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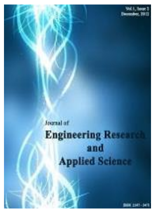

Comparison of PVsyst, PVSOL and HOMER Simulation Software Results with Real Production Data of Solar Power Plants in Different Provinces of Turkey

Emine Erakman Dirlik[1*], Cenk Gezegin[2] , Shir Ahmad Dost Mohammadi[3]

[1,*] Ondokuz Mayıs University, Graduate School of Education, Department of Renewable Energy and Applications, Samsun, Turkey
[2]Ondokuz Mayıs University, Engineering Faculty, Electrical and Electronics Engineering, Samsun, Turkey
[3]Alberoni University, Faculty of Engineering, Department of Electrical and Electronics, Kapisa, Afghanistan

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Abstract
Various simulation software has been developed to simulate photovoltaic systems. Researchers, engineers and investors use these simulation tools for PV power plant sizing, feasibility, technical and economic analysis. The aim of this study is to compare the results of the simulation tool closest to real production data for researchers and investors in Turkey. In this article, actual production data of 7 solar power plants (SPP) in different geographical regions in Turkey are compared with the results of PVSyst, PVSOL and HOMER software. Simulations were made by entering some analysis data such as equipment used in real power plants, slope angles and location information into three software tools. Program outputs were compared with actual production data and it was determined which program gave more meaningful results for Turkey. When the annual results were examined according to the simulation results, the deviation rate of PVSyst was found to be -3.4857%, the deviation rate of PVSOL was 9.027% and the deviation rate of HOMER was found to be 3.2238%, according to the real production data. The most suitable software for these analyzed power plants was found to be HOMER. This study may be useful for future studies in determining the most appropriate simulation software for the analysis of solar power plants in Turkey.

Key words: *PVSOL, PVSyst, HOMER, PV, renewable energy*.

1. Introductıon
According to IEA (International Energy Agency) data, although there are fluctuations in electricity production according to resources in Turkey between 1990 and 2020, the use of coal, natural gas and oil tends to constantly increase, as well as hydroelectricity, biofuel, wind and solar. etc. An increase in production was also observed. In addition, it is seen that the CO^2 emission value increases year by year [1]. Although government incentives have been given to renewable energy investments since the early 2000s, incentives have increased since 2012. In general, VAT and customs duty exemption were given as incentives [2]. This situation accelerated the entry of investors into the market and it has been shown that there has been a noticeable increase in renewable energy production after 2010. However, renewable energy sources are still insufficient in proportion to the increase in consumption due to reasons such as developing industry and increasing population [1]. We are highly dependent on fossil fuels and energy production with hydroelectric power plants is also climate-dependent. However, we need to increase electricity production with domestic and national resources in order to reduce external dependence in energy. Some of the studies in the literature are as follows:

Duman and Güler selected 9 provinces for Turkey and made an economic analysis of grid-connected domestic rooftop PV systems by modeling with HOMER software. The results of the analysis showed that although PV systems give positive results in terms of economic profitability in the South of the country, they are not profitable in the North [3].

In Sharma and Gidwani's study, grid-connected photovoltaic system modeling and financial analysis for dormitory buildings of a university in India was performed using PVSOL program [4].

* Corresponding author:
Email: emine.erakman@kgm.gov.tr

Salehin et al. modeled "PV-diesel generator" and "WT-diesel generator" systems on an island of Bangladesh using HOMER and RETScreen software and conducted techno-economic analysis [5].

In the study by Othman and Hatem, the outdoor performances of 3 different PV modules (polycrystalline, monocrystalline, thin film Cadmium Telluride) were experimentally investigated between 2013 and 2020 under hot and dry climatic conditions in Cairo, Egypt. These three systems were compared in terms of module efficiency, degradation rate and temperature power coefficient. The same system was then simulated in PVsyst, PVSOL and SMA Sunny Design Web software and the outputs of the software were compared with the experimental data. When the annual average data of the software results were compared with the experimental data, the margin of error varied between -6.99% and +4.65%, but the monthly margin of error varied between -23.71% and +22.22% [6].

