Sustainable Cities and Society 80 (2022) 103804

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Evaluation of the technical and economic aspects of solar photovoltaic plants under different climate conditions and feed-in tariff

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ARTICLE INFO

Keywords:
Photovoltaic (PV) module
Soiling factor
Photovoltaic Geographical Information System (PVGIS)
Photovoltaic System (PVSYST)

ABSTRACT

In order to meet the energy demand and reduce the environmental pollution, it is necessary utilize photovoltaic (PV) module to produce electrical energy. There are many factors such as solar radiation, PV module material, wind energy, soiling factor, shading effect, geographical location, cell temperature is affecting the performance of the PV module. In this context, the performance of the multi crystalline based two PV plants has been examined. In this work, test is carried out in two solar plants installed at Kastoria, Greece (500kW, ground mounted) and Kocaeli, Turkey (110kW, roof mounted) and the results are compared with PVSYST software simulation results. From the results, it is found that the temperature losses for Kastoria and Kocaeli plants are obtained as 7.9% and 7.6% respectively. This leads to increase the performance ratio of 79% and 72.2% for Kastoria and Kocaeli plants respectively. Similarly, the maximum energy output is obtained for PVGIS database for all three models (Liu Jordan model, Hay Davies model and Perez model). The Internal Rate of Return for Kocaeli plant is 7.08% and for Kastoria plant is 6.71%. In addition, the Net Present Value for Kastoria and Kocaeli plant is obtained as 821900€ and 174072€ respectively.

1. Introduction

Over the decades, global warming is one of the major issues for many countries around the globe. The excessive usage of fossil fuel is the major cause for the global warming. On the other hand, the fuel cost increasing and the availability of crude in the earth is decreasing gradually. These are the reasons to force the researchers, investors and countries around the globe to look the other energy sources. Though many alternative energy sources are available, because of readily available with zero pollution and free maintenance, solar energy attracted many researchers, investors and countries around the globe to utilize in many applications. During the summer period, the value of global solar radiation will reach upto c.a. 900 – 1000 W/m^2 (El Mghouchi et al., 2016). In this regard the maximum utilization of solar energy by reducing the losses plays an important role to design the solar energy-based systems.

Generally, electrical energy is directly produced form solar energy by using photovoltaic (PV) module. The electrical energy produced from single PV module is very less. This is not sufficient to meet the required energy. In order to meet the energy demand, investors are spending huge money to install solar power plant in many countries (Kosmopoulos et al., 2018, Sanchez-Lorenzo et al., 2013, Griffiths, 2013, Sanchez-Lorenzo et al., 2008). In general, two types of solar based electricity production systems such as 1. Standalone system (off grid) 2. On grid system are used in different applications (Menconi et al., 2016). Though the off-grid system used in many commercial and agricultural applications, because of less power to cost ratio grid connected PV systems obtained more attention among the researchers in developing countries. The metrological conditions are one of the important factors that affects the PV system efficiency (Shukla et al., 2016c). The effective utilization of available solar radiation and the use of correct size PV module are the most important factors to enhance the conversion efficiency. Hence it is necessary to conduct the simulations to manage, distribute the available solar energy and to design the design the solar power plants. To carry out the simulations, the solar radiation and

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https://doi.org/10.1016/j.scs.2022.103804
Received 19 June 2021; Received in revised form 23 February 2022; Accepted 23 February 2022
Available online 25 February 2022

temperature data are required. These data can be collected from different solar measurement stations. Due to the distance between the measurement station and the photovoltaic installation site, the accuracy of the data may reduce (Li and Lam, 2000). Owing to the non-availability of self-measured value, the data which are available in different metrological databases can be sued in simulation.

Numerous studies have been carried out to simulate and study the performance of the PV system with different metrological databases. Quesada et al. (Quesada et al., 2011) developed a dynamic model of a 7.2 kWp power plant and these results are compared with experimental results. During their study, the monocrystalline PV module was used and the model was developed in TRANSYS. Based on their results, the radiation model and the weather data base provide the difference upto 5% and 11% respectively. The model of a 250Wp PV system was developed by Molina and Espejo (Molina and Espejo, 2014). To carry out this study, PV simulation and evaluation Tool (PVSET 1.0) was used and the results are validated with MATLAB/Simulink model. Their study result showed that the results of PVSET model is good agreement with the MATLAB Simulink model.

Cao et al. (Cao et al., 2022) carried out am techno economic analysis to assess the performance of solar and geothermal hybrid energy system using TRANSYS software. The proposed system consists of hybrid solar collector, turbine, chiller unit, pump and storage unit. In this research, maximum of 55.9% exergy efficiency achieved in July and 22.8% obtained in December. Similarly, peak value of 32.77 $/GJ unit product cost obtained in July. Suman et al. (Suman et al., 2021) proposed an algorithm to optimize the configuration of micro grid to obtain reliable power supply. For this purpose, a hybrid power generation system with solar, wind, diesel and battery were considered and hybrid Particle Swarm Optimisation-Grey Wolf Optimiser (PSO-GWO) was used. The test was carried out three different locations and the results show that the Gorigama is the best location compared with Hariharpur and Gurmia. The obtained cost of electricity for Gorigama, Hariharpur and Gurmia are 0.1693 ($/kWh), 0.1742 ($/kWh) and 0.1809 ($/kWh) respectively.

Ouria, and Sevinc (Ouria and Sevinc, 2018) examined the potential application of solar energy in Famagusta city, Cyprus with considering the climatic and Geographic factors. By using DuffieBeckman and Stephenson's cousin methods, the geographic parameters, Height to width ratio and landscape analysis etc. were analysed. Based on these results, the authors concluded that the landscape is poor greenery, solar tools and having more shading problems. To obtain maximum solar energy, the optimum tilting angle 45 - 60° was considered.

