Hindawi
International Transactions on Electrical Energy Systems
Volume 2023, Article ID 4213468, 13 pages
https://doi.org/10.1155/2023/4213468

Research Article

Finding the Best Station to Use Buildings Integrated Photovoltaics (BIPVs) in Eight Different Climates of Iran: Effect of Wind Speed and Photovoltaic Modules Type

Marzieh Talebi,[1] Mehdi Jahangiri ,[2] and Rashid Riahi [2]

[1]*Department of Electrical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran*
[2]*Energy Research Center, Shahrekord Branch, Islamic Azad University, Shahrekord, Iran*

Correspondence should be addressed to Mehdi Jahangiri; mehdi_jahangeri@yahoo.com

Received 8 January 2023; Revised 20 September 2023; Accepted 30 September 2023; Published 19 October 2023

Academic Editor: Anjanee Kumar Mishra

Buildings consume a significant amount of energy worldwide. Therefore, providing a part of this energy consumption with renewable energy, and reducing energy consumption, can lead to reducing pollutants. Due to the importance of the above-mentioned points, this work aims to supply part of the required electricity in the buildings by using solar cells in eight climates of Iran. According to the available photovoltaic modules in the Iranian market, the study has been performed for six different types of solar cells. Considering the effect of temperature and wind speed on the efficiency of solar cells has made the results of the present work more consistent with reality. The simulations are performed for 25 years of the project's useful life using HOMER V2.81 software, and the studied system is connected to the grid. The conclusions displayed that the Passive Emitter Rear Cell Silicon (perc-si) has the highest efficiency (21.22%–22.8%). Marand station is economically suitable (total net present cost (NPC) of 3180$ for a polycrystalline panel), and Gonbad station is appropriate because of high solar energy production (9183 kWh/year) and low environmental pollution (12602.9 kg/year). Due to the diversity and breadth of Iran's climates, the results of the present study can be used for other areas with similar climates.

1. Introduction

Electricity consumption has recently increased in Iran, and much of the country's energy is used in the household sector as electricity (such as lighting, cooling, or heating). The growing need for energy resources, the depletion of fossil energy resources and water from dams, electricity restrictions, and attention to reducing air pollution has made solar energy usage necessary to generate electricity in Iran. Iran has sunlight with desirable power and is one of the most appropriate areas for using solar energy [1].

The growth of energy consumption and uncontrolled use of fossil energy sources, which has increased the price of fossil energy carriers, increased pollution, and degraded environmental resources, ozone depletion, and global warming due to greenhouse gas emissions, is the reason for attention to renewable energy in different countries. Renewable energy, such as solar energy, is available in most parts of the world and is inexhaustible [2]. The development trend of solar energy in the world from 2014 to 2020 is shown in Figure 1 [3]. As shown in Figure 1, solar energy is the number one renewable energy used in the world.

The household consumption of the world's energy is close to half of its consumption. This consumption of energy demand has made homes the largest energy consumers and significant sources of CO_2 emissions and environmental pollution [4, 5] since architects should design efficient buildings with less energy consumption for cooling, heating, and lighting and reduce the emission of environmental pollutants [6].

Photovoltaic is one of the best ways for solar energy usage. Although photovoltaics have many applications in various fields, today, the use of photovoltaic systems is more in the architecture and construction industry fields.

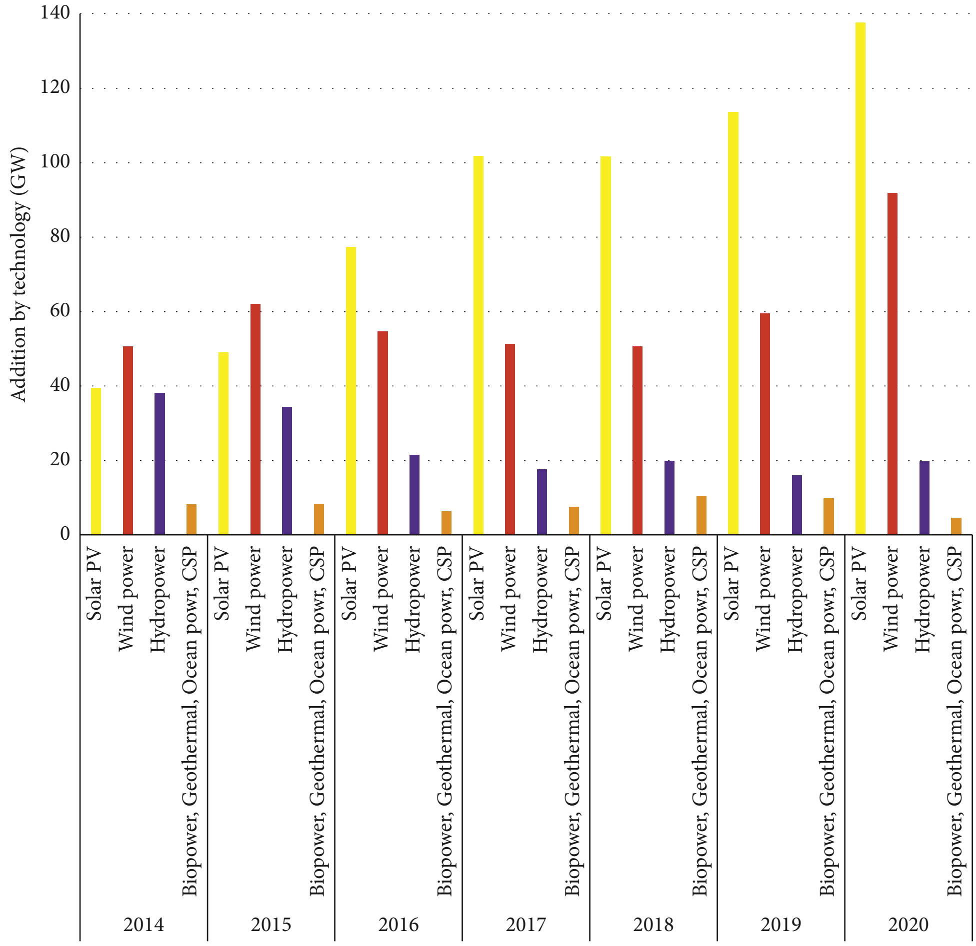

Figure 1: Annual increase in renewable energy capacity by various technologies for the years 2014–2020 [3].

