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Review

Performance Evaluation of Solar Power Plants: A Review and a Case Study

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Abstract: The world's electricity generation has increased with renewable energy technologies such as solar (solar power plant), wind energy (wind turbines), heat energy, and even ocean waves. Iran is in the best condition to receive solar radiation due to its proximity to the equator (25.2969° N). In 2020, Iran was able to supply only 900 MW (about 480 solar power plants and 420 MW home solar power plants) of its electricity demand from solar energy, which is very low compared to the global average. Yazd, Fars, and Kerman provinces are in the top ranks of Iran, with the production of approximately 68, 58, and 47 MW using solar energy, respectively. Iran also has a large area of vacant land for the construction of solar power plants. In this article, the amount of electricity generation using solar energy in Iran is studied. In addition, the construction of a 10 MW power plant in the city of Sirjan is economically and technically analyzed. The results show that with US$16.14 million, a solar power plant can be built in the Sirjan region, and the initial capital will be returned in about four years. The results obtained using Homer software show that the highest maximum power generation is in July.

Keywords: renewable energy; solar power plant; economic and technical analysis; annual performance

Citation: Makkiabadi, M.; Hoseinzadeh, S.; Taghavirashidizadeh, A.; Soleimaninezhad, M.; Kamyabi, M.; Hajabdollahi, H.; Majidi Nezhad, M.; Piras, G. Performance Evaluation of Solar Power Plants: A Review and a Case Study. *Processes* **2021**, *9*, 2253. https://doi.org/10.3390/pr9122253

Academic Editor: Jie Zhu

Received: 9 November 2021
Accepted: 4 December 2021
Published: 14 December 2021

1. Introduction

The renewable energy industry is a significant part of humankind's mitigation mission for the planet's viability. Solar energy is the most plentiful source of renewable energy. If truth be told, wind and other hydraulic energies have been attained from solar energy [1,2]. There are abundant fossil energies such as gas and oil sources in the southern provinces of Iran. However, it has chosen to turn to renewable energy [3]. By minimum environmental effects, Renewable Energy Sources (RESs), such as solar, geothermal, wind, etc., are suitable candidates for electricity generation worldwide [4,5]. In recent years in Iran, the simultaneous production of electricity and fresh water using solar energy has expanded rapidly [6–9]. Iran is located in an appropriate region for solar radiation due to its proximity to the equator (25.2969° N). Studies have proven that the utilization of solar equipment in Iran is expedient, and it can furnish the sector with the country's energy needs [10]. Makkiabadi, et al. [11] studied wind and solar energy potentiality for four cities in Iran. Their results showed that a hybrid solar and wind plant's electricity is 5444.56, 7642.49, 9335.89, and 8084.47 MWh, in four cities, Tabriz, Neyshabur, Ahvaz, and Sirjan, respectively. In 2020, 900 MW of electricity generation in Iran was supplied using solar power plants [12].

By using the angstrom approximated model, Moini et al. [13] purveyed the annual maps of Iran's solar radiation. Besarati [14] provided a map showing solar energy touching the Earth surface in main Iranian cities. Finally, the global horizontal irradiance map for Iran was appraised by Alamdari et al. [15]. They suggested some places with average horizontal solar radiation above 500 Wh/m^2 for photovoltaic (PV) usage. Several studies have, theoretically or experimentally, evaluated the efficiency of solar power plants in the world and Iran. A solar chimney power plant in China with a production capacity of 110–190 kWh and with a collector cover of 196,270 m^2 was analyzed by Dai et al. [16]. Frederick and Reccab [17] investigated electricity generation by a solar chimney power plant in rural areas. Their results showed that about fifty households in rural regions could utilize this plant to consume their electricity.

Nizetic et al. [18] investigated the electrical energy capacity in Mediterranean countries and estimated the value and price of the electric energy generation derived by solar energy. The substantivity study of a solar chimney power plant for providing the remote villages in Algeria was analyzed by Labti et al. [19]. Their results showed that the solar chimney power plant can produce from 140 to 200 kW of electricity and this production was sufficient to satisfy the needs of the isolated areas, and the solar collector of the system might be utilized as a greenhouse for agricultural approaches. The impact of several parameters, such as air velocity, temperature, and moisture, and the effect of geometrical parameters on the performance of a solar chimney plant, was studied by Pasumarthi and Sherif [20,21]. R. Sangi, aimed to appraise the efficiency of solar chimney power plants in some cities of Iran and to estimate the amount of the produced electric energy [22]. Their results indicated that a solar chimney power plant with 350 m chimney height and 1000 m collector diameter could produce the monthly average of 1–2 MW electric power over a year. Hosseini et al. [23] compared six configurations for power plants based in Yazd city of Iran. They suggested an integrated solar combined cycle system with 67 MW$_e$ as the most suitable plan to be Iran's the first solar power plant. They demonstrated that integrated solar combined cycle power plants in Iran could save about $59 million in fuel consumption and reduce about 2.4 million tons in Carbon Cioxide (CO_2) emission over 30 years.

