Assessment of PVGIS Accuracy Against EnergyPlus Simulations in Europe

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Abstract

The accurate assessment of solar photovoltaic (PV) system performance depends on the reliability of simulation tools. This study presents a comparative analysis of the EnergyPlus software and the PVGIS web application, using SARAH3 and ERA5 datasets. EnergyPlus enables detailed modeling of PV systems by accounting for a wide range of physical and environmental parameters, while PVGIS provides a simplified and accessible approach. Simulations were performed under identical input conditions for six European locations selected to represent different ranges of solar irradiation. The results show that deviations between the tools vary depending on climatic and geographical factors, with the highest differences occurring during winter, and stronger agreement in summer. ERA5 demonstrates better overall agreement with EnergyPlus, with an average mean deviation of 5.88%, compared to 6.57% for SARAH3. The findings indicate that PVGIS can provide reliable estimates for preliminary assessments, while detailed analyses require advanced tools such as EnergyPlus.

Key words: EnergyPlus; PVGIS; solar PV system; simulation

1. Introduction

The ongoing energy transition is driving increased adoption of photovoltaic (PV) systems, however, investment decisions remain complex, requiring technical and financial knowledge that many users lack. In the early stages, investors often face limited information and administrative and financial barriers, while the benefits of PV systems are less immediately visible [1,2]. Reliable tools for modeling PV performance are therefore essential to support realistic profitability assessments, improve transparency, and enable informed decision making. To address this need, numerous software tools and web applications for PV simulation have been developed, yet they rely on different methodologies and datasets, leading to variations in predicted results. A review by *Kazem et al.* [3] summarizes 36 tools used over recent decades. *Wu* [4], comparing PVWatts and EnergyPlus, reports annual deviations between 4% and 7%, depending on panel tilt. *Mohammadi and Gezegin* [5] compared PVSyst, PVGIS and HOMER software for modeling a 5 MW solar power plant in Afghanistan and found that PVSyst produced the highest energy yield, while PVGIS and HOMER predicted lower values by 10.6% and 2%, respectively. Additionally, *Larasati and Nugraha* [6] report an average deviation of 14.72% for PVGIS compared with experimental data.

In this study, the Photovoltaic Geographical Information System (PVGIS), a widely used web application developed by the European Commission, was evaluated against EnergyPlus. According to [7,8], PVGIS is a free and reliable tool that provides solar radiation and photovoltaic system performance data for most global locations. It considers geographical coordinates, system orientation, panel tilt, and installed capacity, while using historical data and mathematical models to estimate solar irradiation. The importance of accurate meteorological data is emphasized by *Das et al*. [9], who show that solar irradiance is strongly correlated with

PV output, while *Jiménez Torres et al*. [10] demonstrate that converting horizontal irradiance to a tilted plane introduces additional uncertainty, reporting PVGIS errors of around 3.5–3.8%. Moreover, *Meral and Furkan* [11] highlight that PV performance is influenced not only by irradiance but also by atmospheric conditions such as module temperature, ambient temperature, wind speed, and shading, which must be incorporated into simulation models. These findings underline the need for a comprehensive approach to PV modeling: while PVGIS offers fast and accessible estimates, its simplified methods may limit accuracy, whereas advanced tools such as EnergyPlus provide more detailed and reliable assessments. Accordingly, this study evaluates the level of agreement between PVGIS and EnergyPlus to determine the applicability of PVGIS for accurate PV energy yield estimation.

2. Methodology

The power output of a LUXEN 585 W photovoltaic module (technical specifications in [12]) was evaluated using two modeling environments: the PVGIS web application and the EnergyPlus software. Simulations were performed for six European cities: Edinburgh, Hamburg, Prague, Belgrade, Rome, and Málaga. The locations were selected on the basis of the SolarGIS global horizontal irradiation (GHI) map presented in Figure 1 [13]. The sites span different ranges of annual GHI, as indicated by the color scale on the map thereby covering a broad irradiance gradient across Europe. Thus, the selected locations characterize six irradiation ranges and serve as representative examples of comparable European climates. The exact coordinates for the six locations were extracted from the EnergyPlus WeatherData (EPW) files, representing the meteorological stations used in the simulations, and applied as input coordinates in PVGIS to ensure that both tools modeled the same geographical locations. Within PVGIS, two meteorological datasets were used (PVGIS-SARAH3 and PVGIS-ERA5) to evaluate potential differences in the simulation results. For EnergyPlus, the corresponding EPW weather files were used.