Advances in technology and the need to save energy in the world have led to more and more photovoltaic integration with architecture (to generate electricity). There are many examples of this in different countries, which are progressing daily. In other words, photovoltaic is combined with the building as an element or material. In addition to the advantages of combining photovoltaic with building elements, combining it with architecture also has advantages, and it will not be just an energy source [7]. The initial cost of an integrated photovoltaic system is lower than that of more common nonintegrated systems because we can purchase inexpensive materials and turn off some BIPV module functions [8]. Protection against inclement weather conditions, light refinement, reduced heat loss, and no need for space to install modules are some of the other unique characteristics of BIPV in buildings in contrast to other photovoltaic methods [9]. Therefore, BIPV is one of the most popular and growing systems in the photovoltaic industry.

One-third of the renovation projects belong to BIPV, while the rest new projects. About 50% of the BIPV components are installed in the facade, 30% in the roof, and the rest is a compound of the roof and facade [10]. In 2019, about 9% of the photovoltaic (PV) world trade and the building industry were related to BIPV, which needed more attention [11]. It is expected that about 11,600 million will be invested in this sector in 2027. Most of the investment will be made in the commercial and domestic, and only a slight fraction of it will be invested in the industrial sector. In Iran and the rest of the world, despite passing laws to reduce energy waste in buildings, architects' ignorance of new materials and technologies and mismanagement of construction policies have marginalized BIPV usage in architecture [12]. The BIPV usage in Iran is perfectly reasonable because most regions of Iran have noteworthy radiation potential [13, 14].

In recent years, much research has been conducted on optimal solar energy usage and popular methods of using solar radiation, and photovoltaic cells have been used to convert it into electricity [15]. PV system performance depends on its essential characteristics, and environmental issues, such as ambient temperature and wind speed, play significant roles in photovoltaic operation [16]. Due to the change in radiation intensity at different times, it is noticeable that the energy production by solar cells also changes [17]. We provide an overview of the latest research on BIPV usage in various countries as follows.

Jahangiri et al. analyzed different types of BIPV in terms of energy-economical-technical in different climates of Iran and finally ranked the investigated stations [18]. Their results showed that investment return time has the most weight among the calculated parameters. The ranking results showed that Jask and Ramsar are the most appropriate and inappropriate stations. Finally, the ranking results were verified by several other methods.

Ting et al. simulated a BIPV at Swinburne University, Malaysia [19]. The results showed that 320,000 kWh of electricity per year is required and 39,715 kWh of produced electricity is sold to the grid, and the resulting income is 11,915 RM. The investment ratio is 33.9%, and the investment return period is 14 years.

Rahmati Dehkordi and Jahangiri in Iran, using HOMER software, have evaluated technical-energy-economic-environmental BIPVs in Abadan. Using sensitivity analysis, they considered system losses, the azimuth, and the slope effect on the solar-cell performance. The results indicated that the PV-grid system is the most economical choice. In addition, the conclusions show that a 30° slope angle and a 0° azimuth angle were the most suitable angles, and the price per kWh of the generated electricity in this condition was 0.09 $. Based on the conclusions, the southwest direction of the building is the most appropriate direction to use the solar cell in the vertical wall, and the western in the form of sloped PVs with windows [20].

Using PVsyst and HOMER, Ni et al. designed an economical BIPV in China [21]. They considered the building's geographical location and load characteristics and then chose the appropriate PV module and required area. Then, using HOMER, they estimated parameters such as battery life, assembly, and operation costs. In conclusion, they indicated that a system comprising 6 kW solar cells with a total NPC of 22,326 $ can generate solar energy for 0.406 $ per kWh.

Abu Bakar et al. [22] analyzed the effect of temperature and wind speed on solar photovoltaic modules (PV) at Bahawalpur, Pakistan, for heater junction thin film with different brands and power. The results show that in modules with various powers, the efficiency changes due to wind speed are about 1 to 2%.

Radziemska investigated the effect of temperature on output power and other electrical characteristics of photovoltaic panels. This study showed that the power of silicon photovoltaic panels decreases by 0.65% with an increase of 1 degree Kelvin, and the efficiency of this panel reduces by about 0.08% [23].

Ramanan et al. assessed the performance of a grid-connected BIPV for home use in southern regions of India [24]. Using HOMER, they investigated the effect of solar modules' slope and the azimuth angle. Their results indicated that the facade and east wall are the optimal orientation for solar module installation, while the south wall is appropriate for the sloping roof. The cells installed in the west, east, and south directions generated 1,150 kWh, 1,198 kWh, and 1,050 kWh of electricity, respectively.

In reference [18], ranking has been carried out to determine the optimal climate conditions, and on the other hand, the effect of different solar cell technologies and wind speed on the solar cell system's performance has been neglected. Reference [19] only concentrates on energy-economic performance, disregarding the investigation of climate effects, solar cell types, and wind speed. Moreover, this study overlooks environmental considerations associated with the subject. In references [20, 21], different climates have not been investigated, and the effect of different solar cell technologies and wind speed on their performance has not been investigated. In reference [22], the effects of wind speed and solar cell technology type on PV performance across various climates have not been investigated, and the focus has remained solely on one station. In addition, the place under investigation was not Iran. In reference [23], the effect of temperature was exclusively investigated and disregarded the effect of wind speed on the efficiency of solar cells. The investigated location is also different from the present study, and various climates have not been investigated. In reference [24], the effects of orientation and azimuth angle of solar cells have been explored, while overlooking the effect of wind speed, climate type, and different solar cell technologies. In addition, the investigated location is different from the present study.

For the first time in the present work, we investigated the effect of environmental parameters, such as ambient temperature and wind speed in various climatic regions of Iran, on the performance of the photovoltaic module. In this study, we performed an analysis using HOMER V2.81 software. According to the studies, more needs to be done to study the use of BIPV in different climates of Iran. Therefore, in the present work, the investigation of the data of the 20-year average of 8 regions of Iran and technical-energy-economic-environmental analyses has been performed. Moreover, due to the availability of various solar modules in the Iranian market, the effect of using different modules on the performance of BIPVs has been investigated.