Initially, many researchers have performed the test on horizontal plane. But in practical, solar modules are placed in the same inclined position. Hence these data with horizontal plane are not adequate and cannot be used for the tilted position PV systems. In this context, the researchers have developed model to estimate the total solar irradiation on the tilted planes by using the horizontal data (Notton et al., 2006). In order to monitor, model and simulate the grid connected PV systems, LabVIEW platform was used by Chouder et al. (Chouder et al., 2013). In this study, the dynamic behavior of the PV system was studied with the inverter model. The results of this developed model were compared with the grid connected PV system which is available in Centre de Développement des Energies Renouvelables (CDER) in Algeria. This model results are good agreement with the experimental value.

The researchers have developed different models by considering different parameters and analyzed the performance of the PV systems (De Coninck et al., 2010, Hossain et al., 2017, Diez-Mediavilla et al., 2005, Demain et al., 2013, Padovan and Del Col, 2010). Furthermore, the researchers calculated the PV system energy with considering several losses such as temperature losses, soiling losses, photovoltaic module efficiency losses and inverter efficiency losses etc. The performance of a 5 kWp grid connected PV system installed in Morocco was studied by Attari et al. (Attari et al., 2016). The results of this study showed that the annual electricity yield is 6411.3 kWh and the performance ratio is 79%. Also found that the maximum of about 16% losses observed in the network. Similarly, the minimum of 3.28% is observed in the grid connected system. The performance behavior of the grid connected PV system was studied with the recorded data by Roumpakias. and Stamatelos (Roumpakias and Stamatelos, 2019). This study was carried out for six years (2013 – 2018) and they found that the energy yield varies from 1467.7 to 1675 kWh/kWp without including the AC wiring losses. These results are good agreement with the conclusions of PR analysis. Milosavljević et al. (Milosavljević et al., 2015) analyzed the performance and energy efficiency of a 2kW solar PV plant in Republic of Serbia with considering global solar radiation, atmosphere temperature, wind velocity etc. This study results showed that the annual efficiency of the PV plant is decreased with increase of temperature and 93.6% of the performance ratio was obtained.

The annual yield, inverter efficiency, system losses and performance ratio of 2130.7 kWp of grid connected PV power plant was studied by Cubukcu and Gumus (Cubukcu and Gumus, 2020). Based on the outcome of this study, it was found that about 4.53h/d, 81.15%, 13.18% and 18.86% of final yield, performance ratio, system efficiency and capacity factor was obtained respectively. Kymakis et al. (Kymakis et al., 2009) presented the performance of a 171.36 kWp grid connected PV park in Island of Crete, Greece. This study was carried out with real data of PV systems and found that the obtained average annual performance ratio of the system and the energy output was 67.36% and 1336.4 kWh/kWp respectively. Also, the results revealed that about 5%, 7.12%, 5.86%, 6%, 7.84%, 2% and 4.54% of PV degradation, losses, temperature losses, soiling losses, internal network losses, inverter losses, transformation losses and grid connection losses are obtained respectively. Hussain et al. (Liu and Jordan, 1963) investigated the effect of soling loss on PV module and about 33.54% short circuit current loss was observed also they suggested to use anti-soiling coating, economics of different cleaning processes, and the soiling loss at variable humidity, wind speed, and tilt angle to enhance the PV module performance. Cavieres et al. (JE, 1980) used Artificial Neural Network (ANN) tool to find the impact of soiling effect and partial shading on PV module. This study results revealed that about 73% of an accuracy and the predicted power loss are divided into 8 percentiles from 0 to 100%.

Based on the above literature, it was found that the solar energy based system having more potential than other renewable energy based system. Though many researchers carried out their research to study the PV system performance, these results are based on fixed location. This research results are not sufficient for the investors to identify the suitable location to install the PV system. There is a huge gap available between the researchers and investors. The installed capacity of solar photovoltaic plants has increased gradually due to decreasing costs of expensive equipment, increasing support mechanisms of governments and increasing awareness of environmental problems caused by fossil fuels. Furthermore, the calculation of energy production of solar photovoltaic plants under real weather conditions is not only important for researchers but also for investors. In this way, local studies have critical important for the sustainability. In this regard, the performance of three PV systems solar radiation models with two different metrological databases is examined in this research. To study the performance, multicrystalline PV module 500kW mounted in ground at Kastoria Greece and 110 kW mounted in building roof Kocaeli, Turkey PV plants are considered. Finally, the results are compared with the statistical test results. These results help the investors to identify the suitable location to produce maximum electrical energy by utilizing the available solar energy.

2. Materials and Methods

To study the PV plant energy production, the simulation test was carried out with solar irradiation and temperature values of two different cities. Initially, the radiation and temperature values are measured by using fully automated system at Kastoria, Greece (Fig. 1)

Fig. 1. Geographical map of Kastoria, Greece (Source: Google Map).

Kastoria is located (40° 31' N and 21° 16' E) is located in the geographic region of Macedonia. Then the same values are measured at Kocaeli, Turkey. Kocaeli (40° 51' N and 29° 52' E) is located in North-eastern side of Turkey and bounded by the Black Sea and Marmara (Fig. 2). The average wind speed and temperature of about 10 – 12 mph and 75-85°F are obtained during the testing period. Similarly, the average wind speed (6 – 7 mph) and Temperature (77 - 85°F) are obtained at Kastoria, Greece.

The monthly and daily average solar irradiation and temperature values from PVGIS – CMSAF (2007-2016) and NASA-SSE (1987-2013) databases. PV plants are modelled with real PV module and inverters in PVSYST simulation software. Liu and Jordan, Hay and Davies, Perez models are used as solar radiation model in this study. The solar radiation model and Metrological database performances are also evaluated using RMSE (Root Mean Square Error), MBE (Mean Bias Error) statistical test methods and percentage error. In addition to energy calculations are also performed in this research. For this analysis wind speed 1.5 m/s albedo value (ground reflection coefficient) is 0.2 and soiling factor is 0%, 1% and 3% respectively are assumed. PV module is positioned towards in south direction with tilt angle of 25° and 15° at Kastoria and Kocaeli respectively. To carry out economical study solar feed in tariff of about 13.3 $ cent / kWh and 9€ cent / kWh in turkey and Greece respectively.