PVGIS is a free online tool that allows users to estimate the energy production of a photovoltaic system using a set of basic input parameters (Table 1). Additionally, users can select dataset used in the simulation, choosing between PVGIS-SARAH3 and PVGIS-ERA5 [14]. The SARAH3 dataset is based on Meteosat satellite observations and spans the period 2005–2023, covering Europe, Central Asia, Africa, and parts of South America [15]. For locations outside the SARAH3 coverage area, the ERA5 dataset is recommended. ERA5 is a global reanalysis product that also relies on data from 2005 to 2023 to estimate solar and meteorological conditions worldwide [15]. As these datasets are generated using different methodologies, some variation in the resulting simulation outputs is expected. Input parameters used in the PVGIS simulations are presented in Table 1. For the purpose of this analysis, the system loss effect was neglected. Regarding the panel slope, the value of 38º was adopted, representing the average of the recommended slope values for all the nine locations, determined using the "Optimize slope" function in the PVGIS.

Table 6. *Input parameters used in PVGIS simulations*

PV technology	Installed peak PV power	System loss	Mounting position	Slope	Azimuth
Crystalline silicon	0.585 kWp	0%	Free-standing	38º	0º

EnergyPlus is an open-source, whole-building energy simulation software developed by the U.S. Department of Energy to model thermal behavior and energy performance under dynamic climatic and operational conditions. It integrates building envelope heat transfer, HVAC systems, renewable energy technologies, and control strategies within a single simulation framework [16–18]. Due to its validation and extensive use in scientific research [19–23], EnergyPlus is widely regarded as a reliable tool for analyzing complex building systems under realistic weather conditions. In this study, PV system performance was simulated using the *PhotovoltaicPerformance:EquivalentOne-Diode* model, with input parameters adopted from [12].

Meteorological data were obtained from EPW files for six locations [24], covering the period 2009–2023 and including hourly values of relevant climatic variables such as temperature, wind conditions, solar irradiance, and atmospheric parameters. The PV system was modeled in SketchUp as a fixed, south-facing roof-mounted installation with a tilt angle of 38°, allowing air circulation around the module (Figure 2). System losses were neglected, and identical system configurations were applied across all locations.