2. Methodology

2.1. Effect of Temperature and Wind Speed. One of the effective parameters on the performance of BIPV is the wind speed because the photovoltaic panel is in direct contact with the environment. Wind speed distribution probably has a noteworthy effect on huge BIPV facilities; however, it has yet to be well considered [25]. Since air temperature depends on solar radiation and radiation levels are different in winter and summer, ambient temperature can be a reference to study the effect of solar radiation and wind [26]. The efficiency of the photovoltaic module is a function of the temperature given in the following equation [27]:

$$\eta_{\mathrm{pv}} = \eta_{\mathrm{Tre}}\left[1 - \beta_{\mathrm{re}} \times \left(T_{\mathrm{pv}} - T_{\mathrm{re}}\right) + \gamma \times \log 10 \times \mathrm{Intensity}\right]. \tag{1}$$

In equation (1), η_{Tre} is the electrical efficiency of the solar module at the desired reference temperature T_{re}. β_{re} and γ are different coefficients for different module materials [28], such as 0.0045 K and 0.12 K for crystalline silicon PV modules. We assumed $\gamma = 0$ for most materials. We calculate the module temperature (T_{pv}) [22] using the following equation:

$$T_{pv} = T_a + \frac{T_{NOCT} - 20}{800} \times \text{Intensity} \times \frac{h_{w.NOCT}}{h_{w(v)}} \times \left(1 - \frac{\eta_{STC}}{\tau.\alpha} \times \left(1 - \beta_{STC} \times T_{STC}\right)\right). \quad (2)$$

The focus is on wind speed and the effect of temperature to achieve efficiency in the present work. In equation (2), T_{pv}, solar module temperature, using ambient temperature, T_a, nominal operating temperature of the solar cell, T_{NOCT}, which is higher than ambient temperature, PV cell temperature under the standard test conditions, T_{STC} (in degrees Celsius), and wind speed is calculated. $\tau\alpha$ is considered a constant value (transfer coefficient to absorption) equal to 0.9. h_w is the wind coefficient determined by the following equation [29]:

$$h_w = 8.910 + 2 \times V_h. \quad (3)$$

In equation (3), V_h is the wind speed at the height 10 m above the ground in terms of m/s. In equation (2), $h_{w.NOCT}$ is the wind coefficient at wind speed 1 m/s, approximately. The parameters used for the above equations (different types of solar cells) are listed in Table 1.

2.2. Effect of Different Types of Solar Photovoltaic Panels. Today, solar panels in the market are divided into four main types: monocrystalline panels, polycrystalline, passive emitter rear cells, and thin-film panels. Crystal panels are made of silicon, but thin-film panels are produced through thin layers of various materials, including cadmium telluride (Cd-Te), amorphous silicon (a-Si), and microcrystalline silicon (μc-si). In Table 2, the performance of the used solar panels is shown. Moreover, according to the research, the types of solar panels available in the Iranian market are shown in Table 3. It should be noted that the average cost per watt of solar cells has been received by an inquiry from Amazon and domestic companies (Dadman Yazd and Sanat Bakhsh). The selected solar panels are compared in terms of their advantages and disadvantages in Table 3.

3. Investigated Climates

In Figure 2, the different climates of Iran and the areas covered by them are shown. According to Figure 2, the eight climatic zones in Iran are very cold, cold, temperate and rainy, semitemperate and rainy, semiarid, hot and dry, very hot and dry, and very hot and humid. Considering that this work aims to investigate the effect of climate on the performance of BIPVs, we have selected the cities of Marand, Shahrekord, Rasht, Gonbad, Yazd, Zahedan, Abadan, and Bandar Abbas for very cold, cold, temperate, and rainy climates semitemperate and rainy, semidry, hot and dry, very hot and arid, and very hot and humid, respectively.

The weather data for solar radiation and wind speed are, on average, over 20 years [31] and were extracted from the NASA site.

4. HOMER Software

HOMER software is a simulator of combined cycle systems and renewable energy. HOMER is produced and developed by the National Renewable Energy Laboratory. HOMER can provide possible modes of rearrangement of production systems for the defined loads in the system. In this software, a model of a microgrid system can be presented in which new types of renewable energy generators, including wind turbines, solar cells, fuel cells, electrolyzes, hydrogen tanks, and batteries, along with conventional fossil sources such as gas power plants, diesel, and hydrogen as a hybrid can be used. HOMER simplifies the design of grid-connected or grid-independent power generation systems in various applications. The feasibility and economic optimization of the combined renewable energy systems, including solar and wind energy, can be conducted using HOMER. It can be used to measure hybrid systems based on current net costs. In addition, the software can perform sensitivity analysis for variables with indeterminate values. HOMER software allows us to examine the effect of changing a variable on the entire system [32]. HOMER software can computationally simulate and optimize solar, fuel cell, and biomass hybrid energy and design solar wind hybrid power plants [33, 34].

The battery model used in the simulation is Trojan T-105. Its price of buying, replacing, and annually operating and maintenance is $174, $174, and $5, respectively [35]. For an electric converter with a useful life of 10 years and an inverter and rectifier efficiency of 90% and 85%, respectively, the buying, replacing, and annual operating and maintenance price is $200, $200, and $10 [36]. In the purchase/sale of electricity to/from the grid, a three-time tariff has been used. The purchase price of each kWh of electricity from the grid for peak, normal, and off-peak times is $0.012, $0.007, and $0.005, respectively. These values for selling electricity to the grid are $0.076, $0.045, and $0.032, respectively. The penalty of produced pollutants for each ton of CO_2, CO, SO_2, and NO_x is considered to be 3.1$, 5.7$, 560$, and 184$, respectively [37]. Due to the effect of temperature on the performance of solar cells, the average temperature of each station has been used in the simulation.

In terms of scale and technical aspects, a 5 kW rooftop solar power system in a residential complex connected to the grid has been investigated. According to Figure 3, the average power and peak consumption of this residential complex are 73 kWh/day and 12.6 kW, respectively.

5. The Governing Equations

In HOMER, equations (4)–(9) are used to assess the air clearness index and the generated electricity by photovoltaic

Table 1: Parameters of the investigated solar panels [29].

PV technology	Passive emitter rear cell silicon (perc-si)	Monocrystalline silicon (m-si)	Polycrystalline silicon (p-si)	Amorphous silicon (a-si)	Microcrystalline c silicon (μc-si)	Cadmium telluride (Cd-Te)
Type	Glass-polymer	Glass-polymer	Glass-polymer	Glass-polymer	Glass-polymer	Glass-glass
NOCT(C)	45	45	46	46	44	45
Module efficiency η_STC%	23.4	18.4	14.1	6.0	9.5	10.7
Temperature coefficient of maximal power β_{STC} (%K)	−0.45	−0.38	−0.45	−0.19	−0.24	−0.25

Table 2: Comparison of selected solar panels based on price.

Panel	Average cost per watt ($)
Passive emitter rear	0.32
Monocrystalline	0.3
Polycrystalline	0.27
CdTe	1.1
μ c-si	1.1
a-Si	1

Table 3: Comparison of selected solar panels based on efficiency [30].