Mubarak et al. measured the radiation values with sensors positioned in different directions and at different tilt angles for 3 years in Hannover, Germany and compared the results of the PV system in which direction. Experimental measurement values were simulated and compared in two German software programs PVSOL and PVsyst [7].

Özcan et al. conducted a study on the electricity generation of PV technology using different methodologies on the performance indicators of photovoltaic systems. The experimental data obtained in determining the annual production were simulated in PVSOL and TRNSYS software and it was concluded that PVSOL software better reflects the experimental studies with an accuracy rate of 94.33% [8].

Mohammadi and Gezegin modeled a 5 MW PV power plant to solve the electricity problem of Ghor province of Afghanistan and compared the simulation results of PVSYST, PVGIS and HOMER [9].

In the study by Faridah and Purwadi, 3 villages from 3 different regions of Indonesia were selected and hybrid energy system modeling was performed. Modeling was performed in HOMER, PVSyst and PVSOL software using various combinations of different renewable energy components [10].

Zahraee et al. compared the algorithms used in renewable energy modeling and gave various recommendations on what should be implemented in new software development. It is mentioned that HOMER provides the best simulation among the algorithms [11].

Taghızadegan et al. review and compare various methodologies studied in the literature for optimal sizing of hybrid energy systems, including their advantages and disadvantages, and guide the designer to choose the most suitable method. It is pointed out that HOMER software is the most widely used software [12].

Tozzi and Jo compared renewable energy tools and showed the advantages and disadvantages of each software. It was stated that HOMER performs both simulation and optimization [13].

In Benghanem's study, annual measurements were made for the PV system with uniaxial tracker in Medina and the optimum tilt angle for each month was calculated with MATLAB. It was observed that the annual optimum tilt angle corresponds to the latitude value of the location. Using a fixed tilt angle caused an 8% decrease in annual production compared to adjusting to the optimum tilt angle [14].

In a long-term study by Yu et al. in Japan, it was shown that although the tilt angle for maximum efficiency is generally the latitude of the location, local climate differences and location characteristics can affect the performance of PV systems and the current latitude value may not be the best angle [15].

In the study of Ayara et al. it was stated that changing the panel tilt angle according to the seasons will increase the efficiency. It was also shown that the latitude of the current location is the most appropriate if a fixed tilt is to be used [16].

Gunerhan and Hepbasli calculated the monthly optimum tilt angles for Izmir, Turkey and determined the optimum angles seasonally. They suggested that it would be better in terms of efficiency to install PV panels in accordance with the monthly average calculated tilt angle [17].

In Hussein et al. study, the optimum tilt angle in Cairo was calculated with TRNSYS software and monthly average irradiance data were collected. The software results were then compared with actual production data to determine the optimum annual tilt angle [18].

Reindl, Aberle, et al. experimentally tested the angle at which the best radiation is received with different tilt angles and different geographical orientations in Singapore, and analyzed the accuracy of the software by modeling real data in a modeling software [19].

Cheng et al. wanted to show the relationship between the tilt angle of a fixed tilt PV system and the degree of latitude for 20 locations in the Northern Hemisphere using PVSyst software [20].

In the study by Lua and Zhaob, it was shown that the PV panel efficiency is affected by the dust accumulation on the panels depending on the tilt angle of the panels in real conditions. It has been shown that the smaller the size of the dust particles, the more retention is experienced and the lower the current panel efficiency, as well as wind and tilt angle play an important role in dust accumulation [21].

In the study of Babatunde et al., one-year production data of the PV experimental set in 5 different locations established at the Cyprus International University with different slope and geographical orientations were collected and the effect of dust accumulation on the system according to the positions of the PV panels on the energy production of the panel was measured. Here, it was observed that regular cleaning of the panels increased the efficiency by 2.5% [22].

Beringer et al. showed that the highest irradiation level does not mean that the energy to be produced by the PV system is the highest and that the optimum angle should be found [23].

Souza Silva et al. compared the simulation results of PVSOL, PVSyst and HOMER software with the actual production data of the PV plant (336.96 kWp) installed at the University of Campinas in Brazil. In the comparison results, it was observed that PVSyst software gave more accurate results [24].

