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Research Article

The Influence of Cell Temperature and Installation Angle on Photovoltaic Energy Generation in Iran

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Abstract

This study investigates the impact of cell temperature on the optimal installation and forecasting of photovoltaic (PV) power generation in Iran. Three scenarios are examined to quantify the effect of cell temperature on PV panel performance and installation angle: (1) ignoring temperature effects, (2) installing panels at the angle with maximum annual radiation, and (3) installing panels at the angle with maximum annual energy production. Optimal installation angles, annual solar energy radiation, and electricity production are evaluated at multiple locations throughout Iran. The results demonstrate that the optimal installation angle of PV panels does not significantly differ among the three scenarios. Cell temperature has some effect on panel performance, and the electricity generated by PV located in the areas of the sixth solar radiation decile is more than the areas of the country located in the tenth solar radiation decile. The estimated amount of solar radiation on the panel surface at the optimal angle in cities and settlements in Iran ranges from 1170 to 2517 ($kWh/m^2_{pv}\, year$), while the corresponding electrical energy production ranges from 189.5 to 394.22 ($kWh/m^2_{pv}\, year$).

Keywords: Photovoltaic (PV), Cell temperature, Optimum installation angle, Radiation Atlas, Maximum energy generation,

Introduction

Solar energy is one of the most important renewable energy resources. To utilize this energy, it is critical to pay attention to solar irradiance, which has a different magnitude in different areas of the world. There are reasons why a human should utilize renewable energies. Renewable energies can decrease the emission of greenhouse gases (Azhgaliyeva, 2019; Dudin et al., 2019). These gases have caused global warming and many species are in danger of extinction (Jager et al., 2021). Renewable energy technologies have lots of social, economic, and environmental advantages. Also, utilizing these technologies is a proper way to achieve the goal of sustainable development (Chenic et al., 2022; Oryani et al., 2021; Tipantuña et al., 2021).

The total primary energy consumption and the world's net electricity generation by 2040 will increase by 48% and 69%, respectively, compared to the 2012 energy demand. It is predicted that fossil fuels, which are responsible for about 75% of CO_2 emissions, will have a share of 78% of the energy consumption in 2040 (Al-Badi et al., 2020; Elavarasan et al., 2020). To decrease the effect of climate change caused by global warming, adopting renewable sources

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for meeting energy demands is proposed by the United Nations (Elavarasan et al., 2020). The power output of renewable energy conversion technologies can be changed from zero to the maximum power available (Bakhtvar et al., 2020), which shows the importance of the site of the renewable power plant. Utilizing renewable energy is growing in the world especially in the power sector because the cost of photovoltaic modules and wind turbines fell by 80% and 33%, respectively, in the last decade (Ghorbani et al., 2020; Mbungu et al., 2020). It is predicted that more than 50% of the global energy needs can be supplied by renewable energies (Tipantuña et al., 2021). A comprehensive review by Vakulchuk et al. (Vakulchuk et al., 2020) showed that the geopolitics of renewable energy was paid more attention in the last decade. They mentioned that renewable energy technologies are superior to fossil fuels for international security and peace.

In recent years works on solar PV have improved. Some of the research will discuss in the following. Abdelrahman et al. (Abdelrahman et al., 2019) worked on improving the PV cell's performance experimentally by using phase change materials mixed with nanoparticles. Also, Chin and Salam (Chin & Salam, 2019) studied a novel optimization technique called Coyote Optimization Algorithm to extract the PV cell's parameters. Their model was useful for applications such as the characterization of new PV cells, and fault diagnosis of PV systems.

Santhakumari and Sagar (Santhakumari & Sagar, 2019) reviewed the environmental parameters affecting solar PV. They mentioned dust, ambient temperature, wind velocity, humidity, snowfall, hailstorms, and sandstorms as the most important parameter affecting the efficiency of solar power plants. In addition, Colak et al. (Colak et al., 2020) identified the construction of solar PV in Turkey using Geographical Information Systems technology. Considering many factors, they presented a map for demonstrating the optimal locations for solar energy plants. In the other research, Hashemi et al. (Hashemi et al., 2020) studied the snow loss effect on solar PV's operational efficiency which plays a key role in the operation management of electric grids in snow-prone areas. Agyekum et al. (Agyekum et al., 2021) provided a policy roadmap for utilizing solar PV in Ghana. They clustered Ghana and introduced the best zone for the installation of solar PV. Carmona et al. (Carmona et al., 2021) integrated thermal energy storage and recovery system with photovoltaic thermal and compared it with solar PV. Their proposed setup's efficiency reached 31.35% while solar PV efficiency was 13.12%. Iran is known as a country with lots of oil reservoirs. The share of oil consumption in total final energy demand has decreased from 91% in 1980 to 43% in 2018. In this period the share of natural gas increased from 7% to 56%. It is also seen that the share of renewable energy consumption in total final energy demand has decreased from 1.50% to 0.58% in the mentioned period (Dehkordi et al., 2017; Solaymani, 2021). Electricity demand in Iran will increase to 200 GW in 2030, which can not be covered by fossil fuel resources (Dehkordi et al., 2017). Iran has great potential for using renewable energies (Dehkordi et al., 2017; Mohamad Taghvaee et al., 2017). According to the International Energy Agency (IEA) report the renewable energy technologies which are used in Iran consist of solar PV and wind turbines. In 2020 the total electricity generated by solar PV (with a share of 47.4%) and wind turbines (with a share of 52.6%) in Iran was 1076 GWh (IEA, 2023).

