Figure 5. Interface of PVSOL program during İzmir Bakırçay University SPP drawing.

As can be seen in Figure 5, while modeling İzmir Bakırçay University in the PVSOL program, the modeling was carried out considering the parameters given in Table 3.

Table 3: PVSOL SPP installation parameters.

Parameter	Value
Location	İzmir/Türkiye
Data resolution	1 saat
Horizontal diffuse radiation simulation	Hofmann
Simulation of radiation on inclined surface	Hay&Davies
PV module model	PLM-250P-60
Producer	Perlight Solar Co.LTD.
Slope	12°
Layout direction	186°
Inverter model	Danfoss SMA FLX Pro 17
Construction 1 Number of PV modules	270
Construction 2 Number of PV modules	270
Construction 3 Number of PV modules	265
Construction 4 Number of PV modules	265
Construction 5 Number of PV modules	265
Construction 6 Number of PV modules	265
Total number of PV modules	1600
Total number of inverters	24

The simulation results made with the SPP model modeled with the PVSOL software are shown in Table 4.

Table 4. PVSOL simulation results.

Parameter	Value
SPP output	400 kWp
Mains supply in the first year	607,904 kWh/year
Consumption in standby	283 kWh/year
Avoided CO2 emissions	285,583 kg/year
Accumulated cash flow (year 2020)	509,994.30 ₺
Amortization period	9.1 years
Electricity production cost	0.05 ₺ / kWh
Certain investment expenses	1,500.00 ₺ / kWp
Investment costs	600.000₺

The monthly energy production calculated in the simulation is shown in the graph in Figure 6.

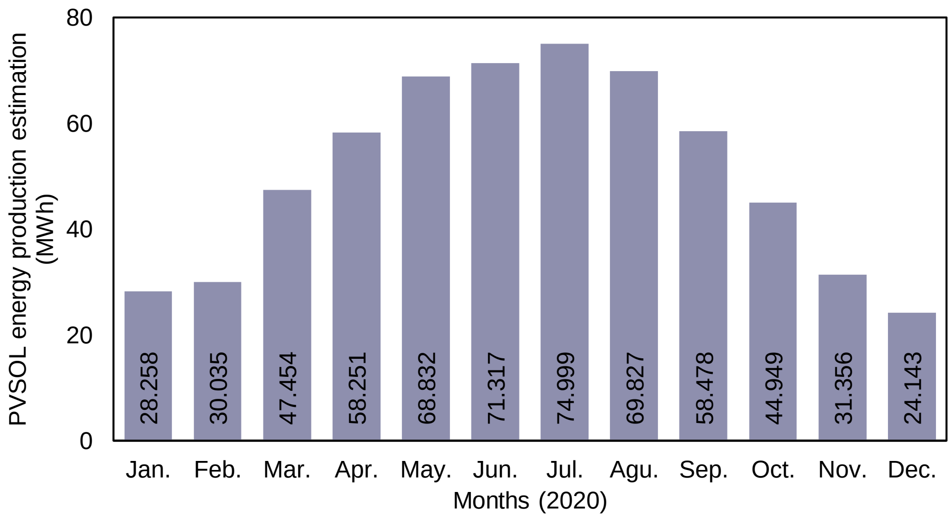


Figure 6. PVSOL annual energy production forecast.