In their study, González-Peña et al. performed a comparative analysis by modeling with 5 different renewable energy software tools with real data of 3 different PV power plants in 3 different regions that have been operating in the market for the last 12 years. The PV modules in the plants are fixed, horizontal axis tracker and dual axis tracker. It was observed that the software tools provided higher energy than the actual data for cold months and better predictions for hot months. The deviation in annual results was found to be below 10%. Here, it is thought that there is a difference between real measurements due to the meteorological infrastructure from which the software tools receive climate data, and while real data and simulation data give close results in fixed systems, the results given by software tools in complicated systems such as dual tracker systems are far from accuracy [25].

In the study by Umar et al. the actual production data of a 1 MW PV plant installed at a University in India were recorded and compared with the software outputs of the plant simulated in 10 different renewable energy software tools. In addition, it is also seen that renewable energy software tools have been compared among themselves [26].

Milosavljević et al. compared the simulation data of 14 different renewable energy software tools with the production data of a 2kWp PV system installed in real climatic conditions. In the study, SolarPro software gave the closest value to real data in irradiation data, while PVGIS software gave the closest result to real data in production data [27].

As the literature review shows, renewable energy sources are highly dependent on the climate, which results in high fluctuations in production. In addition, there are many factors affecting irradiation for PV systems. One of the most important factors affecting production is the tilt angle. As shown in many studies, the production of PV systems with tilt angles that can be manually adjusted according to the seasons instead of fixed systems is higher. In this way, the cost disadvantage of PV collectors with solar tracking systems can be partially eliminated. On the other hand, renewable energy software tools have become quite common as they can provide preliminary information on approximate cost and production data [28]. The most important factor here is to find out which software performs better in which area. In addition, how close the results of simulation software are to the actual data in terms of plant location is also an important performance and comparison indicator.

2. Renewable Energy Softwares

There are many renewable energy software tools with different features used in the literature. The most popular ones are Solarius PV, SAM (solar advisor model), PVsyst, PVWatts, PVGIS (photovoltaic geographical information system), HOMER (hybrid optimizationmodel for electric renewables), SolarGIS, PVSOL, RETScreen, BlueSol, HelioScope, PolySun, Solar Pro and PV F-Chart. Which of these software tools we choose is entirely a matter of what the user wants to do. For example, HOMER may have a strong engineering aspect, while RETScreen may have a strong economics and finance aspect. Or we may need a software like PVSOL that can do shading and a more detailed loss calculation. The software we have chosen for this study are HOMER, PVSyst and PVSOL. Table 1. shows the characteristics of our selected software according to various parameters.

PVSyst software is a European-based PV energy system simulator developed by the University of Geneva for the European Energy Center. PVSyst receives meteorological data from Meteonorm and NASA-SSE, but external stakeholder databases can also be used in the studies. It can calculate with or without grid connection. It can also calculate shading according to the surrounding buildings as well as 3D modeling [25]. PVSOL software is a software for planning, design and simulation of photovoltaic systems developed by Valentin Software. PVSOL receives meteorological data from Meteonorm and the German Meteorological Service. It can analyze PV systems for electric vehicles as well as grid-connected or off-grid calculations. It can analyze shading, 3D modeling and visual design [25]. HOMER (Hybrid Optimization Model of Electric Renewable) software; developed by NREL (National Renewable Energy Laboratory) HOMER receives meteorological data from NASA-SSE. It can calculate with or without grid connection, but does not have 3D modeling capability. Other hybrid renewable energy systems can also be analyzed [11].