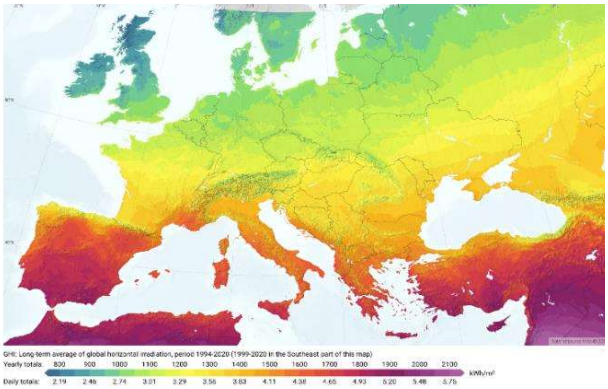

Figure 1. *GHI map of Europe [13]*



Figure 2. *3D model of the fixed roof-mounted PV system*

3. Results and Discussion

EnergyPlus and PVGIS-SARAH3

The results indicate that the PVGIS-SARAH3 dataset generally predicts lower energy yields than EnergyPlus across all analyzed locations. Based on Tables 2–3, the observed absolute deviations between the two tools are: Edinburgh: from 2.77% (March) to 17.32% (November); Hamburg: from 1.29% (October) to 15.32% (December); Prague: from 0.09% (September) to 15.92% (February); Belgrade: from 0% (July) to 19.02% (February); Rome: from 0.19% (June) to 12.81% (November); Málaga: from 1.54% (February) to 10.81% (December). These findings suggest that PVGIS-SARAH3 exhibits the lowest agreement with EnergyPlus during winter months, while no consistent pattern can be identified for periods of strongest agreement Considering the absolute monthly deviations, the number of months with deviations exceeding 10% provides an additional indicator of dataset precision. The counts are as follows: Edinburgh (2), Hamburg (5), Prague (5), Belgrade (3), Rome (1), Málaga (2). Although in some cases higher deviations occur during warmer months (Hamburg, 10.10% in August), most are observed in colder periods, when diffuse radiation is more dominant and total solar gains are more difficult to calculate. Hamburg and Prague exhibit the highest number of such deviations, whereas Rome shows the lowest, followed by Edinburgh and Málaga. This suggests that total solar radiation alone does not directly determine accuracy, and that other influencing factors must be considered. For colder months (October–March), the average deviation is 8.69%, compared to 4.45% for warmer months (April–September). Across all locations, Hamburg and Prague again show the highest mean deviations (8.68% and 7.42%, respectively), while Rome demonstrates the strongest agreement with a value of 4.33%. This trend is largely consistent with the influence of diffuse radiation, as locations with lower diffuse components tend to yield better agreement. However, Málaga deviates from this pattern, with a mean deviation of 5.80%. This can be attributed to its complex topography, which may lead to underestimation of solar irradiance in satellite-based datasets such as SARAH3. Furthermore, the results for Belgrade highlight the influence of air pollution, as the city is significantly polluted during winter months, which corresponds to higher deviations in this period, while summer results show the strongest agreement among all locations. Overall, diffuse radiation, terrain complexity,

and local environmental conditions (air pollution), significantly affect the accuracy of SARAH3 simulations, with an overall mean absolute monthly deviation of 6.57%.

Table 7. *Monthly PV energy production obtained from EnergyPlus (EPW) and PVGIS (SARAH3) for nine analyzed locations, with comparison- part 1*

Month	Edinburgh			Hamburg			Prague		
	EPW [kWh]	SARAH3 [kWh]	Difference	EPW [kWh]	SARAH3 [kWh]	Difference	EPW [kWh]	SARAH3 [kWh]	Difference
Jan	22.99	19.78	13.98%	20.63	18.59	9.90%	28.69	28.02	2.35%
Feb	33.31	32.12	3.56%	37.57	32.34	13.93%	50.17	42.18	15.92%
Mar	55.51	53.97	2.77%	62.82	57.01	9.25%	75.43	65.7	12.90%
Apr	75.27	72.73	3.38%	91.19	80.33	11.91%	93.37	82.8	11.32%
May	84.29	81.18	3.69%	94.52	85.19	9.87%	89.62	87.22	2.68%
Jun	81.29	75.75	6.81%	89.36	84.65	5.27%	89.25	87.91	1.50%
Jul	79.64	76.93	3.41%	85.55	82.61	3.44%	91.44	88.41	3.32%
Aug	72.93	69.34	4.92%	83.39	74.97	10.10%	79.62	83.11	4.39%
Sep	54.94	56.94	3.64%	62.77	63.68	1.46%	72.03	72.09	0.09%
Oct	35.91	39.16	9.04%	45.58	44.99	1.29%	60.96	52.66	13.62%
Nov	22.93	26.9	17.32%	19.92	22.39	12.39%	30.94	28.89	6.64%
Dec	14.36	15.05	4.78%	13.52	15.59	15.32%	22.06	25.23	14.36%

Table 8. *Monthly PV energy production obtained from EnergyPlus (EPW) and PVGIS (SARAH3) for nine analyzed locations, with comparison- part 2*