Panel	Efficiency
Passive emitter rear	Highest level of efficiency (5% higher than monocrystalline panels)
Monocrystalline	14%–22%
Polycrystalline	13%–19%
CdTe	13%–18%
μ c-si	10%–12%
a-Si	6%–10%

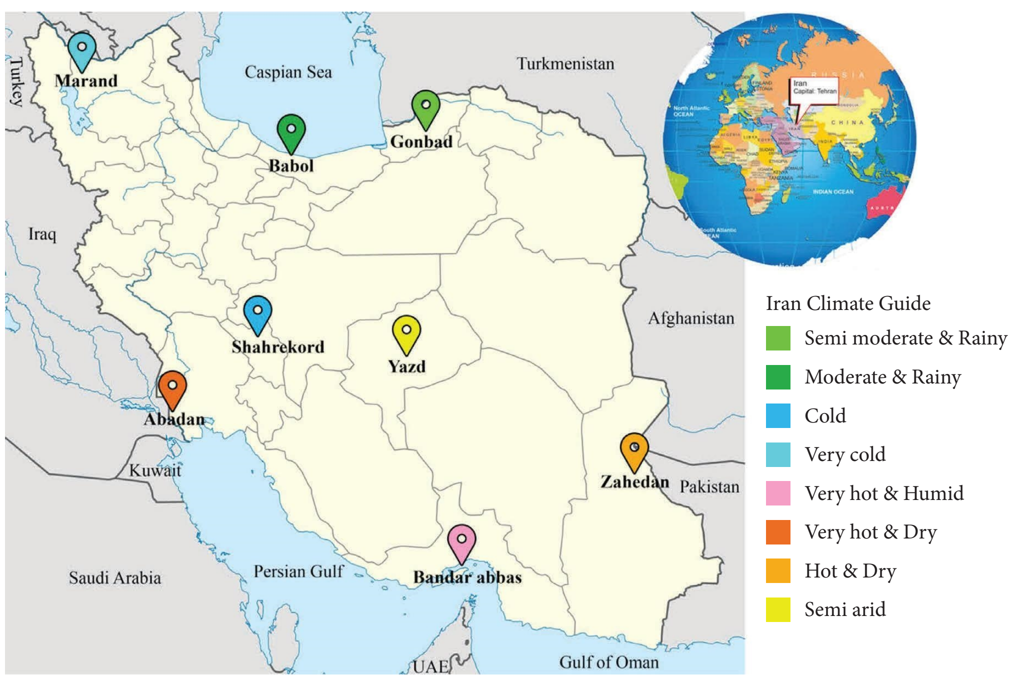

Figure 2: Climatic divisions of Iran and investigated areas.

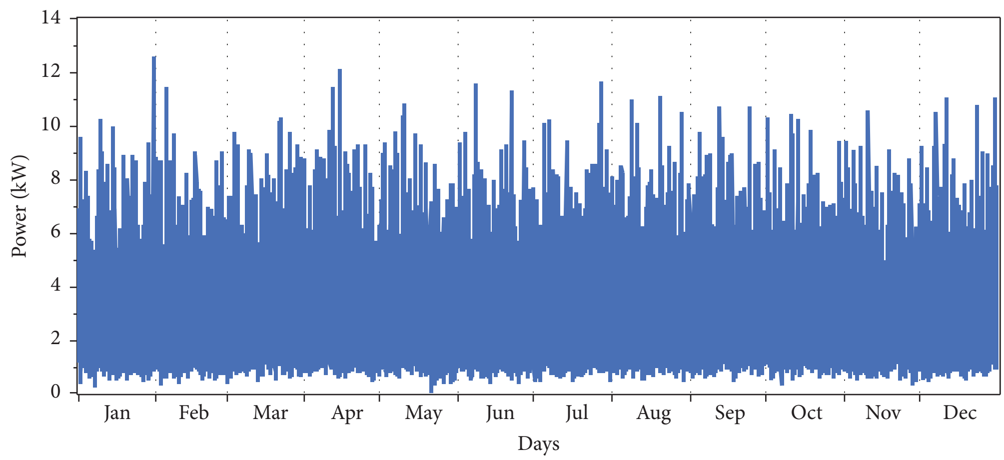

Figure 3: Electricity load.

cells [38, 39]. The geographical location and the average monthly radiation data of the investigated areas are used in these calculations as follows:

$$H_{oh} = \frac{24 \times 60}{\pi} G_{sc} \times d_r \times (\omega_s . \sin\varphi . \sin\delta + \cos\varphi . \cos\delta . \sin\omega_s), \tag{4}$$

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi n}{365}\right), \tag{5}$$

$$\delta = 0.409 \sin\left(\frac{2\pi n}{365} - 1.35\right), \tag{6}$$

$$\omega_s = \mathrm{Arccos}(-\tan\varphi . \tan\delta), \tag{7}$$

$$\overline{k_T} = \frac{\overline{H}}{\overline{H_{oh}}}, \tag{8}$$

$$P_{pv} = Y_{pv} \times f_{pv} \times \frac{\overline{H_T}}{\overline{H_{T,STC}}}. \tag{9}$$

According to the efficiency of HOMER software and the total NPC parameter, various structures containing the lowest NPC would be ranked [40, 41]. Due to the uncertainty, the software can perform sensitivity analysis for parameters such as losses because of dust, wiring, and shading and the intensity of radiation reaching the surface of photovoltaic cells. Economic assessments in HOMER are carried out using the following equations [42, 43]:

$$NPC = \frac{C_{ann,total}}{CRF\left(i, R_{proj}\right)},$$
$$\mathrm{CRF} = \frac{i\,(1+i)^N}{(1+i)^N - 1},$$
$$i = \frac{i' - f}{1 + f},$$
$$\mathrm{COE} = \frac{C_{\mathrm{ann,total}}}{E_{\mathrm{Load\ served}}}. \tag{10}$$

In HOMER, if the net monthly electricity is calculated, the total annual energy cost is assessed through the following equation [43]:

$$C_{\mathrm{grid.\ energy}} = \sum_{i}^{\mathrm{rates}} \sum_{j}^{12} \begin{cases} E_{\mathrm{net\ grid\ purchases}.i.j} \bullet c_{\mathrm{power}.i}, & \text{if } E_{\mathrm{net\ grid\ purchases}.i.j} \geq 0, \\ E_{\mathrm{net\ grid\ purchases}.i.j} \bullet c_{\mathrm{sellback}.i}, & \text{if } E_{\mathrm{net\ grid\ purchases}.i.j} < 0. \end{cases} \tag{11}$$

The mentioned includes selling/buying electricity to/from the national electricity grid every month for one year. Positive (or zero) or negative of buying electricity from the grid are two conditions of this equation. The purchase price of electricity from the grid is different from the selling price of electricity to the grid.

6. Results

In Table 4, the wind speed effect on the output efficiency of the investigated panels is shown. As equations (1)–(3), efficiency depends on wind speed and ambient temperature. According to the results, the crystal passive emitter rear cell is the most efficient, followed by the monocrystal and polycrystal panels. Also, the lowest efficiency is related to a-Si panels and silicon microcrystals. Various panels have been studied due to the price of each kWh of electricity produced in the eight climates of Iran. It should be noted that these panels are popular in Iran, and the conclusions of the present work can be used as a guide for making the right decision in the field of solar energy.