However, Haratian et al. (Haratian et al., 2018) showed that the most economical solution for renewables in Iran is solar PV and battery setup. This shows an unbalanced situation between what should be done and what has been done so far in the case of utilizing renewable energies in Iran. Tavana et al. (Tavana et al., 2019) reported that one of the most feasible alternative energy resources in Iran is solar energy. Also, it is mentioned by the authors (Tavana et al., 2019) that between CSP and solar PV, solar PV is a better choice due to its lower price and its better adoption to any power requirement from small-scale to large-scale production. Zahedi et al. (Zahedi et al., 2022) discussed different types of renewable energies in Iran. They concluded that utilizing solar PV in rural areas is very suitable, and it is best to integrate them with a wind turbine or fossil fuels. Installing solar PVs in remote areas was supported by Rathore et al. (Rathore et al., 2021), too. Zazoum (Zazoum, 2022) used machine learning models to explore the relationship between input parameters and solar photovoltaic (PV) power. The study considered two different ML approaches, support vector machine (SVM) and Gaussian process regression (GPR), and used basic input parameters such as solar PV panel temperature, ambient temperature, solar flux, time of the day, and relative humidity to predict solar PV power. The Matern 5/2 GPR algorithm performed best, and the models accurately predicted power output. Gomaa et al. (Gomaa et al., 2022) modeled a new thin and thick cooling cross-fined channel box using ANSYS software to improve performance. Results showed that a cooling fluid flow rate of 3 L/min was optimal, reducing surface temperature and outlet cooling water temperature. Under solar irradiance of 1000 W/m2, thin and thick box heat exchangers had average surface temperatures of 30.7 °C and 30.8 °C, and water-cooling temperatures of 38.9 °C and 32.4 °C, respectively. Sobhani et al. (Sohani et al., 2022) mentioned that an investigation into the impact of meteorological parameters on the performance of a solar panel found that solar radiation had the strongest effect on photocurrent, while the ambient temperature was the most effective parameter on thermal voltage. The photocurrent was found to have a greater impact on CO2 emission reduction, with a 20% increase resulting in 14.6% greater savings. Aslam et al. (Aslam et al., 2022) in a review paper provided guidelines for designing and forecasting PV technologies, analyzing existing PV power plants, identifying factors affecting PV performance, and proposing methods to enhance performance. The review will aid researchers, designers, and investors in addressing challenges and solutions when using photovoltaic technologies. Ranjbaran et al. (Ranjbaran et al., 2019) reported that the floating photovoltaic (FPV) system has multiple benefits and has garnered attention. In their study, they provided an analytical analysis and updated review of FPV as a power generation system, including a comparison with ground-mounted PV, interconnection schemes, and electrical design. Ashtiani et al. (Ashtiani et al., 2020) presented a novel framework using a teaching and learning-based optimization algorithm to optimize the sizing of grid-connected PV/battery systems for minimizing total net present cost. Results showed the system's efficiency, with NPC and COE factors compared to other optimization algorithms, and validated across different cities and climates. Ghodusinejad et al. (Ghodusinejad et al., 2022) evaluated the performance of a PV system in five Iranian cities with varying climatic conditions. The SMART method was used to rank the cities, with Yazd providing the best performance. The study investigated the effect of weather and climatic conditions on PV system efficiency and performance using a mathematical model. Olabi and Abdelkareem (Olabi & Abdelkareem, 2022) focused on developing efficient energy systems, policy recommendations for renewable energy, and greenhouse gas emissions reduction. Talaat et al. (Talaat et al., 2022) used artificial neural networks and multiverse optimization/genetic algorithm to predict the performance of photovoltaic panels based on ambient temperature, wind speed, and solar irradiance, achieving a high prediction accuracy with a normalized root mean square error of 3.65E-4 and 2.82E-4 for the multilayer feedforward neural network - genetic algorithm and the multilayer feedforward neural network - multiverse optimization models, respectively. Mayyas et al. (Nahar Myyas et al., 2022) proposed a self-cleaning mechanism to improve solar cell efficiency and recycle cleaning water while harvesting rainwater. An experiment in Salt (Jordan) showed automated cleaning was superior to manual cleaning and compressed air. The device could increase solar cell performance, gather rainwater, and contribute to decarbonization in the energy industry. Pandey et al. (Pandey et al., 2022) discussed the increasing importance of renewable energy resources such as solar, wind, biomass, tidal, and geothermal due to their unpolluting and renewable nature focused on ambient conditions. They focused on solar energy as the most promising source of inexhaustible energy and described the two main solar energy harvesting techniques: direct electricity generation using solar photovoltaic panels and indirect conversion using solar thermal collectors. Shoeibi et al. (Shoeibi et al., 2022) reviewed the literature on the methods and impacts of thermoelectric devices on solar systems, providing insights into the state-of-the-art and gaps. They mentioned that solar energy and thermoelectric systems have been combined for various purposes, including cooling, heating, and power generation. Zhao et al. (Zhao et al., 2022) proposed a silica micro-grating photonic cooler to radiatively cool solar cells. The cooler improved thermal emissivity and has an anti-reflection effect for sunlight. An outdoor experiment showed that it can passively reduce the temperature of commercial silicon cells by 3.6°C under solar irradiance. Conceicao et al. (Conceição et al., 2022) provided a comprehensive analysis of soiling research in the solar energy field throughout history, including current state-of-the-art, extended literature survey, and future prospects and research directions. They also mentioned the effect of ambient situation on solar energy harvesting. Hu et al. (Hu et al., 2022) reviewed advancements in radiative cooling and its application in solar energy systems. Radiative cooling can increase PV efficiency, extend working periods, and enhance thermal-to-power efficiency in CSP plants. Their paper aimed to guide future developments in radiative sky cooling applications. Zhang et al. (Zhang et al., 2022) This paper discussed recent developments in renewable energy systems for building heating, cooling, and electricity production with thermal energy storage. It presented various renewable energy-based systems, including hybrid systems and methods for their optimization, with a focus on thermal energy storage using phase change materials. Their work also identified some of the challenges facing renewable energy systems and provided guidance for future development. Naveenkumar et al. (Naveenkumar et al., 2022) highlighted the importance of energy storage in solar energy systems and presented the application of phase change materials (PCMs) in solar thermal power plants, solar desalination, solar cooker, solar air heater, and solar water heater. They mentioned that PCMs are commonly utilized in solar energy applications due to their ability to improve important technical parameters, such as prolonged heat energy retention, despite their complex availability and high cost. Mousavi and Yousefi (Mousavi Reineh & Yousefi, 2022) calculated the environmental costs of electricity generation and also to analyzed the impact of environmental costs on the price of electricity supply. The quantity of virtual water per kilowatt-hour of electricity supplied from thermal power plants and renewable energies was calculated by the authors. In addition, the quantity of particulate matter and greenhouse gases emitted from thermal power plants were determined by them.