2.1. Data Reduction

2.1.1. Estimation of Total Solar Irradiation on Tilted Surfaces

In order to utilize the maximum solar radiation, PV modules are placed at some inclined positions. Generally, the total solar radiation consists of three main parameters such as beam radiation ($I_{T,b}$), diffuse radiation (isotropic ($I_{T,d,iso}$), circumsolar ($I_{T,d,CS}$) and horizon brightening ($I_{T,d,hz}$) and reflected radiation (($I_{T,refl}$) from various surfaces. The total solar radiation (I_T) on the tilted surface can be computed as

$$I_T = I_{T,b} + \left(I_{T,d,iso} + I_{T,d,CS} + I_{T,d,\,hz}\right) + I_{T,\,refl} \quad (1)$$

Where $I_{T,b}$ - beam radiation, $I_{T,d,iso}$ - diffuse radiation (isotropic), $I_{T,d,}$

Fig. 2. Geographical map of Kocaeli, Turkey (Source: Google Map).

$_{CS}$ – circumsolar radiation, $I_{T,d,hz}$ - horizon brightening radiation and $I_{T,refl}$ - reflected radiation

Sky models are mathematical representations of solar radiation. There are lots of models have been derived and the main difference among them is the way they treat three parts of diffuse radiation. Liu and Jordan (Perez et al., 1990) assumed all the diffuse radiation was uniformly distributed over the sky, Hay and Davies (RETSCREEN 2004) didn't take horizontal brightening into account while Perez et al. (SMA 2014) had all of the diffuse terms. The equations to find the total solar radiation are summarized in Table 1.

2.1.2. Estimation of Electricity on Calculation

Electrical output of a PV plant is depending on the monthly average array efficiency, total module area, total incident solar radiation, inverter efficiency etc. (Robaa, 2008). This can be calculated by using equation (2).

$$E_t = \eta_l \times A_C \times I_T \times \eta_{inv} \times [(1 - \lambda_P)(1 - \lambda_C)] \tag{2}$$

Where η_l is the average array efficiency, A_c is the collector area, I_T is the total solar radiation, η_{inv} is the inverter efficiency and

Where

2.1.3. Testing methods

Performance ratio (PR) is the ratio of actual energy output and theoretically energy output of PV systems (Glover and McCulloch, 1958).

$$PR = \frac{Actual\ Output}{Theoritical\ nominal\ Output} \tag{3}$$

Mean Bias Error (MBE) is used to evaluate the accuracy of prediction and this method gives information on long-term performance of model. In ideal case it values is equal to zero otherwise low MBE is desired (Brigham, 1979).

$$MBE = \frac{\sum(Extimated\ Value - Observed\ Value)}{Number\ of\ observations} \tag{4}$$

Root Mean Square Error (RMSE) is used to evaluate the accuracy of prediction and this method gives information on short-term performance of model. Its values are always positive and the smaller value of RMSE is always desired (Costa et al., 2021).

$$RMSE = \sqrt{\frac{\sum(Extimated\ Value - Observed\ Value)^2}{Number\ of\ observations}} \tag{5}$$

Percentage error is used to see difference between estimated and actual (observed) value or in other words; it is the measure of uncertainty.

$$\%\,Error = \frac{(Extimated\ Value - Observed\ Value)}{Actual\ Value} \times 100 \tag{6}$$

2.1.4. Economic Analysis

Payback period (PB) calculates how long it takes to recover the cost of project and it can be calculated as (Kimber et al., 2006).

$$Payback\ Period = \frac{Investment\ required\ for\ a\ project}{Net\ Annual\ cash\ in\ flow} \tag{7}$$

Internal Rate of Return (IRR) is discount rate that makes the net present value of all cash flows equal to zero. This can be expressed as (Kimber et al., 2006).

$$NPV = \sum_{i=1}^{i} \frac{C_i}{(1 + IRR)^i} - C_o = 0 \tag{8}$$

Net present value (NPV) is the sum of the present value of cash inflow and cash outflow over a period of time and given by (Kimber et al., 2006).

$$NPV = \sum_{i=1}^{T} \frac{C_i}{(1 + r)^i} - C_o \tag{9}$$

Where C_i is the cash inflow, C_o is the cash outflow, i is the time period and r is the discount rate.

Table 1
Summary of equations used to find the solar radiation.

Solar radiation Model	Equation
Liu and Jordan (Perez et al., 1990)	$I_T = I_{h,b}R_b + I_{h,d}\left(\frac{1+\cos\beta}{2}\right) + I_{h,\rho}\left(\frac{1-\cos\beta}{2}\right)$
Hay & Davies (RETSCREEN 2004)	$I_T = (I_{h,b} + I_{h,d}A_i)R_b + I_{h,d}(1 - A_i)\left(\frac{1+\cos\beta}{2}\right) + I_{h,\rho}\left(\frac{1-\cos\beta}{2}\right)$
Perez et al. (SMA 2014)	$I_T = (I_{h,b}R_b) + I_{h,d}\left[(1 - F_1)\left(\frac{1+\cos\beta}{2}\right) + F_1\frac{a}{b} + F_2\sin\beta\right] + I_{h,\rho}\left(\frac{1-\cos\beta}{2}\right)$

3. Results and Discussions

This section examines the impact of soiling factor on the energy production of PV plant. In this study, three different cases such as case I, case II and Case III are considered. In the case I, soiling factor is zero and PVGIS database only considered. During the case II, three different soiling factors such as 0%, 1% and 3% are considered with PVGIS database. Case III is similar to the Case A. but in case C, both PVGIS and NASA database are considered. Furthermore, the economic results such as payback period, internal rate of return (IRR) and net present value (NPV) are discussed.