According to the results, the highest efficiency, 22.8%, is related to the crystal passive emitter rear cell and Bandar Abbas city. Also, Marand city and the a-Si panel, with an efficiency of 5.53%, have the lowest efficiency among the investigated panels and cities. Since weather conditions such as humidity and dust affect solar cells' efficiency, the effects of wind speed and temperature have been studied. If the wind speed increases and ignores the dust effect, the solar cell efficiency increases. Increasing wind speed cools the solar cell and increases efficiency. This effect also depends on the weather conditions and the type of cell.

Table 5 shows how various technologies influence electricity generation in different climates. When prioritizing PV technologies across different climatic regions, it becomes evident that passive emitter rear technology is the most suitable option due to its consistently superior electricity generation across all climates. Following closely behind, monocrystalline and μ c-si technologies have the second and third positions, respectively, in terms of solar energy production across all climates. Conversely, the results of Table 5 indicate that a-Si, polycrystalline, and CdTe technologies are less favorable choices, ranking the lowest due to their limited electricity generation capabilities in different climates. As a general result, it can be said that the effect of different solar cells in different climates of Iran is the same and the difference is only in the generated electricity in each climate. This result is particularly important in choosing and prioritizing PV technologies based on different weather conditions in Iran.

The results of energy, economic, and environmental parameters for all six panels and all eight investigated stations are presented in Table 6. Based on the results, the panel that has been selected as the most suitable panel has the lowest total NPC among the desired panels. Therefore, the polycrystalline panel in Marand city has the most suitable total NPC price. Moreover, CdTe and silicon microcrystalline panels with total NPC = \$7330 have the highest value and, therefore, are the most unsuitable. The amount of generated solar electricity is an important parameter, and this, produced by the crystal passive emitter rear cell, is the highest in Gonbad station. Also, the most appropriate values for the parameters of the least electricity purchase from the grid and the most electricity sales to the grid are at this station. The environmental analysis results show that pollution is produced because of the grid electricity usage. The lowest emitted pollution, 12,602.9 kg per year, is related to Gonbad city and crystal panels with inactive emitter coating. According to Table 6, the simulation results and data analysis for different types of solar panels and eight climatic zones of Iran have been studied. The results show that, for all cases, using an on-grid network is the most optimal and cost-effective option. Investigation of the parameters of the lowest total NPC, highest PV production, lowest purchased, highest sold, and lowest emission for different types of solar panels and the studied cities shows that Gonbad is the most suitable station in a semitemperate and rainy climate. Based on the results, the lowest price of solar energy produced is

Table 4: The effect of wind speed on the output efficiency of different panels in the investigated areas.

City	Ambient temperature (C)	Wind speed (m/s)	Efficiency (%)					
			Monocrystalline	Polycrystalline	Passive emitter rear	a-Si	CdTe	μ c-si
Abadan	25.90	3.1	18.05	13.87	22.54	5.9	10.65	9.47
Babol	13.56	3.9	17.09	13.11	21.69	5.6	10.06	8.94
Bandar Abbas	26.96	6.0	18.27	14.01	22.80	6.03	10.72	9.53
Gonbad	15.23	4.6	17.25	13.24	21.53	5.71	10.15	9.97
Marand	8.84	4.3	16.71	12.82	21.22	5.53	9.84	8.75
Shahrekord	13.88	4.2	17.13	13.14	21.74	5.67	10.08	8.96
Yazd	18.84	5.2	17.57	13.48	22.31	5.81	10.33	9.18
Zahedan	18.23	3.3	17.45	13.39	22.14	5.78	10.28	9.85

Table 5: The impact of different technologies on the amount of solar electricity produced in each climate.

City	a-Si	CdTe	μ c-si	Monocrystalline	Passive emitter rear	Polycrystalline
Abadan	8363	8431	8451	8492	8529	8430
Babol	6943	6990	7003	7032	7059	6989
Bandar Abbas	8591	8662	8682	8726	8765	8660
Gonbad	9010	9081	9109	9144	9183	9080
Marand	8874	8940	8959	9000	9039	8939
Shahrekord	8708	8775	8794	8734	8874	8773
Yazd	8719	8787	8807	8849	8890	8786
Zahedan	8375	8437	8461	8493	8530	8436

Table 6: Simulation results of different types of panels in the studied areas.

Panel	Min total NPC ($)	Max PV production (kWh/year)	Min purchased (kWh/year)	Max sold (kWh/year)	Min emission (kg/year)
Monocrystalline	3329 (Marand)	9144 (Gonbad)	21117 (Gonbad)	1299 (Gonbad)	12606 (Gonbad)
Polycrystalline	3180 (Marand)	9080 (Gonbad)	21122 (Gonbad)	1297 (Gonbad)	12610 (Gonbad)
Passive emitter rear	3429 (Marand)	9183 (Gonbad)	21114 (Gonbad)	1300 (Gonbad)	12602.9 (Gonbad)
a-Si	6831 (Marand)	9010 (Gonbad)	21128 (Gonbad)	1296 (Gonbad)	12615 (Gonbad)
CdTe	7330 (Marand)	9081 (Gonbad)	21122 (Gonbad)	1297 (Gonbad)	12609.9 (Gonbad)
μ c-si	7330 (Marand)	9109 (Gonbad)	21120 (Gonbad)	1298 (Gonbad)	12607.9 (Gonbad)

$0.021/kWh. The results also show that the polycrystalline panel is the most suitable for the studied areas because of the lowest total NPC.

Figure 4 shows the cash flow diagram for the Marand station, the most economically suitable station for using polycrystalline solar cells. This figure shows that $1,750 was paid for purchasing a solar cell and an electrical converter in the first year. There is an annual cost of operating the equipment and buying electricity from the grid. In the 10th and 20th years, the price of replacing the electrical converter is added to the expenses. In total, the cost of the salvage of 200 $ is positively considered for the remaining useful life of the converter.

In Figure 5, the average monthly electricity production is displayed. The results show that 30% of the produced electricity is solar, and the grid supplies 70% of the remaining. According to the results, the most purchased electricity from the grid is in December, when solar cells produced the least electricity.