Some research considering the application of solar energy showed the impact of the optimal angle of PV panels and the cell temperature on power generation (Hao et al., 2022; Hassan et al., 2022; Karimi et al., 2022).

After reviewing the research background, it is evident that most studies have focused on determining the optimal installation angle for photovoltaic panels to maximize input power. However, it is important to note that simply placing a PV panel at an angle to receive maximum input power does not necessarily guarantee maximum output power. To quantify the impact of installation angle on output power, this study defines three scenarios:

1- Eliminating the effect of temperature on PV panel performance,

2- Installing the panel at an angle that receives maximum annual solar energy,

3- Installing the panel at an angle that provides maximum annual electrical energy.

This study investigates these scenarios across a significant number of locations in Iran, examining the annual solar energy incident on the panel surface, the annual produced electric energy, and the optimal installation angle for each scenario. This article aims to evaluate the effect of climate on PV performance. At first, it may seem that the points with high radiation intensity are susceptible to the construction of solar PV power plants. This article shows that other climatic conditions of the construction of the Solar PV power plant can affect the performance of the power plant in a way that the points located in the sixth decile from the point of view of radiation intensity can have higher performance (the amount of electrical energy produced) than the points located in the 10th decile in terms of radiation intensity.

Modeling

In this study, 4900 points in Iran are considered. Whether data on these points have been gathered and beam radiation (I_b) and diffuse radiation (I_d) of these points have been obtained (Fathi et al., 2023). Weather conditions in this study have been extracted using Meteonorm software. The points close to the residences were randomly selected. This point was added to the article.