3.1. CASE I

In this case, the simulation test was carried out to find the peak power, PV efficiency, energy production and performance ratio etc. this test was conducted at Kastoria and Kocaeli at standard operating conditions (STC) (i.e. 25°C cell temperature, 1000 W/m^2 solar irradiation and air mass 1.5 spectrum) with only PVGIS database and zero soiling factor. The obtained results are presented in Figs. 3 and 4. These results are clearly showed that the peak power of PV plant located at Kastoria is higher than that of the Kocaeli plant. Similarly, Kastoria plant provides 14.42% PV efficiency at STC. But the PV plant efficiency of the Kocaeli plant is slightly high compare with the Kastoria plant. In addition, the yearly energy production of the Kastoria plant is very high (700 MWh) compared with that of the Kocaeli plant (130.7 MWh). The obtained performance ratio for the Kastoria and Kocaeli plants are 79% and 72.2% respectively. These simulation results clearly indicate that the PV plant with ground mounted PV module provides better efficiency than that of roof Mounted PV module.

Generally, the PV plant efficiency is affected by different parameters such as atmosphere temperature, solar irradiation, PV module material, Wind speed etc. Due these parameters, the losses in the PV plant are increasing. Hence, different loss calculations are carried out in this research. Based on the simulation output, the obtained temperature loss for Kastoria and Kocaeli plants are 7.9% and 7.6%. While fixing the PV module on the ground, the soil heat is transferred to the PV module that affects the PV plant performance. This is the reason to obtain more temperature loss in the Kastoria PV plant. Shading is another problem that affects the performance of the PV plant. This problem is more common in the roof mounted PV plant. Hence the peak shading loss of 12.9 % is obtained for Kocaeli plant. Whereas for Kastoria plant it reduced to 1.9%. Due to this reason, less light is transmitting through the glass in the PV module. Hence less Incident Angle Modifier (IAM) loss is obtained for Kocaeli plant. But slightly high IAM loss (i.e. 2.9%) is obtained for Kastoria plant. The obtained inverter efficiency losses for

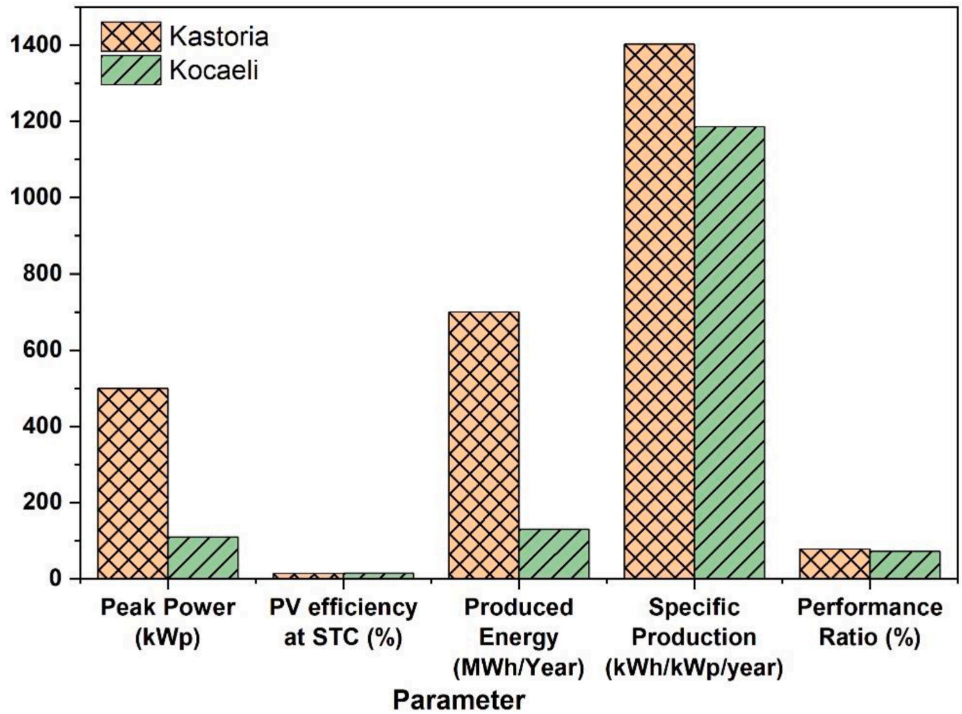

Fig. 3. Simulation results of Kastoria and Kocaeli plants.

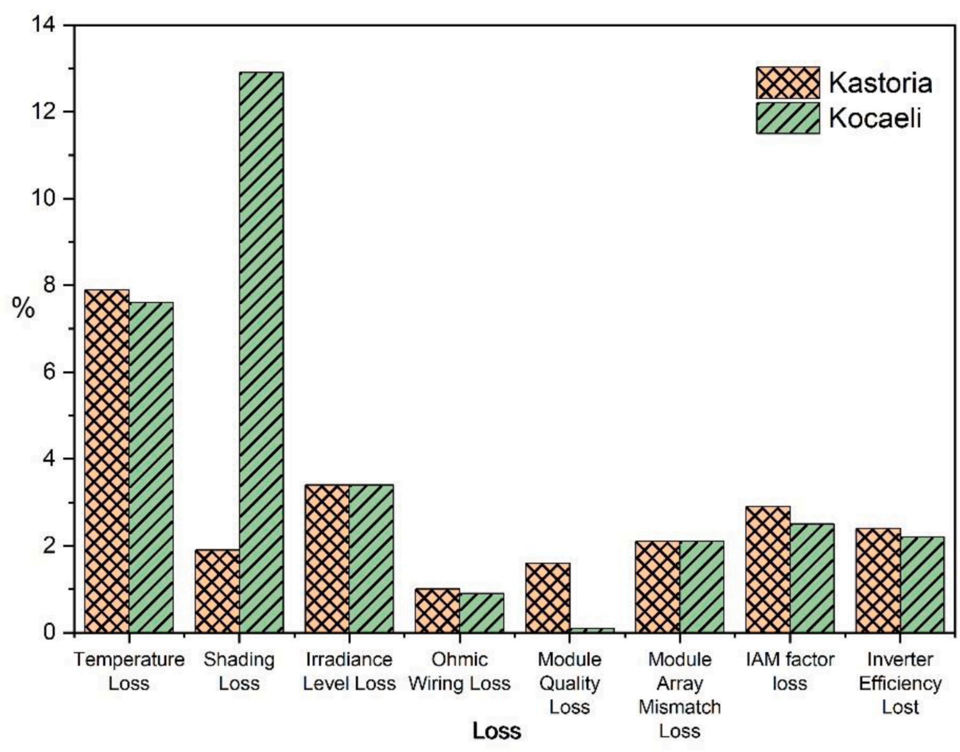

Fig. 4. Losses of Kastoria and Kocaeli plants.