7. Future Works

In continuation of the present work, various aspects can be examined, such as the impact of weather changes on the performance of different solar cells [44], the use of artificial intelligence in selecting more suitable solar cells [45], the

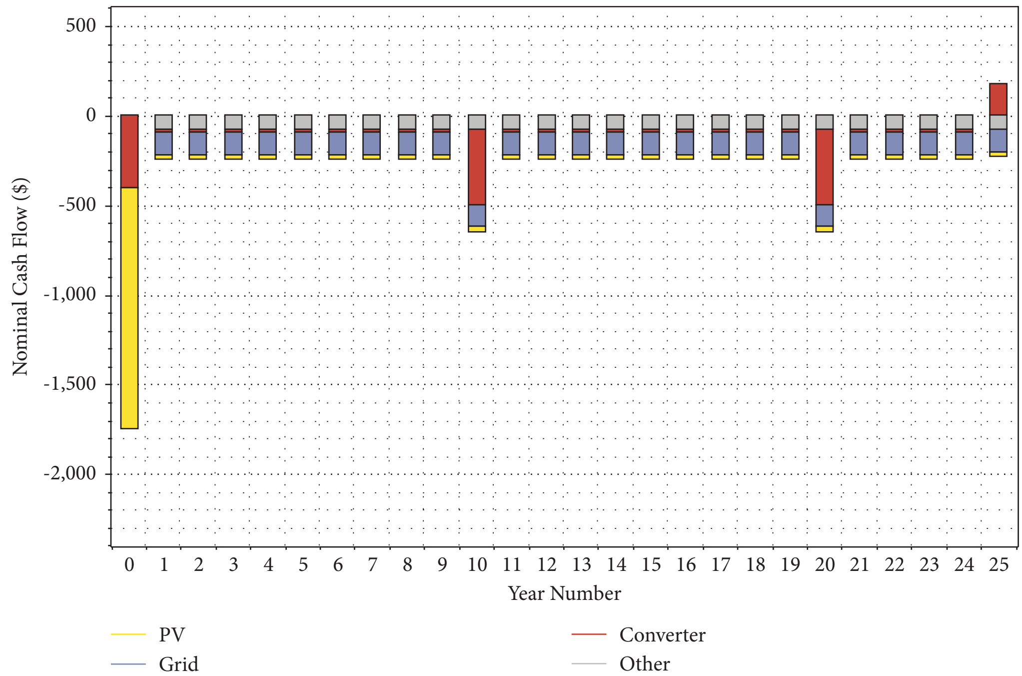

Figure 4: Cash flow diagram for the Marand station.

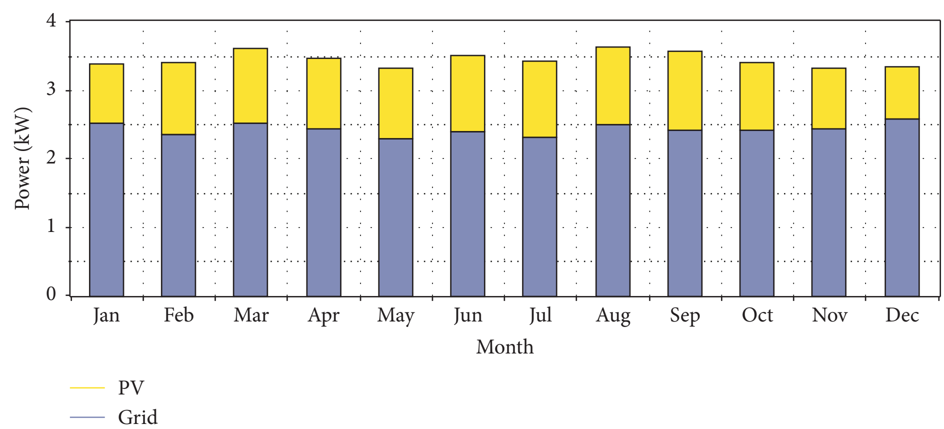

Figure 5: Average monthly electricity production for Marand station.

amount of green hydrogen production by each type of solar-cell technology [46], supplying electricity for electric vehicles [47], combining solar cells with heat pumps [48], and investigating emerging energy sources and comparing them to the actual state [49].

8. Conclusion

The use of solar cells in buildings, such as BIPV, has been one of the fastest advances in the last decade. It should be noted that considering the effect of temperature and wind speed on the solar cell's efficiency in various climates of Iran, along with the effect of solar-cell type, has yet to be considered. Therefore, this work aims to investigate the above parameters by HOMER V2.81 software for household use. The results show that the highest and lowest solar-cell efficiencies are related to crystal passive emitter rear cells (22.8% Bandar Abbas) and a-Si solar cells (53.5% Marand), respectively. The highest efficiency among the studied stations is related to Bandar Abbas, which has the highest wind speed. The lowest total NPC, 3,180$, is related to the Marand station and polycrystalline solar cell. The highest rate of solar electricity production, 9,183 kWh/year, is produced in Gonbad station. The lowest electricity purchased from the network (21114 kWh/year) and the most electricity sold to the network (1300 kWh/year) is related to the Gonbad station. Also, regarding CO_2 emissions, Gonbad station is the most environmentally friendly station, which emits 12602.9 CO_2 annually. Finally, the results of the present work can be applied to all similar climates in other parts of the world by analyzing the results and using up-to-date data.

Nomenclature

i:	Annual interest rate (%)
f:	Annual inflation rate (%)
i':	Nominal interest rate (%)
CRF:	Capacity recovery factor (−)
R_{proj}:	Lifetime of project (year)
k_t:	Clearness index (−)
f_{PV}:	Derating factor (%)
G_{sc}:	Solar constant (0.082 MJ/m^2-min)
Y_{PV}:	Output power of solar cell under standard conditions (kW)
$\overline{H_T}$:	Incident radiation on the cell's surface on a monthly basis (kW/m^2)
H_{oh}:	Extraterrestrial radiation (MJ/m^2-day)
P_{PV}:	Output power of PV cells (kW)
d_r:	Inverse relative distance earth-sun
$C_{\text{ann,total}}$:	Total annual cost ($)
H:	Monthly average daily radiation on a horizontal plane (MJ/m^2-day)
$C_{\text{grid,energy}}$:	Total annual energy charge (kWh)
$E_{\text{net grid purchases}}$:	The net grid purchases (grid purchases minus grid sales) (kWh)
COE:	Levelized cost of electricity ($/kWh)
C_{power}:	The grid power price ($/kWh)
PV:	Photovoltaic
BIPV:	Building integrated photovoltaic
$E_{\text{load served}}$:	Real electrical load by system (kWh/year)
h_w:	Wind convection
I:	Irradiance
T_a:	ambient temperature
$\overline{H_{T,\text{STC}}}$:	Incident radiation on the cell's surface under standard conditions (1 kW/m^2)
T_{pv}:	Cell/module temperature
V_h:	Wind speed measured 10 meters above the ground (m/s)
STC:	Standard test condition
NOTC:	Nominal operating cell temperature
ω_s:	Sunset hour angle (Radian)
n:	Number of days during the year (−)
φ:	Latitude (Radian)
δ:	Declination of the sun (Radian)
β:	Temperature coefficient of maximal power of the solar cells
η:	The efficiency of the solar cells
τ:	The transmittance of the cover system
α:	The absorption coefficient of the solar cells
N:	Useful life-time (year)
NPC:	Net present cost ($).