Total radiation on a tilted surface

The total radiation on a tilted surface (I_T) is obtained by employing the Isotropic Sky model from Duffie and Beckman (Eq. 1 to Eq. 5) (Duffie et al., 2020).

$$I_T = I_b R_b + I_d\left(\frac{1+cos\beta}{2}\right) + I\rho_g\left(\frac{1-cos\beta}{2}\right) \tag{1}$$

$$R_b = \frac{(1-cos^2\delta\ sin^2\omega)^{1/2}}{cos\phi\ cos\delta\ cos\omega + sin\phi\ sin\delta} \tag{2}$$

$$\delta = 23.45 \times \sin\left(360 \times \frac{284+n}{365}\right) \tag{3}$$

$$I = I_b \times cos\theta_z + I_d \tag{4}$$

$$\theta_z = cos^{-1}(cos\phi\ cos\delta\ cos\omega + sin\phi\ sin\delta) \tag{5}$$

In these equations, I_b is the beam radiation, I_d is the diffuse radiation, R_b is the geometric factor, β is the slope angle, δ is the declination angle, n is the i-th day of the month, ϕ is the latitude, ω is the hour angle which is calculated from -172.5° to 172.5° with an increment of 6.5°, and θ_z is the zenith angle.

Solar PV model

Solar PV panels supply electricity during daylight when the irradiation is high enough and do have not any production at night (Akhtari & Baneshi, 2019). In this work, the PV model is obtained from (Akhtari & Baneshi, 2019). Eq. 6 shows the output power of a flat plate panel.

$$P_{pv} = Y_{pv} f_{pv}\left(\frac{I_T}{I_{T,STC}}\right)[1+\alpha_P(T_c - T_{c,STC})] \quad [\mathrm{W}] \tag{6}$$

In Eq. 6, Y_{PV} (kW) is the nominal capacity of PV, f_{PV} (%) is the derating factor, $I_{T,STC}$ (W/m^2) is the incident radiation at standard test conditions, α_P (%/°C) is the temperature coefficient of power, T_c (°C) is the PV cell temperature, and $T_{c,STC}$ (°C) is the PV cell temperature under standard conditions.

The operation efficiency of PV panels varies with the PV cell temperature. PV cell temperature is obtained by Eq. 7.

$$T_c = T_a + I_T\left(\frac{T_{c,NOCT} - T_{a,NOCT}}{I_{T,NOCT}}\right)\left(1-\frac{\eta}{\tau\alpha}\right) \tag{7}$$

While T_a (°C) is the ambient temperature, and NOCT subscript shows the test condition of the PV cells: The total radiation of 800 W/m^2, the ambient temperature of 20 °C, and T_C = 47°C while $\eta = 0$. Some research has shown that the effect of wind on PV cells in low elevations is low (Kaldellis et al., 2014; Osma-Pinto & Ordóñez-Plata, 2019). Hence, the effect of wind is neglected in this research.

Optimum installation angle

The optimal installation angle for PV panels can vary depending on the application and installation location. Common indices used to determine the optimal installation angle include maximum solar radiation on the surface throughout the year, maximum solar radiation on the panel surface during cold seasons, etc.

In this study, the difference in electrical energy production value was considered for the same hours. The model used in this study is based on the model proposed by Fathi et al. (2021). This model finds the optimal orientation angle and duration for a photovoltaic panel at an angle with the ability to be deployed on n angles. The index introduced by Fathi and colleagues provides access to the maximum solar energy on the surface by changing the angle at n times using Eq. 8.

$$Max \sum_{i=1}^{x_1} I_{T,i}(y_1) + \sum_{i=x_1+1}^{x_2} I_{T,i}(y_2) + \cdots + \sum_{i=x_{n-2}+1}^{x_{n-1}} I_{T,i}(y_{n-1}) + \sum_{i=x_{n-1}+1}^{\frac{8760}{\Delta t}} I_{T,i}(y_n)$$

$$s.t \qquad (8)$$

$$1 \leq x_1 \leq x_2 \leq \cdots \leq x_n < \frac{8760}{\Delta t}$$

$$x_1, x_2, \ldots, x_{n-1}, y_1, y_2, \ldots, y_n \geq 0$$

Here, $I_{T,i}$ represents the irradiation energy on the surface during the i-th time interval, y_j is the installation angle of the panel during the j-th deployment, x_k represents the k-th time interval, and Δt is the time interval. It is common to consider Δt as one hour in studies.

If the optimal orientation index changes from maximum input energy in a year to maximum electrical energy, the introduced model is modified using Eq. 9 by Eq. 8.

$$Max \sum_{i=1}^{x_1} \eta_i * I_{T,i}(y_1) + \sum_{i=x_1+1}^{x_2} \eta_i * I_{T,i}(y_2) + \cdots + \sum_{i=x_{n-2}+1}^{x_{n-1}} \eta_i * I_{T,i}(y_{n-1}) + \sum_{i=x_{n-1}+1}^{\frac{8760}{\Delta t}} \eta_i * I_{T,i}(y_n)$$

$$s.t \qquad (9)$$

$$1 \leq x_1 \leq x_2 \leq \cdots \leq x_n < \frac{8760}{\Delta t}$$

$$x_1, x_2, \ldots, x_{n-1}, y_1, y_2, \ldots, y_n \geq 0$$

Here, η_i represents the average electrical efficiency of the PV panel during the i-th time interval.