Kastoria and Kocaeli plants are 2.4% and 2.2% respectively. Many researchers carried out the research at different locations and obtained same trend of results. The comparison of this research result with the previous study results is given in Table. 2. The findings of this study clearly indicates that the efficiency of the PV plant located at Kocaeli, Turkey is higher than that of Kastoria plant. From this it can be suggested to the investors that the rate of return for the Kocaeli plant is high compared with the Kastoria plant.

3.2. Case II

The impact of soiling factor on the energy output of the PV plant is analyzed in this case. The effect of soiling factor on the statistical results studied as well. This study was carried out with three different soiling

Table 2
Comparison of results with previously published article results.

Ref.	Authors	Region	Factor considered	Analysis type	Key points	Conclusions
(Hanifi et al., 2020)	Costa et al. (2021)	Brazil	Dust	Experimental	Study carried out in 3 different locations such as Belo Horizonte (Minas Gerais), Porto Alegre (Rio Grande do Sul), Brotas de Macaúbas (Bahia) for 5 years	Found that the soiling affects the performance of the PV module significantly during the winter period.
(Chanchangi et al., 2021)	Kimber et al. (2006)	USA	Dust	Simulation	The empirical model was developed to calculate the performance degradation by using the real time test results.	PV module performance decreased by 0.2%/ day during the summer period and losses reach to 1.5 to 6.2%/year.
[38]	Hanifi et al. (2020)	Germany	Dust	Simulation and experimental	Effect of soiling on three different module designs such as full cell and half-cell layout was analyzed experimentally and the results are validated with simulation results.	65% more power output is obtained in portrait orientation compared to the full cell layout.
[39]	Chanchangi et al. (2021)	Nigeria		Experimental	Effect of wind, rain, humidity and dust on PV module performance was analyzed.	A yield loss of 78.3% for a-Si, 77% for CdTe, 70% for pc-Si and 68.6% for the mc-Si module are obtained.
	Current study	Kastoria, Greece and Kocaeli, Turkey		Simulation	The impact of soiling factor on the energy production of PV plant was studied with PVGIS and NASA database	12.9 % and 1.9% power loss reduction is obtained for Kocaeli plant and Kastoria plant respectively

factors (i.e. 0%, 1% and 3%) with PVGIS database. The energy output of the PV plant was found by using Liu – Jordan model. Finally, the obtained results are compared with the Hay – Davies model and Perez et al. model. The variation of energy output for three different soiling factor is illustrated in Fig. 5 also the variation of percentage error for different soiling factor is depicted in Fig. 6. This simulation outcome clearly indicates that the PV plant with 0% soiling factor yields more energy output with less error percentage. Whereas the energy output is decreasing with increasing of soiling factor. For 1% and 3% soiling factor the obtained energy output is 686.87 MWh and 672.23 MWh respectively. While using Hay – Davies model, the obtained energy output values are 692.82 MWh and 678.03MWh. These values are further increased to 706.02 MWh and 690.93 MWh respectively. Furthermore, the error percentage values are increasing while increasing the soiling factor. Compared with other models, the least error percentage is obtained for Perez et al. model.

The same trend of results also obtained for PV plant located at Kocaeli. Around 124.08 MWh, 126.09 MWh and 127.51 MWh energy output values are observed for the PV plant with 0% soiling factor with Liu Jordan Model, Hay- Davies model and Perez et al. model respectively. In the case of 1% soiling factor the values are decreased to 123.29 MWh, 124.77 MWh and 126.18 MWh respectively. Whereas for 3% soiling factor, these values are further decreased to 120.85 MWh, 122.12 MWh and 123.50 MWh respectively. Generally, the term soiling factor denotes the deposition of unwanted particles such as dust, dirt, snow etc. on the PV module. When more particles accumulated on the PV module

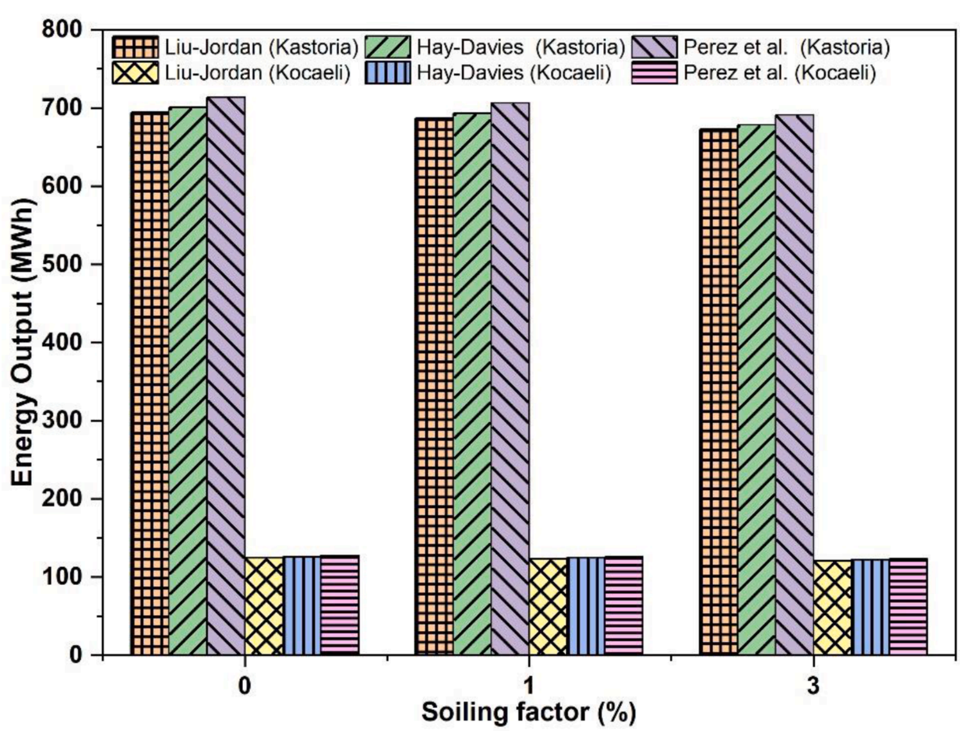

Fig. 5. Variation of energy output for three different soiling factor.