Data Availability

All data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] S. N. Shorabeh, M. K. Firozjaei, O. Nematollahi, H. K. Firozjaei, and M. Jelokhani-Niaraki, "A risk-based multi-criteria spatial decision analysis for solar power plant site selection in different climates: a case study in Iran," *Renewable Energy*, vol. 143, pp. 958–973, 2019.

[2] M. R. Assadi, M. Ataebi, E. S. Ataebi, and A. Hasani, "Prioritization of renewable energy resources based on sustainable management approach using simultaneous evaluation of criteria and alternatives: a case study on Iran's electricity industry," *Renewable Energy*, vol. 181, pp. 820–832, 2022.

[3] S. Ali, Z. Zheng, M. Aillerie, J. P. Sawicki, M. C. Pera, and D. Hissel, "A review of DC Microgrid energy management systems dedicated to residential applications," *Energies*, vol. 14, no. 14, p. 4308, 2021.

[4] R. Kalbasi, F. Izadi, and P. Talebizadehsardari, "Improving performance of AHU using exhaust air potential by applying exergy analysis," *Journal of Thermal Analysis and Calorimetry*, vol. 139, no. 4, pp. 2913–2923, 2020.

[5] A. Nariman, R. Kalbasi, and S. Rostami, "Sensitivity of AHU power consumption to PCM implementation in the wall-considering the solar radiation," *Journal of Thermal Analysis and Calorimetry*, vol. 143, no. 3, pp. 2789–2800, 2021.

[6] C. Zomer, I. Custódio, A. Antoniolli, and R. Rüther, "Performance assessment of partially shaded building-integrated photovoltaic (BIPV) systems in a positive-energy solar energy laboratory building: architecture perspectives," *Solar Energy*, vol. 211, pp. 879–896, 2020.

[7] R. Thomas, *Photovoltaics and Architecture*, Spon Press, London, UK, 2003.

[8] K. Fuglestad, "Building integrated photovoltaics for Norway," M.Sc. thesis, UNIVERSITY OF OSLO, Oslo, Norway, 2021, http://bipvno.no.

[9] M. Tabakovic, H. Fechner, W. Van Sark et al., "Status and outlook for building integrated photovoltaics (BIPV) in relation to educational needs in the BIPV sector," *Energy Procedia*, vol. 111, pp. 993–999, 2017.

[10] E. Delponte, F. Marchi, F. Frontini, C. Polo, K. Fath, and M. Batey, "BIPV in EU28, from niche to mass market: an assessment of current projects and the potential for growth through product innovation," in *Proceedings of the 31st European photovoltaic solar energy conference and exhibition*, pp. 3046–3050, Hamburg, Germany, September 2015.

[11] Pv Sites, "BIPV market and stakeholderanalysis and needs," 2020, http://www.pvsites.eu.

[12] P. Bonomo, A. Chatzipanagi, and F. Frontini, "Overview and analysis of current BIPV products: new criteria for supporting the technological transfer in the building sector," *VITRUVIO-International Journal of Architectural Technology and Sustainability*, vol. 1, pp. 67–85, 2015.

[13] F. Esmaeilion, A. Ahmadi, S. Hoseinzadeh, M. Aliehyaei, S. A. Makkeh, and D. Astiaso Garcia, "Renewable energy desalination; a sustainable approach for water scarcity in arid lands," *International Journal of Sustainable Engineering*, vol. 14, no. 6, pp. 1916–1942, 2021.

[14] P. S Mohsen, F. Pourfayaz, R. Shirmohamadi, S. Moosavi, and N. Khalilpoor, "Potential, current status, and applications of renewable energy in energy sector of Iran: a review," *Renewable Energy Research and Applications*, vol. 2, no. 1, pp. 25–49, 2021.

[15] J. A. Turner, "A realizable renewable energy future," *Science*, vol. 285, no. 5428, pp. 687–689, 1999.

[16] R. Siddiqui and U. Bajpai, "Deviation in the performance of solar module under climatic parameter as ambient temperature and wind velocity in composite climate," *International Journal of Renewable Energy Resources*, vol. 2, no. 3, pp. 486–490, 2012.

[17] A. R. Gxasheka, E. E. Van Dyk, and E. L. Meyer, "Evaluation of performance parameters of PV modules deployed outdoors," *Renewable Energy*, vol. 30, no. 4, pp. 611–620, 2005.

[18] M. Jahangiri, Y. Yousefi, I. Pishkar, S. J. Hosseini Dehshiri, S. S. Hosseini Dehshiri, and S. M. Fatemi Vanani, "Techno–econo–enviro energy analysis, ranking and optimization of various building-integrated photovoltaic (BIPV) types in different climatic regions of Iran," *Energies*, vol. 16, no. 1, p. 546, 2023.

[19] D. T. S. Ting, H. N. Afrouzi, M. B. M. Siddique, A. Hassan, and J. Ahmed, "Modelling and simulation of building-integrated photovoltaics (BIPV) installations in Swinburne university," in *Recent Advances in Electrical and Electronic Engineering and Computer Science: Selected Articles from ICCEE 2021*, pp. 39–46, Springer, Malaysia, Singapore, 2022.

[20] S. Rahmati Dehkordi and M. Jahangiri, "Sensitivity analysis for 3E assessment of BIPV system performance in abadan in southwestern Iran," *Journal of Renewable Energy and Environment*, vol. 9, no. 1, pp. 1–12, 2022.

[21] Z. Ni, J. Jiang, X. Cai et al., "System design and economic configuration of building integrated photovoltaic," in *Proceedings of the 37th European Photovoltaic Solar Energy Conference and Exhibition*, pp. 1891–1895, Online, EU, September 2020.

[22] K. Abu Bakar, "Effect of temperature and wind speed on efficiency of PV module," Complex Engineering Problem (CEP)-Technical report https://www.researchgate.net/publication/340226677, pp. 1–15, University of Engineering and Technology, Lahore, 2020.

[23] E. Radziemska, "The effect of temperature on the power drop in crystalline silicon solar cells," *Renewable Energy*, vol. 28, no. 1, pp. 1–12, 2003.

[24] P. Ramanan, K. Kalidasa Murugavel, A. Karthick, and K. Sudhakar, "Performance evaluation of building-integrated photovoltaic systems for residential buildings in southern India," *Building Services Engineering Research and Technology*, vol. 41, no. 4, pp. 492–506, 2020.