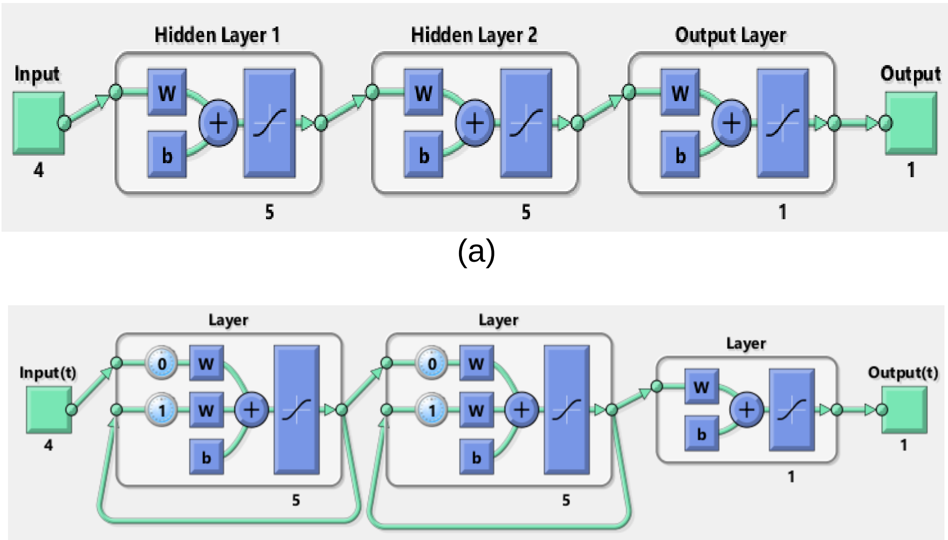
3.2. Estimation with ANN

In this study, data obtained from 5 different measurement stations and the İzmir Bakırçay University Rectorate covering the years 2018-2020 were used to train artificial neural networks (ANNs). The meteorological factors presented as inputs to the ANNs include insolation duration, insolation intensity, number of cloudy days, and average ambient temperature data. The data targeted as output is the monthly energy production data produced by the İzmir Bakırçay University SPP. Of the total 2400 meteorological measurements and power generation data, 86% were used to train ANNs, while the remaining 14% were used for testing ANNs.

The ANNs used in the study were designed with Feed-Forward Backpropagation (FFB) shown in Figure 7a and Elman Backpropagation (ELMB) architecture shown in Figure 7b. These network architectures have initial weights with randomly determined small values in the range of [0,1]. In addition, data with large values in the input data update the weights more effectively than necessary and slow down the training speed [15]. To increase the training speed and success rate, the input data was scaled to the range [0-1] using the Min-Max normalization method shown in Equation 1.

$$x_i' = \frac{x_i - x_{min}}{x_{max} - x_{min}} \quad [1]$$

In this equation, x'_j represents i th normalized data, x_j represents i th data, x_{min} represents lowest valued data in the dataset and x_{max} represents highest valued data of the dataset.



(b)

Figure 7. Diagram of architecture and parameters of (a) FFB and (b) ELMB network.

The reason why FFB network is preferred in this study is that it is one of the simplest structures of ANNs. Operations in FFB networks can be simply expressed as a transformation that maps an input sequence to an output sequence with the help of randomly assigned very small weights. [17]. This transformation process is shown in Equation 2.

$$Y_i = f\left(\sum W_{ij} X_j\right) \quad [2]$$

In this equation, Y_j represents i th output, X_j represents j th input vector and W_{ij} represents ij th vector's weight

While 2 of the 4 different ANN models were designed with FFB architecture, the other 2 were designed with ELMB architecture. After the networks constructed with the parameters specified in Table 5 were trained with meteorological data and energy production data from the past years, they were simulated with a part of the data that was never shown. Tangent sigmoid (TANSIG) and logarithmic sigmoid (LOGSIG) functions were used as activation functions in artificial networks. TANSIG shows nonlinear and dynamic variations in the [-1, 1] range and LOGSIG in the [0, 1] range.

The mean absolute percentage error (MAPE) method, the formula of which is given in Equation 3, was used to calculate the ANN error values.

$$\text{MAPE}\ (\%) = \frac{\sum_{i=1}^{n} \frac{|y_i' - y_i|}{y_i'}}{n} \times 100 \quad [3]$$

In this equation, y_i' represents target (actual) output value, y_i represents estimated output value, and n represents total number of outputs.