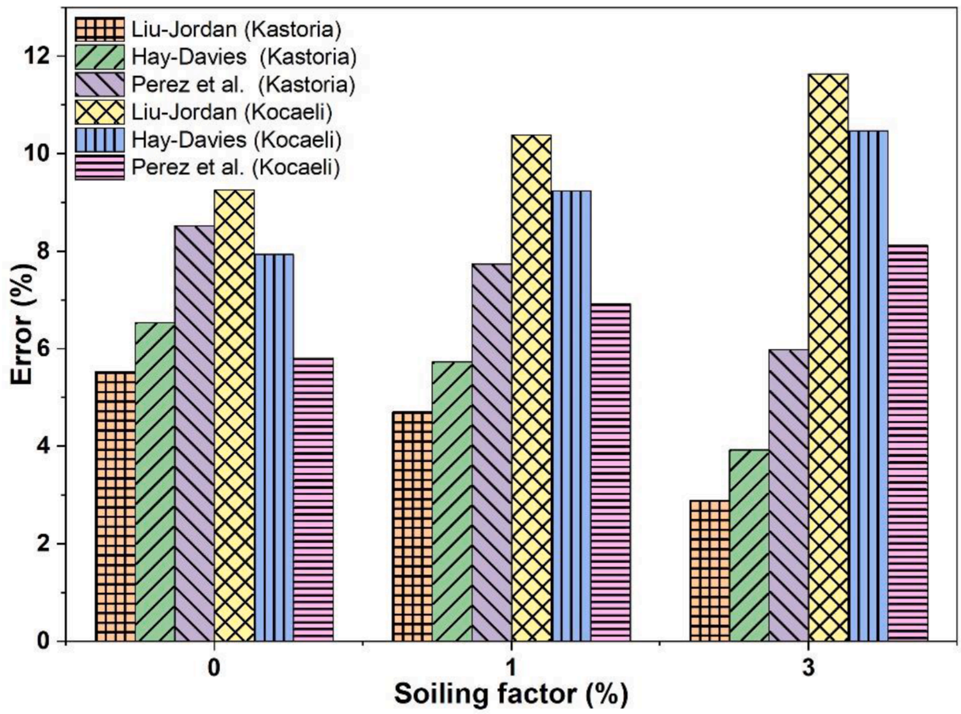

Fig. 6. Variation of Percentage error for three different soiling factor.

surface, the soiling factor values also increased. Hence, the PV module absorbs less solar radiation and produces less power. This might be the reason to obtain less energy output for 3% soiling factor in all the models.

3.3. Case – III

In the case III, the soiling factor is assumed as zero and the energy output is estimated by using PVGIS database and NASA database. During the simulation, the average global solar radiation and average ambient temperature are considered as 1582.7 kWh/m^2, 12°C for PVGIS database and 1478.9 kWh/m^2, 12.2°C for NASA database respectively. The obtained simulation results are tabulated and presented in Table 3 and Table 4. Based on this simulation result, it is observed that the maximum energy output is obtained for PVGIS database in all models. For NASA database, around 647.06 MWh and 659.63 MWh energy output are obtained for Hay Davies model and Perez et al model respectively. Additionally, the peak error percentage values of about 11.95% is achieved for Hay Davies model with NASA database.

This test is conducted from January to December and the energy production rate is estimated. These values are compared with the two different database simulation results and presented in Fig. 7. From this figure, it can be seen that the amount of energy production rate is gradually increased from January to July, then the decreasing trend is observed till December. Generally, the solar intensity will be high during the month of May, June, July and August. Hence more solar radiation is absorbed by the PV module. This will be the reason to obtain more energy production rate during this period.

Table 3
Comparison of Databases in terms of Solar Irradiation on Horizontal and Ambient Temperature for Kastoria.

Database	Global Solar Irradiation on Horizontal (kWh/m^2)	Average Ambient Temperature (C °)
PVGIS-CMSAF	1592.7	12.0
NASA-SSE	1478.9	12.2

Table 4
Comparison of Energy productions of Kastoria; PVGIS and NASA databases.

	Hay-Davies (RETSCREEN 2004)		Perez et al. (SMA 2014)	
Database	Energy (MWh)	Error %	Energy (MWh)	Error %
PVGIS-CMSAF	700.27	4.71	713.56	2.90
NASA-SSE	647.06	11.95	659.63	10.24

Note: Actual Energy Output is 734.92 MWh.

The same procedure is repeated for PV plant located at Kocaeli and the obtained results are tabulated and given in Table 5 and Table 6. Based on the results, it can be observed that the maximum of 127.52 MWh energy production and 11.64 error percentage are achieved for Perez et al model with PVGIS database. Whereas for NASA database, the value decreased to 120.99 MWh and 5.95%. While using Hay Davies model, the energy production and error percentage values are obtained as 126.09 MWH and 10.39% respectively. The variations of energy production rate with different model are illustrated in Fig. 8. The obtained results are in similar trend with the results obtained for PV plant located at Kastoria. It can be seen the Peak energy production rate of about 15.55 MWh is obtained for Perez et al. model with PVGIS database. Similarly, the least energy production rate is obtained as 16.38 MWh for Hay Davies model with NASA database.