Table 1. Possibilities And Resources Of Each Power Simutaion Software [24]

Object	Description	HOMER	PVSOL	PVSYST
System Simulations	Stand-alone (Off-grid)	✓	✓	✓
	Grid-Tie PV systems (On-grid)	✓	✓	✓
	Pump systems		✓	✓
	Hybrid systems Photovoltaic and Battery	✓	✓	
	Others Hybrid systems	✓		
	Photovoltaic System for Electric Vehicles		✓	
Site Paramethers	Analysis of the terrain data			
	Weather database	✓	✓	✓
	Temperature Settings of the Site	✓	✓	✓
Building Physics	Building 3D modeling		✓	✓
	Image capturing/Geo maps		✓	
	Import maps image		✓	✓
	Shading analysis due to neighboring buildings		✓	✓
Building Energy Performance	Monthly	✓	✓	✓
	Hourly	✓	✓	✓
Mounting Forms System	Ground	✓	✓	✓
	Roof	✓	✓	✓
	Roof integrated	✓	✓	✓
	Facade integrated			✓
	Solar Tracker	✓	✓	✓
Financial	Payback prediction	✓	✓	✓
	Direct Finance	✓	✓	✓
	Loan/Lease/Mortgage	✓	✓	✓
Emissions avoided	CO_2	✓	✓	✓
Operating System Compatibility	Windows Vista, 7, 8 e 10	✓	✓	✓
	MACOS			
	Linux			
	Virtualization of Windows in Linux or MACOS with VirtualBox	✓		✓
	Virtualization of Windows in Linux with VMWare	✓	✓	✓
	Virtualization of Windows in Linux or MACOS with Parallels	✓	✓	✓

3. Methodology

The operation and production data of 7 installed PV plants in Konya, Van, Tokat, Elazığ, Amasya, Denizli and Malatya provinces in Turkey were used. These provinces are representative of 4 different climate zones in Turkey. Amasya has Black Sea climate, Konya and Tokat have temperate continental climate, Elazığ, Malatya and Van have harsh continental climate and Denizli has Mediterranean climate. Technical information about the power plants is shown in Table 2. The names of the power plants are shown using pseudonyms determined according to the provinces where they are located. The production data of the power plants were recorded from the date of commissioning until December 2022. The tilt angles of the panels are 25°. Simulations were performed in PVSyst, PVSOL and HOMER software using operational information.

Table 2. Technical Information of Power Plants in Operation

Power Plant Name	**Panel Manufacturer / Specification / Model / Power**	**Power**	**Number of Panels**	**Inverter Manufacturer / Type / Model / Power**	**Number of Inverters**
Konya	*Phono Solar / Polycrystalline / Phono Solar PS325P-24T /325Wp*	*12,084 MWp*	*37164*	*ABB / Central / PVS800-57B/ 1645 kW*	*6*
Van	*Hanwha / Polycrystalline / Poly (Qplus G4.3)/ 285Wp*	*12,095 MWp*	*42438*	*ABB / Central / PVS800-57B / 1645 kW*	*6*
Tokat	*First Solar / Thin Film / First Solar FS 4117A 3 / 117,5Wp*	*5,58 MWp*	*47454*	*ABB / Central / PVS800-57 / 1000 kW*	*5*
Elazığ	*Jinko Solar / Polycrystalline / TKM315PP-72/ 315Wp*	*9,06 MWp*	*28766*	*SMA / String/ STP 60-10/ 60 kW*	*133*
Amasya	*First Solar / Thin Film / FS-4117A-3 / 117,5Wp*	*11,28 MWp*	*95520*	*HUAWEI / String/ SUN2000-33KTL/ 33 kW*	*348*
Denizli	*Yingli Solar / Polycrystalline / YL250P-29/ 250Wp*	*7,39 MWp*	*29655*	*ABB / String / TRIO-27,6-TL-OUTD-S2 /30 kW*	*223*
Malatya	*Astrohalo / Monocrystalline / 5BB CHSM6612M / 380Wp*	*12,97 MWp*	*34128*	*ABB / Central / PVS800-57B/ 1645 kW*	*6*

4. Analysis and Comparison

Figures show the monthly average of the actual production data of SPP and the simulation results modeled with PVSyst, PVSOL and HOMER software.

According to the provinces, the software with the best results were HOMER in Amasya, PVSyst in Denizli, PVSyst in Elazığ, PVSOL in Konya, HOMER in Malatya, PVSyst in Tokat and PVSyst in Van.