The defined optimization problem consists of linear constraints and a non-linear objective function. The objective function consists of a set of parameters of trigonometric functions. Therefore, the solution method affects the obtained optimal solution and the reported optimal solution may be local.

Results

In this study, a significant number of locations (4900 points) distributed throughout Iran, including all cities and most areas near settlements, have been selected to investigate the impact of cell temperature on PV panel performance across three scenarios. The first scenario considers no effect of cell temperature on the panel's performance, while the second and third scenarios examine the cell temperature effect on panel performance and installation angle at maximum annual input and output energy, respectively. To compare the three scenarios, the optimal installation angle, annual solar energy on the panel surface, and produced electrical energy are examined.

Optimum installation angle

The installation angle of the panel affects the amount of sunlight on the surface of the photovoltaic panel and consequently the temperature of the cell and finally the power output from the panel. To examine the 3 scenarios, it is enough to calculate the angle of the panel installation in two situations, the first situation is the maximum input power to the surface of the photovoltaic panel (First and Second Scenario) and the second situation is the maximum output power (Third Scenario).

Figure 1 shows the different values of the constant optimal deployment angle in two states expressed in four groups with the same number of points.

The range of the optimal fixed installation angle difference is estimated between 0.42 to 1.08, indicating a 1.16% to 3.39% variation compared to the angle based on maximum input power to the photovoltaic panel (Scenarios One and Two). Therefore, it can be concluded that the optimal installation angle based on maximum input power or maximum output power has little difference.

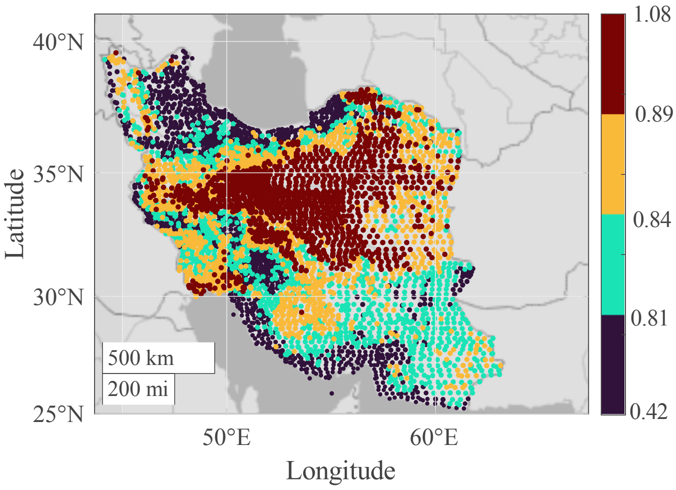

Figure 1. The difference in optimal fixed installation angle of PV panel in maximum input power (scenarios one and two) and maximum output power (scenario three)

Solar radiation incident on the PV surface

Changing the installation angle of the photovoltaic panel affects the amount of solar irradiance on its surface. As the difference in installation angle based on the two criteria is less than 1 degree in almost all examined points, it is expected that the input energy to the panel would also change minimally. Figure 2 illustrates the decrease in input energy to the panel when installed at an angle based on maximum output power (Scenario three) compared to an angle based on maximum input power (Scenarios One and Two).

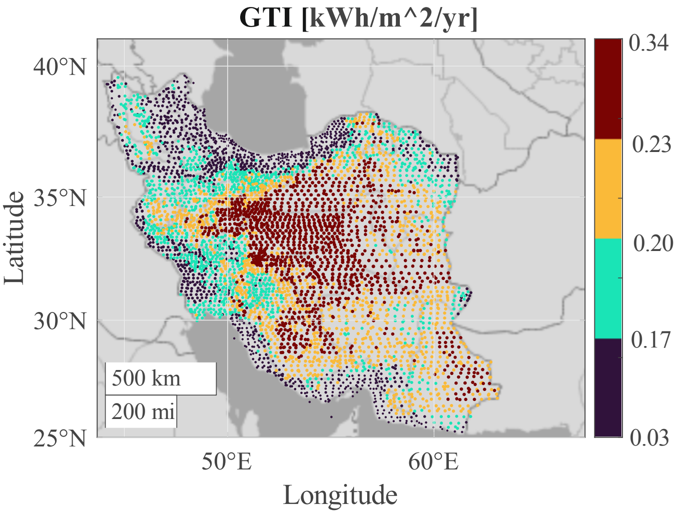

Figure 2. The amount and percentage of the reduction in solar radiation intensity on the surface of a PV panel installed at the angle with the maximum output power (scenario three) compared to the angle with the maximum input power (scenarios one and two)