3.4. Statistical Analysis

In this study, statistical analysis is carried out and the results of short term and long term statistical test are presented in Table 7 and Table 8 respectively. In order to complete this analysis, MBE and RMSE are calculated by using the estimated values and the measured values. Actual energy production values are compared with results of estimations from PVSYST software [38] by using three solar radiation models and two meteorological databases (NASA-SSE and PVGIS-CMSAF) in terms of some statistical test results. Based on the obtained results, it is found that the peak RMSE value of 8.79 MWh is obtained for the PV plant with NASA – SSE database at Kastoria. For the Kocaeli plant about

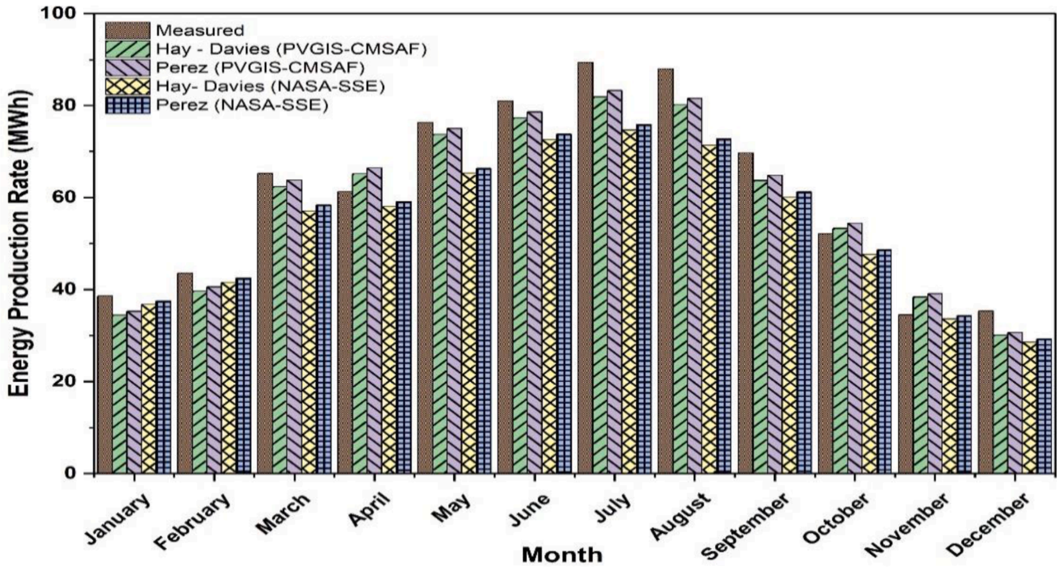

Fig. 7. Comparison of Monthly Energy Production of Kastoria by using different Meteorological Databases.

Table 5
Comparison of Databases in terms of Solar Irradiation on Horizontal and Ambient Temperature for Kocaeli.

Database	Global Solar Irradiation on Horizontal (kWh/m^2)	Average Ambient Temperature (C ^{o})
PVGIS-CMSAF	1523	13.2
NASA-SSE	1470	13.2

Table 6
Comparison of Energy productions of Kocaeli; PVGIS and NASA databases.

	Hay-Davies (RETSCREEN 2004)		Perez et al. (SMA 2014)	
Database	Energy (MWh)	Error %	Energy (MWh)	Error %
PVGIS-CMSAF	126.09	10.39	127.52	11.64
NASA-SSE	119.58	4.69	120.99	5.95

Note: Actual Energy output is 114.22 MWh and covers only 11 months excluded January.

1.92 MWh and 1.75 MWh RMSE values are obtained for PVGIS database and NASA – SSE database respectively by using Hay – Davies model. For the Perez et al model, thses values are slightly increased to 1.99 MWh and 1.78 MWh respectively. Whereas for the Kastoria plant these values are significantly increased to 4.74 MWh and 8.79 MWh respectively. The peak error percentage of about 19.19% is achieved for PV plant with PVGIS database at Kocaeli by using Perez et al. model.

Similar kind of results are obtained for long term test as well. These results clearly indicates that about 11.64 % of MBE is obtained for PV plant with PVGIS database at Kocaeli using Perez et al. model. Whereas for Hay – Davies model, these values are decreased to 10.39% and 4.69% for PVGIS database and NASA – SSE database respectively.

3.5. Economic Analysis

The detailed economic analysis of the PV plant is carried out by considering the PB, NPV and IRR. As per the equations (7), (8) and (9), the obtained results for Case I are listed in the Table 8. The details available in the Table 9 clearly shows that the PV plant located at Kastoria yields 1403 kWh/kWp. This value is slightly higher compared with Kocaeli plant (i.e. 1186 kWh/kWp). Similarly, about 79% and 72.2% performance ratio is obtained for Kastoria and Kocaeli plant respectively. The payback period for Kastoria plant is 11.5 years is obtained for Kocaeli plant. For Kocaeli plant the IRR is obtained as 7.08% whereas for Kastoria plant this value is slightly reduced to 6.71%. Finally, the NPV for Kastoria and Kocaeli plants are obtained as 821900 and 174072 € respectively.

Similar trend of economic results is obtained for the Case – II as well. The obtained results for case – II are summarized in Table 10. In this case, the highest NPV value of about 906212€ is obtained for the Kocaeli plant. Compared with the case – I, slightly high IRR value (i.e 9.02%) is obtained for Kocaeli plant.

4. Conclusions

A simulation test is carried out to study the impact of soiling factor on the performance of PV module in this study. During this study, three different cases such as Case – I (soiling factor is zero and PVGIS database), Case – II (soiling factors - 0%, 1% and 3% with PVGIS database) and case – III ((soiling factor is zero and PVGIS and NASA database) are considered. Also, the economic analysis is carried out by considering payback period, net present value and the internal rate of return. The important findings of this study are summarized and given as follows.