[25] E. D. Rounis, A. K. Athienitis, and T. Stathopoulos, "BIPV/T curtain wall systems: design, development and testing," *Journal of Building Engineering*, vol. 42, Article ID 103019, 2021.

[26] A. K. Athienitis, J. Bambara, B. O'Neill, and J. Faille, "A prototype photovoltaic/thermal system integrated with transpired collector," *Solar Energy*, vol. 85, no. 1, pp. 139–153, 2011.

[27] S. Dubey, J. N. Sarvaiya, and B. Seshadri, "Temperature dependent photovoltaic (PV) efficiency and its effect on PV production in the world–a review," *Energy Procedia*, vol. 33, pp. 311–321, 2013.

[28] G. Notton, C. Cristofari, M. Mattei, and P. Poggi, "Modelling of a double-glass photovoltaic module using finite differences," *Applied Thermal Engineering*, vol. 25, no. 17-18, pp. 2854–2877, 2005.

[29] C. Schwingshackl, M. Petitta, J. E. Wagner et al., "Wind effect on PV module temperature: analysis of different techniques for an accurate estimation," *Energy Procedia*, vol. 40, pp. 77–86, 2013.

[30] M. A. Islam, M. Akhtaruzzaman, N. Amin, and K. Sopian, "Commercial viability of different photovoltaic technologies," in *Comprehensive Guide on Organic and Inorganic Solar Cells*, pp. 347–393, Academic Press, Cambridge, MA, USA, 2022.

[31] M. Jahangiri, A. Haghani, S. Heidarian, A. Alidadi Shamsabadi, and L. M. Pomares, "Electrification of a tourist village using hybrid renewable energy systems, Sarakhiyeh in Iran," *Journal of Solar Energy Research*, vol. 3, no. 3, pp. 201–211, 2018.

[32] M. J. Khan and M. T. Iqbal, "Pre-feasibility study of stand-alone hybrid energy systems for applications in Newfoundland," *Renewable Energy*, vol. 30, no. 6, pp. 835–854, 2005.

[33] P. Kumar, R. Pukale, N. Kumabhar, and U. Patil, "Optimal design configuration using HOMER," *Procedia Technology*, vol. 24, pp. 499–504, 2016.

[34] A. Singh, P. Baredar, and B. Gupta, "Computational simulation and optimization of a solar, fuel cell and biomass hybrid energy system using HOMER pro software," *Procedia Engineering*, vol. 127, pp. 743–750, 2015.

[35] A. M. Abed, H. A. Lafta, R. Alayi et al., "Utilization of animal solid waste for electricity generation in the northwest of Iran 3E analysis for one-year simulation," *International Journal of Chemical Engineering*, vol. 2022, Article ID 4228483, 8 pages, 2022.

[36] H. Saghaei, P. Elyasi, and B. J. Shastri, "Sinusoidal and rectangular Bragg grating filters: design, fabrication, and comparative analysis," *Journal of Applied Physics*, vol. 132, no. 6, Article ID 064501, 2022.

[37] A. Tang, F. H. Alsultany, V. Borisov et al., "Technical, environmental and ranking analysis of using solar heating: a case study in South Africa," *Sustainable Energy Technologies and Assessments*, vol. 52, Article ID 102299, 2022.

[38] S. Kanata, S. Baqaruzi, A. Muhtar, P. Prasetyawan, and T. Winata, "Optimal planning of hybrid renewable energy system using Homer in Sebesi Island, Indonesia," *International Journal of Renewable Energy Resources*, vol. 11, no. 4, pp. 1507–1516, 2021.

[39] K. K. Sharma, A. Gupta, R. Kumar et al., "Economic evaluation of a hybrid renewable energy system (HRES) using hybrid optimization model for electric renewable (HOMER) software-a case study of rural India," *International Journal of Low Carbon Technologies*, vol. 16, no. 3, pp. 814–821, 2021.

[40] N. Ganjei, F. Zishan, R. Alayi et al., "Designing and sensitivity analysis of an off-grid hybrid wind-solar power plant with diesel generator and battery backup for the rural area in Iran," *Journal of Engineering*, vol. 2022, Article ID 4966761, 14 pages, 2022.

[41] M. Jahangiri, A. Mostafaeipour, H. U. Rahman Habib, H. Saghaei, and A. Waqar, "Effect of emission penalty and annual interest rate on cogeneration of electricity, heat, and hydrogen in Karachi: 3E assessment and sensitivity analysis," *Journal of Engineering*, vol. 2021, Article ID 6679358, 16 pages, 2021.

[42] A. Mostafaeipour, M. Qolipour, M. Rezaei, M. Jahangiri, A. Goli, and A. Sedaghat, "A novel integrated approach for ranking solar energy location planning: a case study," *Journal of Engineering, Design and Technology*, vol. 19, no. 3, pp. 698–720, 2020.

[43] A. Rahimi Ariae, M. Jahangiri, M. Haghgo Fakhr, and A. Alidadi Shamsabadi, "Simulation of biogas utilization effect on the economic efficiency and greenhouse gas emission: a case study in isfahan, Iran," *International Journal of Renewable Energy Development*, vol. 8, no. 2, pp. 149–160, 2019.

[44] N. Matera, D. Mazzeo, C. Baglivo, and P. M. Congedo, "Will climate change affect photovoltaic performances? A long-term analysis from 1971 to 2100 in Italy," *Energies*, vol. 15, no. 24, p. 9546, 2022.
[45] N. Matera, D. Mazzeo, C. Baglivo, and P. M. Congedo, "Hourly forecasting of the photovoltaic electricity at any latitude using a network of artificial neural networks," *Sustainable Energy Technologies and Assessments*, vol. 57, Article ID 103197, 2023.
[46] G. K. Karayel, N. Javani, and I. Dincer, "Green hydrogen production potential for Turkey with solar energy," *International Journal of Hydrogen Energy*, vol. 47, no. 45, pp. 19354–19364, 2022.
[47] D. Mazzeo, N. Matera, R. De Luca, and R. Musmanno, "A smart algorithm to optimally manage the charging strategy of the Home to Vehicle (H2V) and Vehicle to Home (V2H) technologies in an off-grid home powered by renewable sources," *Energy Systems*, vol. 15, pp. 1–38, 2022.
[48] N. Matera, D. Mazzeo, and P. M. Congedo, "Energy-sustainable hospitals: integration of a novel compound parabolic concentrator system with two storage tanks for domestic hot water production at high and low temperatures," *Applied Thermal Engineering*, vol. 221, Article ID 119773, 2023.
[49] D. Mazzeo, N. Matera, P. Bevilacqua, and N. Arcuri, "Energy and economic analysis of solar photovoltaic plants located at the University of Calabria," *International journal of heat and technology*, vol. 33, no. 4, pp. 41–50, 2015.