Figure 2 shows that changing the optimal installation angle from a maximum annual input energy to maximum electrical energy has a very small effect on the difference in solar radiation on the panel surface. In 4900 examined points, this amount varied from 0.0317 $\left[\frac{kWh}{m^2yr}\right]$ to 0.343 $\left[\frac{kWh}{m^2yr}\right]$ (on average less than 0.2 $\left[\frac{kWh}{m^2yr}\right]$). In the worst case, the solar radiation on the panel surface decreased by 0.016%. However, the solar radiation intensity on the panel surface varies from 1171 $\left[\frac{kWh}{m^2yr}\right]$ to 2517 $\left[\frac{kWh}{m^2yr}\right]$when installed at the angle with the maximum annual received solar radiation. Figure 3 illustrates the solar energy incident on the panel surface when installed at the angle with the maximum annual received solar radiation.

Comparing Figures 2 and 3 with each other indicates that the change in the optimization index of panel deployment is from maximum annual energy received to maximum annual electrical energy, and it will not have a significant impact on the solar energy incident on the panel surface throughout the year due to a very small change in the angle of panel deployment.

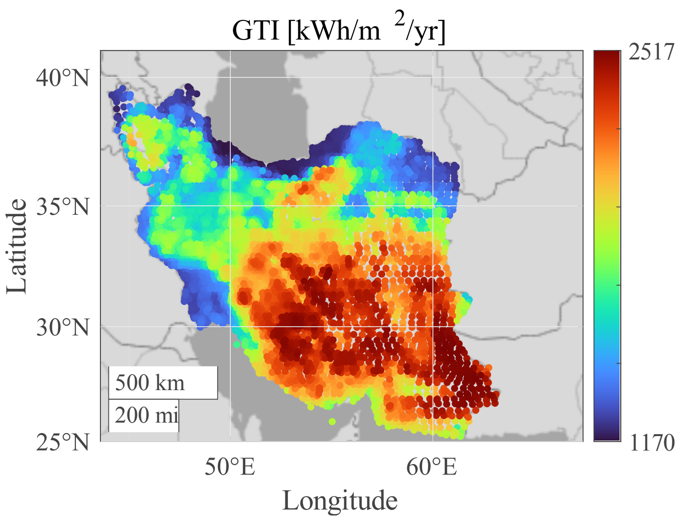

Figure 3. Solar energy captured when the PV surface is installed at the maximum solar capture angle

PV panel efficiency

Although the difference between the two angle determination indices does not have any effect on the panel deployment angle and the prediction of input energy to the panel, it can have a significant impact on the electrical energy produced and therefore the technical and economic viability of the panel. In the first scenario, the effect of temperature on panel output has been ignored. Therefore, in all cases, its efficiency is considered to be 15.44%. However, in the other two scenarios, the average efficiency will change. Figure 4 envisages the average annual efficiency of the photovoltaic panel investigated at the points of the second scenario, which varies between 14.83% to 17.02%. The difference in efficiency between the second and third scenarios will be a maximum of 0.0042% at the points under consideration. The maximum yield is observed in regions situated on the slopes of the Alborz and Zagros Mountain ranges, whereas the minimum yield is found in areas adjacent to the southern strip of the country. Table 1 presents key information regarding the points with the maximum and minimum yield.

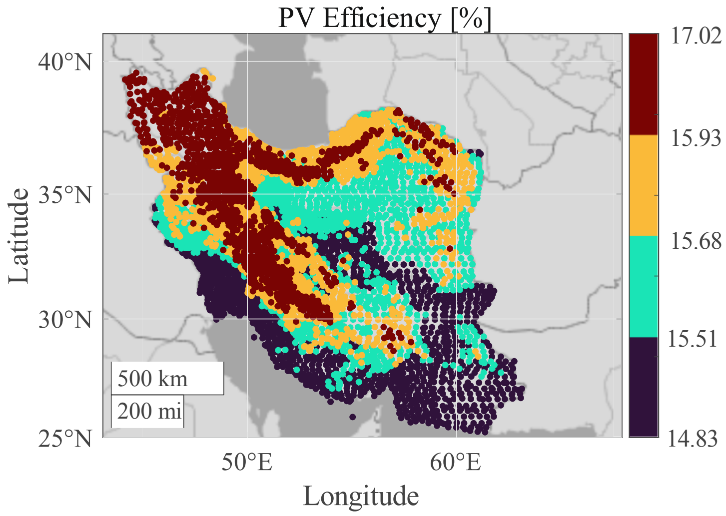

Figure 4. Average annual efficiency of the studied photovoltaic panel in the second scenario

Table 1. Key information of locations with maximum and minimum efficiency according to the third scenario.