1 From the results, it can be found that the soiling effect of a PV system is mainly depends on the climate conditions. The case – I simulation results indicates that the performance ratio of the PV plant located at Kastoria is higher than that of the Plant located at Kocaeli.
2 Based on the Case – II results, a slight drop in energy production is observed with soiling factor in both plants. For Kocaeli plant, the values ranged from 672.23 MWh to 686.87 MWh for soiling factor 1% to 3%. Whereas for Kastoria plant, the values ranged from 123MWh to 120.85 MWh. This results clearly indicates that the energy output of the PV system is indirectly proportional to the soiling factor
3 The analysis of energy output for Hay Davies model and Perez et al model is found to be significant and from this it can be found that, a slight drop in energy production with less error percentage is observed in Hay Davies model compared with Perez et al. model in PVGIS-CMSAF and NASA - SSE data base. Hence, the Perez et al. model is most suitable to estimate the PV plant energy output located in Kocaeli and Kastoria
4 The payback period for Kastoria plant is 11.5 years is obtained for Kocaeli plant. For Kocaeli plant the Internal Rate of Return (IRR) is

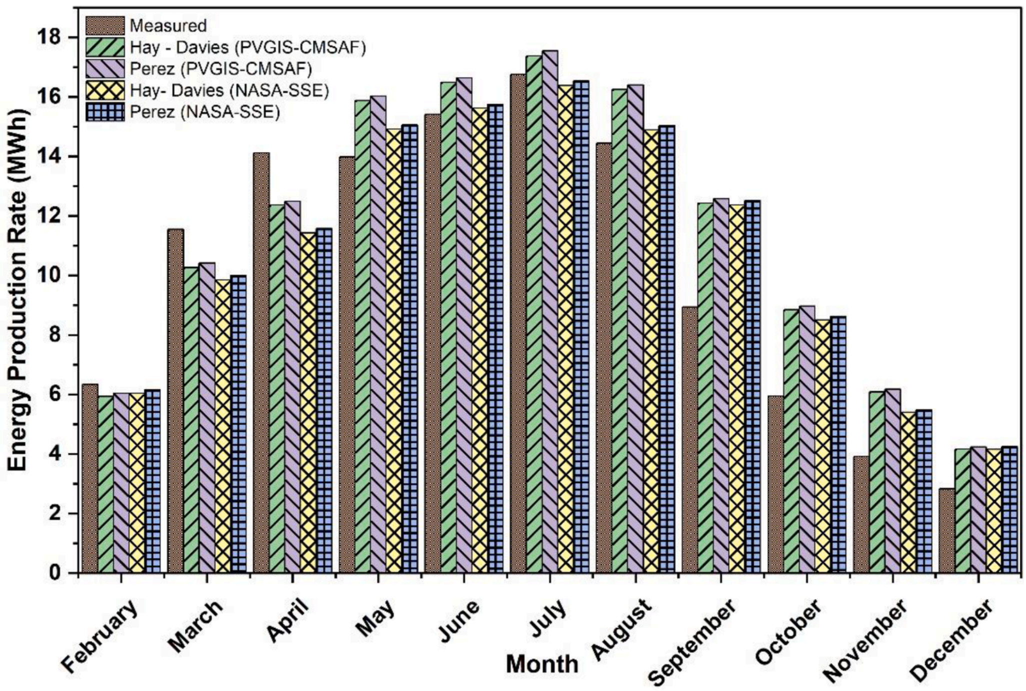

Fig. 8. Comparison of Monthly Energy Production of Kocaeli by using different Meteorological Databases.

Table 7
Short Term Statistical test results.

Database	Hay-Davies (RETSCREEN 2004)				Perez et al. (SMA 2014)			
	Kocaeli		Kastoria		Kocaeli		Kastoria	
	RMSE (MWh)	RMSE %	RMSE (MWh)	RMSE %	RMSE (MWh)	RMSE %	RMSE (MWh)	RMSE %
PVGIS-CMSAF	1.92	18.48	4.74	7.74	1.99	19.19	4.13	6.75
NASA-SSE	1.75	16.9	8.79	14.36	1.78	17.21	7.85	12.82

Table 8
Long Term Statistical test results.

Database	Hay-Davies (RETSCREEN 2004)				Perez et al. (SMA 2014)			
	Kocaeli		Kastoria		Kocaeli		Kastoria	
	MBE (MWh)	MBE %	MBE (MWh)	MBE %	MBE (MWh)	MBE %	MBE (MWh)	MBE %
PVGIS-CMSAF	1.08	10.39	-2.89	-4.71	1.21	11.64	-1.78	-2.9
NASA-SSE	0.49	4.69	-7.32	-11.95	0.62	5.93	-6.27	-10.24

Note: Negative Values of MBE mean under estimation.

Table 9
Economic Analysis for case I.

		Kastoria (Greece)	Kocaeli (Turkey)
Installation Type		Ground-mounted	Roof-mounted
PV Capacity	kWp	500	110
Solar irradiation on horizontal	kWh/m^2	1592.4	1523.0
Estimated performance	kWh/kWp	1403	1186
Performance Ratio	%	79	72.2
Payback Period	years	11.5	10.5
IRR	%	6.71	7.08
NPV	€	821900	174072
Feed-in tariff *	€cent/kWh	9.0	12.21

obtained as 7.08% whereas for Kastoria plant this value is slightly reduced to 6.71%.

From the above results, it can be seen that the estimated energy outputs and statistical test results are high for the PV plant located at Kocaeli compared to Kastoria plant. It is also seen that the choice of meteorological database is so important that affects the energy output and statistical test results significantly. For both plants NASA-SSE database offers lower solar irradiation accordingly lower energy output values than PVGIS-CMSAF. It can be recommended that if it is possible to measure solar irradiation and temperature values at PV installation sites that would lead better results by including soiling and shading losses. The results of this simulation study can be applied to build a new solar photovoltaic plant in Kastoria and Kocaeli.

Table 10
Economic Analysis for case II.

		Kastoria (Greece)	Kocaeli (Turkey)
Installation Type		Ground-mounted	Ground-mounted
PV Capacity	kWp	500	500
Solar irradiation on horizontal	kWh/m^2	1592.4	1523.0
Estimated performance	kWh/kWp	1403	1317
Performance Ratio	%	79	78.5
Payback Period	years	11.5	9.5
IRR	%	6.71	9.02
NPV	€	821900	906121
Feed-in tariff *	€cent/kWh	9.0	12.21

***Note:** Feed-in-tariff is the guarantee payment contract for the electricity that is produced by renewable energy sources over a long-term period such as 10-20 years.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This study is supported by FEN-B-101013-0399, FEN-D-091116-0505, FEN-C-DRP-110618-0349 and FEN-C-YLP-080519-0168 in Marmara University.

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