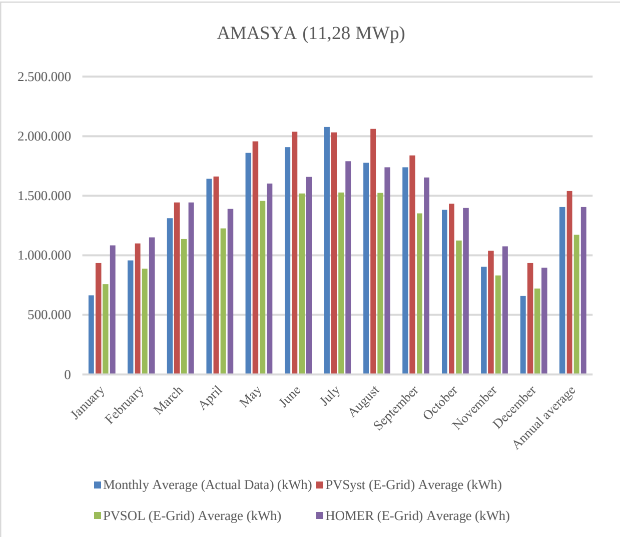

Figure 1. Analysis of Production Data and PVSyst, PVSOL, HOMER Simulation Results for Amasya Solar Power Plant

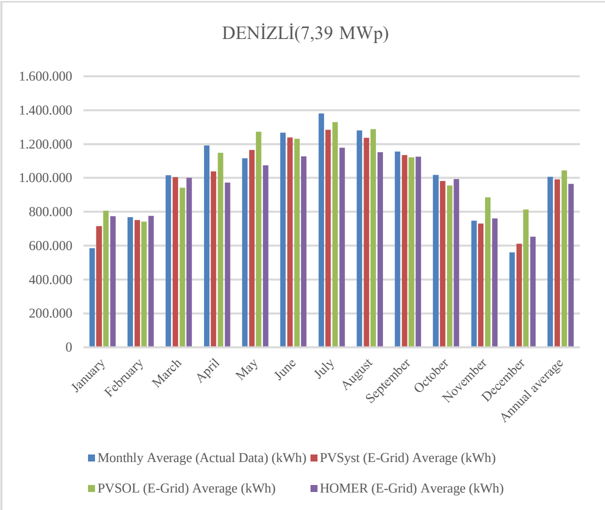

Figure 2. Analysis of Production Data and PVSyst, PVSOL, HOMER Simulation Results for Denizli Solar Power Plant

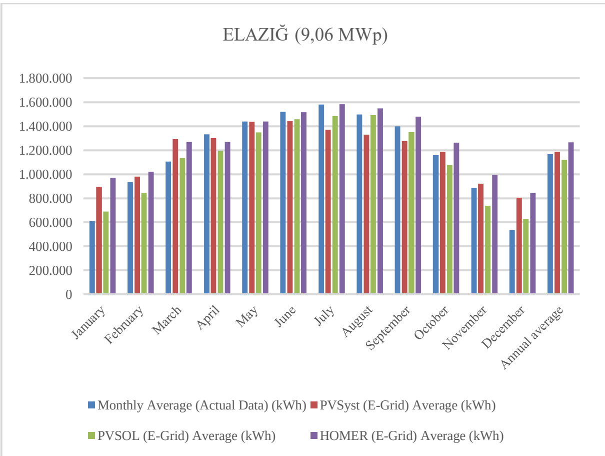

Figure 3. Analysis of Production Data and PVSyst,

PVSOL, HOMER Simulation Results for Elazığ Solar Power Plant

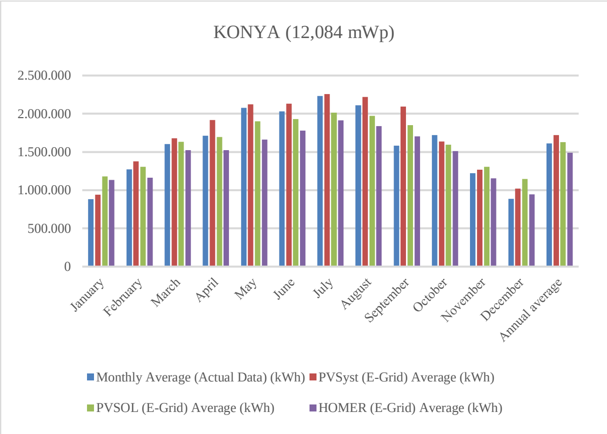

Figure 4. Analysis of Production Data and PVSyst, PVSOL, HOMER Simulation Results for Konya Solar Power Plant