The success and MAPE% error rates of the networks as a result of the simulation are also shown in Table 5.

Table 5. Training and simulation parameters and results with 4 different ANN models.

Parameter	**Value**			
Model number	1	3	3	4
Architecture	FFB	FFB	ELMB	ELMB
Training algorithm	TRNGDX	TRNGDX	TRAINLM	TRAINLM
Training function	LRNGDM	LRNGDM	LRNGDM	LRNGDM
Performance function	MSE	MSE	MSE	MSE
Layer count	3	3	3	3
Neurons at layer 1	5	5	5	5
Transfer function at layer 1	TANSIG	LOGSIG	TANSIG	LOGSIG
Neurons at layer 2	5	5	10	10
Transfer function at layer 2	TANSIG	LOGSIG	TANSIG	LOGSIG
Minimum gradient	1.00E-07	1.00E-07	1.00E-07	1.00E-07
Training iterations	400	400	153	107
Best iteration	201	362	103	6
Training regression (%)	98.48	85.87	-	-
Validation regression (%)	99.28	92.89	-	-
Test regression (%)	98.71	90.91	-	-
General regression (%)	98.51	89.17	-	-
Error rate (MAPE%)	4.43	11.09	1.77	9.99
Success rate (%)	95.57	88.91	98.23	90.01

When the performances in Table C are examined, it is seen that the most successful network model is model number 3 designed with ELMB architecture. Also, when models 3 and 4 are compared, using TANSIG as the transfer function gave an 8.22% increase in success compared to using LOGSIG.

When models 1 and 2 designed with FFB architecture are examined, it is seen that using TANSIG as a transfer function provides higher performance and success rate.

4. Comparison of the Findings

SPP output estimation values obtained from PVSOL program and estimation values obtained from ANN model were compared with actual values. The comparison made is shown in the graph in Figure 8.

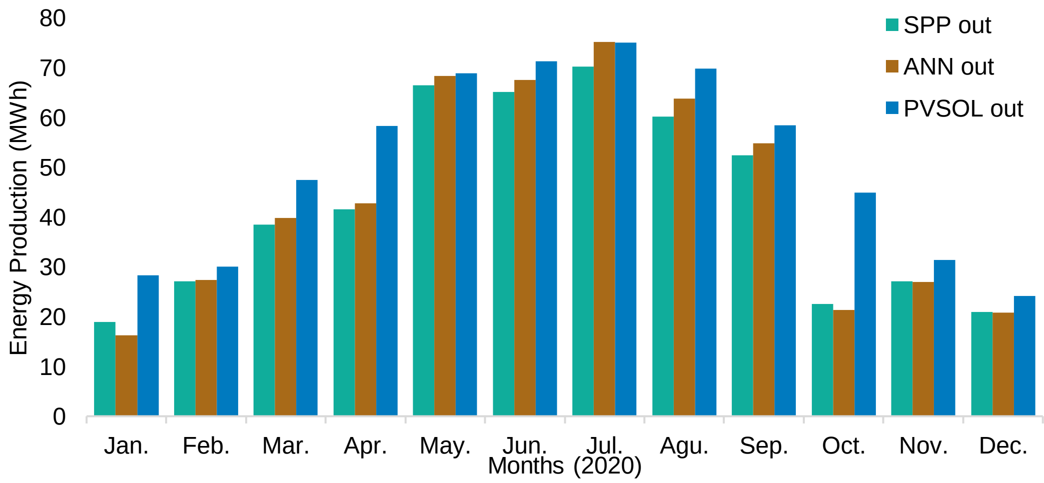


Figure 8. Comparison of the estimate power output results of ANN and PVSOL.

As shown in Figure 8, the estimation results obtained with the PVSOL software are higher than the actual values. While the software provided close estimations to the real values in some months such as February, May, July, September, November, and December, the forecast values in January, March, April, June, August, and October were less accurate. Notably, the error rates in January, April, and October were up to two times higher.