Month	Belgrade			Rome			Málaga		
	EPW [kWh]	SARAH3 [kWh]	Difference	EPW [kWh]	SARAH3 [kWh]	Difference	EPW [kWh]	SARAH3 [kWh]	Difference
Jan	41.56	39.03	6.08%	58.48	61.04	4.38%	81.23	83.8	3.16%
Feb	60.25	48.79	19.02%	73.27	68.68	6.27%	83.78	82.49	1.54%
Mar	85.08	73.97	13.06%	93.82	85.49	8.88%	107.66	96.12	10.72%
Apr	95.15	83.32	12.43%	101.59	92.12	9.32%	106.62	97.44	8.61%
May	91.57	89.37	2.40%	100.19	97.93	2.25%	110.34	105.54	4.35%
Jun	90.55	90.53	0.02%	100.65	100.46	0.19%	106.89	104.89	1.87%
Jul	100.05	100.05	0.00%	107.74	109.51	1.64%	114.53	109.54	4.36%
Aug	102.85	96.64	6.04%	105.53	106.24	0.67%	114.11	108.95	4.52%
Sep	84.57	80.78	4.48%	92.04	90.64	1.52%	104.28	99.58	4.51%
Oct	66.61	70.85	6.36%	82.01	80.16	2.26%	96.01	90.8	5.43%
Nov	47.24	49.28	4.33%	52.80	59.56	12.81%	71.85	78.85	9.74%
Dec	37.64	34.97	7.08%	56.45	57.45	1.77%	70.26	77.86	10.81%

EnergyPlus and PVGIS-ERA5

The results indicate that the PVGIS-ERA5 dataset provides slightly different outcomes compared to the previous case with PVGIS-SARAH3. Based on Tables 4–5, the observed absolute deviations between PVGIS-ERA5 and EnergyPlus are as follows: Edinburgh: from 1.40% (May) to 22.12% (Dec); Hamburg: from 0.20% (Oct) to 22.02% (Nov); Prague: from 1.01% (July) to 19.21% (Dec); Belgrade: from 0.33% (May) to 16.87% (Jan); Rome: from 0.19% (May) to 10.32% (Nov); Málaga: from 0.62% (Oct) to 15.36% (Nov). Similar to the previous dataset, PVGIS-ERA5 shows the lowest agreement with EnergyPlus during colder months and the strongest agreement in warmer months, indicating that a high percentage of diffuse solar irradiation continues to represent a challenge. When considering the absolute values of monthly deviations, the number of months with deviations higher than 10% again provides an additional measure of dataset precision. The counts are: Edinburgh (5), Hamburg (2), Prague (3), Belgrade (1), Rome (1) and Málaga (2). In this case, all higher deviations occur in colder months, while precision remains strong during warmer periods, confirming the previous observation.

Edinburgh exhibits the highest number of such deviations, followed by Prague, whereas Belgrade and Rome show the most consistent agreement with EnergyPlus. Analysis of the mean absolute monthly deviations indicates that Edinburgh again stands out with 9.86%, while other locations range between 4.23% (Rome) and 5.71% (Prague), again demonstrating that total solar radiation alone does not determine accuracy. For colder months (October–March), the average deviation across all locations is 8.31%, compared to 3.44% for warmer months (April–September). Additionally, during winter months, PVGIS-ERA5 tends to slightly overestimate energy yields compared to EnergyPlus, which may reflect differences in the mathematical modeling approach for diffuse solar radiation. Overall, the mean absolute monthly deviation across all locations is 5.88%, indicating slightly higher precision than PVGIS-SARAH3. Comparing the two datasets, PVGIS-ERA5 generally provides more accurate results for most European locations, with the exception of Edinburgh, where SARAH3 remains slightly more precise.