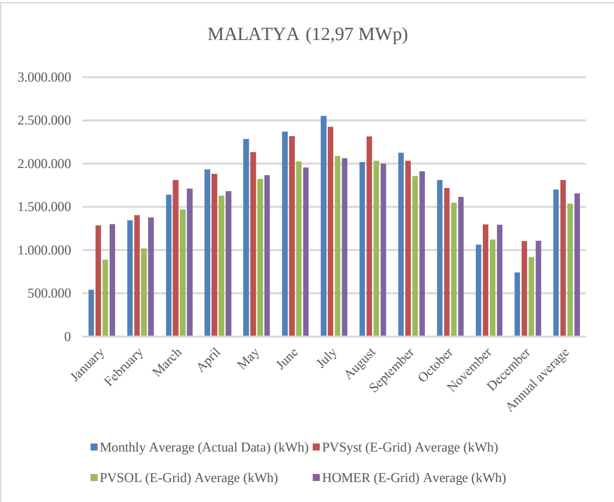

Figure 5. Analysis of Production Data and PVSyst, PVSOL, HOMER Simulation Results for Malatya Solar Power Plant

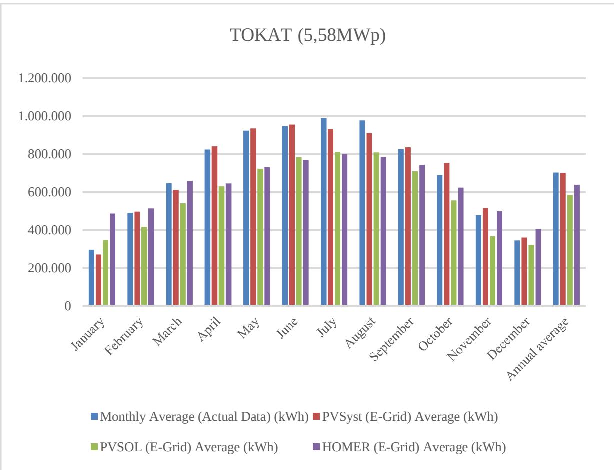

Figure 6. Analysis of Production Data and PVSyst, PVSOL, HOMER Simulation Results for Tokat Solar Power Plant

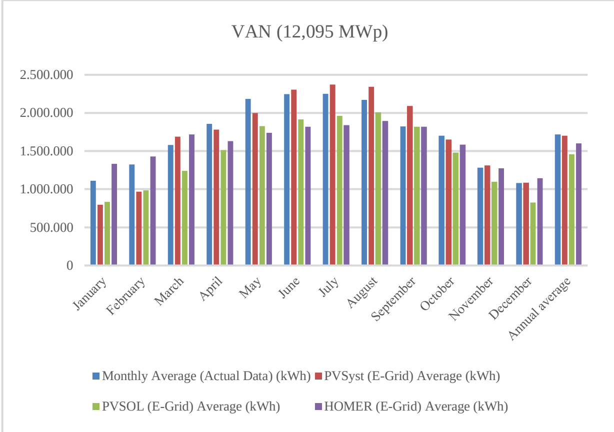

Figure 7. Analysis of Production Data and PVSyst, PVSOL, HOMER Simulation Results for Van Solar Power Plan

5. Conclusion

In this study, the analysis was performed for different climate zones. In 7 different provinces, the actual production data of the power plants are compared with the production data calculated in PVSyst, PVSOL and HOMER software. The mounting angle of the panels in all power plants is 25 o. When we evaluate this inclination angle for the whole of Turkey, even if the latitude angles of the provinces in different climate zones are close to each other, they show different production values due to the change in environmental conditions due to their special locations.

Climatological conditions are thought to directly affect production data and cause variances in software results. If we look at the environmental factors of the geography where the power plant is located, such as precipitation regime and amount, sunbathing/clouding times, and the duration of snow on the ground, we can make sense of the fluctuations in production data. In addition, when we look at the software results, we see that the software can make the correct prediction with almost zero error in some months. In future studies, it can be investigated why this situation occurs and studies can be carried out to make the software provide more accurate results.