In contrast, the ANN model provided much more accurate estimations, showing more consistent success in all months. For instance, in October, the PVSOL software estimated the electricity generation as 45,553 kWh, while the number 3 ANN model estimated it as 21,314.51 kWh, which is closer to the actual value of 22,500.09 kWh. The comparison of estimation errors of the ANN model and PVSOL model is presented in Figure 9, using MAPE values.

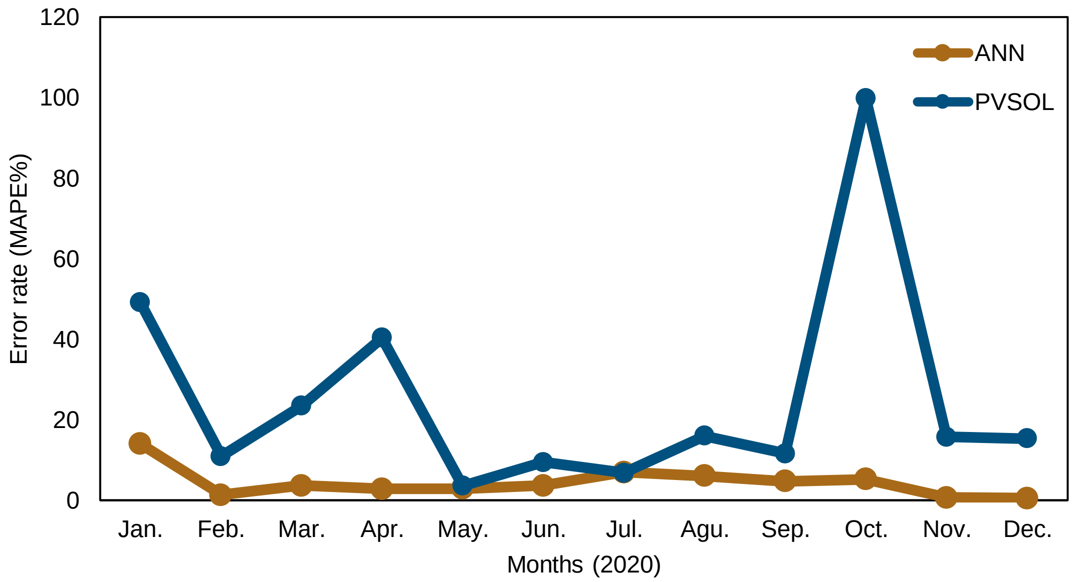


Figure 9. Comparison of the estimation error rates ANN and PVSOL.

5. Result

Before starting the construction of the SPPs, complex mathematical calculations should be used to consider many geographical and meteorological parameters. Classical mathematical calculations require a lot of time for the analyzing SPPs. With the development of technology and the availability of high processing power, artificial intelligence provided by ANNs has become much simpler and more accessible. The idea of using ANNs for forecasting and analysis of PV panels and SPPs has been the subject of many studies recently.

In this study, meteorological data of 4from four different measurement stations located in the same geographical region with the SPP energy production data located in İzmir Bakırçay University Seyrek Campus for the years 2018-2020 were used. The sunshine duration (h), sunshine intensity (kcal/cm2), number of cloudy days (days/month) , average ambient temperature (°C) and SPP production data (kWh) were normalized and presented to the ANNs. Eighty-six percent of the data was used for training and fourteen percent for testing. The data used for training were verified by examining the data on the ANNs. In the trials with test data, estimations were made with an average error rate of 1.77% and 11.09%, according to the MAPE calculation method resulting from four different models.

Regression analyzes and MAPE values were first examined for the successful results of the estimations made. Considering the regression analyzes and MAPE values, ANN modeling with ELMB architecture, using TANSIG transfer function and trainlm learning algorithm, achieved the most successful result, reaching a MAPE rate of 1.77% and a training regression value of 98.23%.

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