Table 9. *Monthly PV energy production obtained from EnergyPlus (EPW) and PVGIS (ERA5) for nine analyzed locations, with comparison- part 1*

Month	Edinburgh			Hamburg			Prague		
	EPW [kWh]	ERA5 [kWh]	Difference	EPW [kWh]	ERA5 [kWh]	Difference	EPW [kWh]	ERA5 [kWh]	Difference
Jan	22.99	25.03	8.85%	20.63	21.05	2.02%	28.69	32.18	12.15%
Feb	33.31	38.02	14.16%	37.57	37.31	0.70%	50.17	48.27	3.79%
Mar	55.51	61.68	11.12%	62.82	64.54	2.74%	75.43	73.89	2.05%
Apr	75.27	78.71	4.57%	91.19	88.41	3.05%	93.37	88.3	5.43%
May	84.29	85.47	1.40%	94.52	90.05	4.73%	89.62	90.86	1.38%
Jun	81.29	76	6.50%	89.36	87.31	2.30%	89.25	87.37	2.10%
Jul	79.64	76.09	4.46%	85.55	85.08	0.55%	91.44	90.52	1.01%
Aug	72.93	68.54	6.02%	83.39	78.47	5.90%	79.62	83.1	4.38%
Sep	54.94	56.74	3.28%	62.77	64.39	2.59%	72.03	70.56	2.03%
Oct	35.91	41.02	14.22%	45.58	45.67	0.20%	60.96	53.71	11.90%
Nov	22.93	27.88	21.59%	19.92	24.31	22.02%	30.94	31.91	3.12%
Dec	14.36	17.54	22.12%	13.52	15.42	14.06%	22.06	26.3	19.21%

Table 10. *Monthly PV energy production obtained from EnergyPlus (EPW) and PVGIS (ERA5) for nine analyzed locations, with comparison- part 2*

Month	Belgrade			Rome			Málaga		
	EPW [kWh]	ERA5 [kWh]	Difference	EPW [kWh]	ERA5 [kWh]	Difference	EPW [kWh]	ERA5 [kWh]	Difference
Jan	41.56	48.57	16.87%	58.48	61.75	5.59%	81.234	84.65	4.21%
Feb	60.25	57.92	3.87%	73.27	69.32	5.40%	83.778	89.05	6.29%
Mar	85.08	83.88	1.41%	93.82	90.48	3.56%	107.656	106.35	1.21%
Apr	95.15	91.17	4.18%	101.59	96.13	5.37%	106.622	104.46	2.03%
May	91.57	91.87	0.33%	100.19	100	0.19%	110.341	108.28	1.87%
Jun	90.55	88.78	1.95%	100.65	97.99	2.65%	106.893	104.37	2.36%
Jul	100.05	96.17	3.88%	107.74	104.22	3.27%	114.530	108.28	5.46%
Aug	102.85	94.37	8.25%	105.53	102.64	2.74%	114.107	108.99	4.48%
Sep	84.57	80.87	4.38%	92.04	87.19	5.27%	104.279	100.62	3.51%
Oct	66.61	69.95	5.01%	82.01	79.16	3.48%	96.011	95.42	0.62%
Nov	47.24	51.35	8.71%	52.80	58.25	10.32%	71.851	82.89	15.36%
Dec	37.64	40.5	7.61%	56.45	58.09	2.90%	70.265	77.82	10.75%

4. Conclusions

This study presents a comparative analysis of the EnergyPlus simulation software and the PVGIS web application, using both SARAH3 and ERA5 datasets to assess the energy performance of photovoltaic (PV)

systems across multiple European locations. The analysis was conducted under identical input conditions, with locations selected based on the SolarGIS global horizontal irradiation map to represent different ranges of annual solar irradiation. The results show that deviations between the tools are not uniform, but depend on climatic and geographical factors, terrain complexity, atmospheric pollution, and differences in underlying modeling approaches. The highest deviations are consistently observed during winter months, primarily due to the increased share of diffuse solar radiation, while strong agreement is achieved in summer when direct irradiance dominates. Between the two datasets, ERA5 demonstrates slightly better overall agreement with EnergyPlus, with a mean absolute monthly deviation of 5.88%, compared to 6.57% for SARAH3, although SARAH3 performs better in the case of Edinburgh. Overall, PVGIS shows good agreement with EnergyPlus. It can therefore be considered a reliable tool for simplified and rapid energy yield assessments, while for more detailed and accurate analyses, advanced tools such as EnergyPlus remain more appropriate.

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