In order to increase the accuracy of the software results, it would be useful for the software developers to update the meteorological data to better reflect local climate information. The general belief in the literature about how many degrees the slope angle should be is that the latitude of the location gives the optimum data for annual production. However, it is concluded that the special location of the place may change the optimum slope angle.

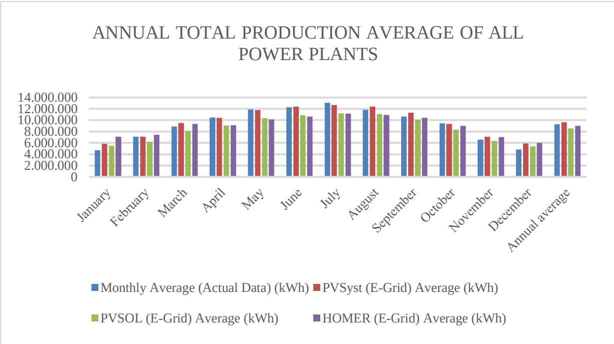

Figure 8. Display of the annual total production average for all power plants

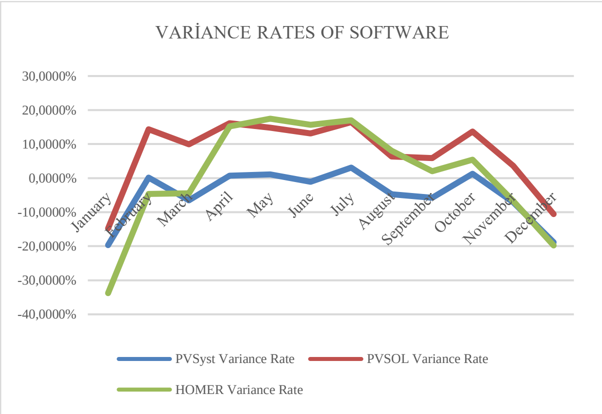

Figure 9. Monthly average variance rates of software

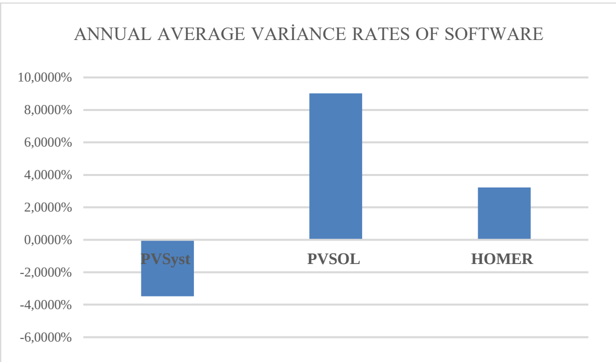

Figure 10. Annual average deviatıon rates of software

Monthly deviation rates of the software varied between -19.6758% and 0.1540% for PVSyst, between -14.7747% and 3.6608% for PVSOL, and between -33.7771% and 2.06% for HOMER. . Accordingly, when the annual results were examined, the deviation rate of PVSyst was found to be -3.4857%, the deviation rate of PVSOL was 9.027% and the deviation rate of HOMER was 3.2238%. The most suitable software for these analyzed power plants was found to be HOMER.

In the literature, a deviation between the software result and real data of less than 10% is considered a sufficient criterion for the reliability of the software. Although there were monthly differences in this study, the deviation value never exceeded 10% based on annual average values. Since making angle adjustments, which is a requirement of a special location when installing solar power plants, requires good observation and knowledge, it will be more beneficial for experts to work on these issues in terms of increasing efficiency. Increasing renewable energy investments increases the importance of using simulation software tools that provide results closest to real values. The use of correct simulation software is important for pre-feasibility analysis and optimization, technical and economic analysis. In addition, pre-investment financing ensures realistic calculation of investment costs and revenues, thus accelerating investors' investments in the renewable energy market. Increasing renewable energy investments is a big step towards the green and sustainable world we will leave to our future.

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