		Maximum Efficiency			Minimum Efficiency		
		1st	2nd	3rd	1st	2nd	3rd
Average Annual Efficiency[%]		17.02	16.89	16.76	14.08 14.08	14.84	14.84
Annual Solar Radiation on a Surface $\left[\frac{kWh}{m^2 yr}\right]$		1968.58	1963.71	1841.10	1900.43 1900.10	1901.32	1907.82
Annual Solar Radiation Rank		4018	4039	4569	4352 4359	4346	4315
Annual Electricity Generated $\left[\frac{kWh}{m^2 yr}\right]$		335.02	331.76	308.55	281.88 281.83	282.09	283.07
Annual Electricity Generated Rank		2280	2481	4045	4569 4572	4572	4543
Location	Area	Mazandaran, She Hezare	Mazandaran, Larijan Sefli	Alborz, Roodbar Qasran	Khuzestan, Safi Abad Khuzestan, Mianrood	Khuzestan, Shams Abad	Khuzestan, Zarab
	Lat	36.41375	35.97703	36.03228	32.24784 32.22787	32.24446	32.28791
	Lon	50.93921	52.08434	51.64954	48.42151	48.45925	48.42824

Based on the results reported in Table 1, the regions with the highest performance are ranked third in terms of performance in the first quintile and first and second in the second quintile. This high performance has resulted in significantly better annual electricity generation rankings for these regions. Conversely, although the points with the lowest performance are located in the second quintile in terms of annual solar radiation intensity, their lower performance has led to their placement in the first quintile in terms of annual electricity production.

Electricity generated

In the previous sections, it has been shown that temperature and solar radiation intensity have an impact on the performance of photovoltaic panels. Therefore, if points are prioritized based on their annual solar radiation intensity, it may not necessarily lead to prioritization based on their maximum electricity generation potential. Analysis of the electricity generation atlas for photovoltaic panels under investigation shows that annual electricity production ranges from 189.5 $\left[\frac{\mathrm{kWh_{elec}}}{\mathrm{m^2yr}}\right]$ to 394.22 $\left[\frac{\mathrm{kWh_{elec}}}{\mathrm{m^2yr}}\right]$. Figure 5 illustrates that the majority of points with the lowest annual electricity generation potential are located in the northern strip and near the Caspian Sea, while the majority of points with the highest annual electricity generation potential are located in Fars Province.

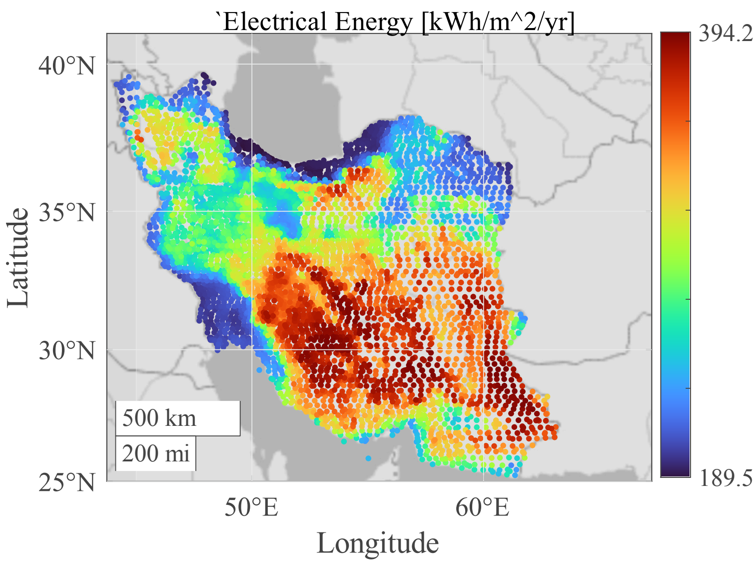

Figure 5. The electricity generation Atlas of PV panels for 4900 selected points

Table 2 examines points with maximum and minimum annual electricity generation potential.

Based on the results reported in Table 2, it can be concluded that the maximum annual average photovoltaic panel yield or maximum radiation on the panel surface does not necessarily result in maximum annual electricity generation. Figure 6 illustrates the distribution of photovoltaic panel production based on the amount of sunlight radiation on the panel surface for each decile. Based on the findings depicted in Figure 6, the impact of ambient temperature is significant to the extent that some points located in the sixth decade, despite having higher solar radiation intensity, may produce an annual amount of electric energy equivalent to lower points in the tenth decile.

In this study, since the problem is non-linear to achieve a better global or local answer, the non-linear problem has been solved by several methods such as Interior Point, Sequential Quadratic Programming, and GA, but still, it cannot be claimed that the reported answer is the global optimum.

Table 1. Locations with maximum and minimum annual electricity generation.

		Maximum Electricity Generated			Minimum Electricity Generated		
		1st	2nd	3rd	1st	2nd	3rd
Average Annual Efficiency [%]		15.74%	15.67%	15.68%	16.18%	15.88%	15.83 %
Average Annual Efficiency Rank		2151	2553	2463	302	1535	1772
Annual Solar Radiation on Surface $\left[\frac{kWh}{m^2yr}\right]$		2504.13	2515.48	2507.35	1171	1378.2	1386.98
Annual Solar Radiation Rank		7	2	4	4900	4899	4898
Annual Electricity Generated $\left[\frac{kWh}{m^2yr}\right]$		394.22	394.2	393.27	189.5	218.85	219.57
Location	Area	Sistan Va Baloochestan, Taftan Jonoubi	Sistan Va Baloochestan, Cheshmeh Ziarat	Sistan Va Baloochestan, Joon Abad	Boushehr, Bordekhoon	Mazandaran, Shirood	Gilan, Rasht
	Lat	28.65	29.26	28.9	51.73	36.85	37.28
	Lon	60.9	60.63	60.89	27.89	50.79	49.59

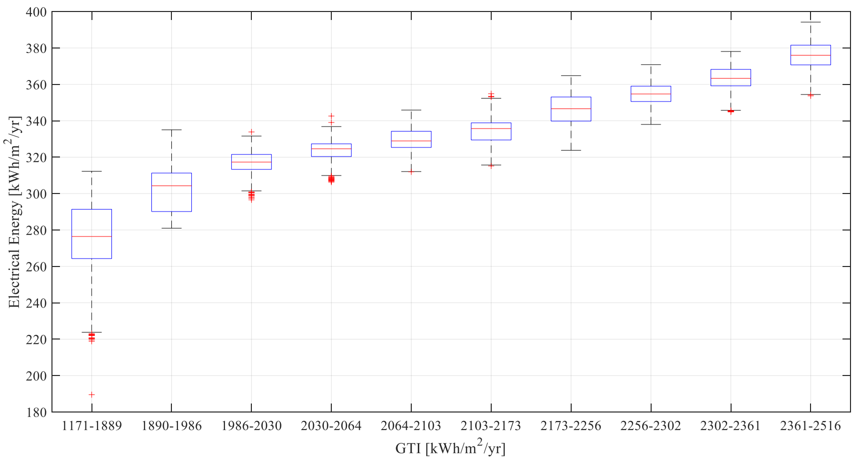

Figure 6. Distribution plot of PV panel production related to the sunlight radiation on the panel surface for each decile**.**

Conclusion

It is common to install photovoltaic panels at a fixed angle in power plants. This angle is determined based on various factors such as the maximum solar energy absorbed by the surface and the maximum solar energy absorbed during a season (in the event of an energy carrier shortage during that season). Solar radiation and climate have an impact on the temperature of photovoltaic cells, which affects the efficiency of this energy conversion technology. This study aims to investigate the effect of panel installation angle on the annual maximum electrical energy production by deploying the panel at the angle of maximum solar energy absorbed by the panel surface, with three scenarios defined: 1) no effect of temperature on panel performance, 2) panel deployment at the angle with the maximum annual solar energy absorbed by its surface, and 3) panel deployment at the angle with the maximum annual electrical energy production. In this study, the annual input energy, electrical energy production, and optimal installation angle were examined at 4900 points in Iran.

The results show that there is no significant difference in the optimal panel installation angle calculation in each of the three scenarios. The installation angle of the first two scenarios will be similar, and the installation angle of the first and second scenarios will be calculated to be 0.42 to 1.08 degrees less than the optimal installation angle calculated in the third scenario. Changing the installation angle from the maximum solar radiation to the maximum electrical energy production of the photovoltaic panel causes a decrease of up to 0.34 $\left[\frac{kWh}{m_{PV}^2 yr}\right]$ in solar radiation absorbed by the surface of the panel, which in the worst-case scenario has decreased by 0.016% of the solar radiation absorbed by the panel surface. Therefore, the electrical energy production in the second and third scenarios is very low. The maximum difference in the annual average efficiency of the photovoltaic panel for an area in the second and third scenarios (changing the installation angle from the maximum annual solar radiation to the angle with the maximum annual electrical energy production) is about 0.0042%.

The temperature has a significant impact on the panel's efficiency, and in addition to the installation angle, it is important to consider the panel's cooling system to prevent it from overheating. Therefore, further research is needed to explore the impact of different cooling methods on the panel's efficiency. In general, optimizing the installation angle of photovoltaic panels and using appropriate cooling methods can significantly increase the electrical energy production of these systems.

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