Solar power plants are essential to human beings, not only for their potential to supply electricity, but also for their help to mitigate CO_2 emissions [24–28]. Wang et al. [29] studied economic and technical aspects of low-medium temperature solar energy plants. Their results showed that both enhancement in power generation and reduction in CO_2 emission could be achieved with solar energy plants. Some other studies have also focused on technical and economic analyses of solar power plants [30–33]. To show the electricity production capacity of the solar power plants in the United States, Vasilis et al. [34] presented a theoretical analysis for PV-CAES and CSP power plants between 2011 and 2050 of general plans. They suggested that the US government build large solar power plants to produce 3800 TWh of electricity by 2050. This is enough to replace fossil fuels, and it can also be utilized to produce electrolytic hydrogen. Fathoni et al. [35] evaluated the technical end economic potentials of solar energy applications in Indonesia as a country with thousands of islands.

Southern countries near the equator have the highest solar radiation levels, and the construction of various types of solar power plants in these countries has been expanding rapidly in recent years [36–41]. Shafiey Dehaj and Hajabdollahi [42] modeled and optimized a wind/PV/battery/diesel hybrid system for different cities of Iran. Their results showed that optimum cost increases 4.63% and 17.60% for the best and worst conditions, respectively, for these cities in different solar, wind, and ambient temperature ranges. Numerical modeling of a solar chimney power plant in the southern region of Iran was studied by Bayareh [43]. In the 20,000 m^2 area of Aksaray city in Turkey, an economic analysis of a solar power plant was presented by Taner [44]. It was confirmed that this plant can produce 1.65 million kWh/m^2 per year. For the southern region of Tunisia, Trabelsi et al. [45] simulated a power plant with a parabolic collector. They investigated different climatic conditions and examined this power plant's electrical, thermal, and economic efficiency with harm and dry cooling. An economical, technical, and comparative analysis of PV power plants to be installed in the southern region of Libya was studied by Eljrushi and Zubi [46]. Some other researchers also have studied Concentrated Solar Power (CSP) plants to work in some countries such as Iran, Turkey, and Iraq [47–53]. A review and a design methodology of CSP plants were presented by Zhang et al. [54]. They introduced all solar collector types and evaluated daily and monthly variations of the solar irradiation flux.

Pelay et al. [55] studied CSP plants with storage systems to find the key factors that affect the development of this technology in the efficient and cost-effective production of electricity. The after production CSP was envisaged to act at maximum temperatures than those currently utilized, for enhanced capacity and reduced cost of power production [56–60]. An analogy of CO_2 emissions from fuel fossil and solar power plants in the United States was presented by Kreith et al. [61]. In the last decade, several researchers performed the Life Cycle Assessment (LCA) of solar energy systems and analyzed the environmental impacts of solar power plants on life and nature [62–66]. Nowadays, European, African, and Asian countries have begun to use solar power plants for building, agriculture, and industries [67]. In 2019, Spain was the largest solar market in Europe, producing about 4.7 GW. Germany, Netherlands, France, and Poland are in the following ranks with solar electricity production of 4 GW, 2.5 GW, 1.1 GW, and 784 MW, respectively.

After a brief introduction, the paper will continue, focusing on the following essential items:

1. A summary of the world's electricity generation using solar energy,
2. Extensive study on the electricity production in Iran using solar energy,
3. Economic and technical analysis of the construction of a 10 MW solar power plant in the southern region of Iran (Sirjan city).

This paper investigates the potential of electricity generation in Iran by using solar energy. Unfortunately, this potential has been overlooked so far. For this purpose, the paper contains the history and perspective of electricity generation by solar plants. Installed solar power plants are evaluated along with designed and simulated plants. Finally, this paper guides those who want to design a solar power plant in the southern regions of Iran and presents a brief report on the costs of building and operating such a plant.

2. Solar Energy Usage in the World

The technologies restraining RESs like wind and solar energy are determined by a power compression different instruction of value lower than fossil fuels [68–70]. As a result, the transmission to RESs is envisaged to strengthen the universal rivalry for land. For instance, the grabble of bioenergy energy has been already recognized as the main driver of recent land-use change in advanced regions [71–73]. Such an analysis technique would be a substantial contribution to solar power generation development both and regionally and nationally [74]. Furthermore, the use of PV panels to generate electricity has been increasing in recent years. The generation of electricity using solar and wind energy worldwide from 2000 to 2023 shows that the use of solar power energy to generate electricity is increasing rapidly [75,76].

Attig Bahar et al. [77] made an overall review of solar energy and the future desire to use solar energy. The time-averaged map of surface absorbed longwave radiation, assuming clear sky and no aerosol monthly 0.5 × 0.625 deg over January 1990–January 2021 (W/m^{-2}) is shown in Figure 1. As it turns out, countries near the equator, such as Iran, Iraq, and Saudi Arabia, have acceptable levels of solar energy [78]. K.H Solangi et al. [79] reported that the world cumulative installed solar energy was 22.98 GW in 2009, a rapid change of 46.9% compared to 2008. Saleh H Alawaji [80] evaluated several research projects in terms of their technical and economic performance and feasibility in Saudi Arabia.

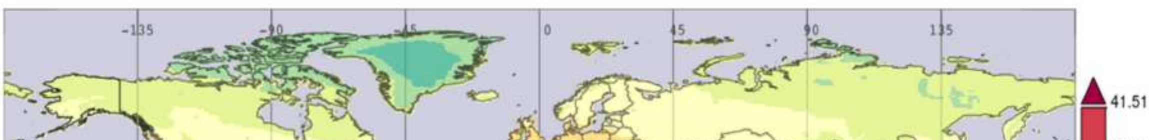


Figure 2 [81] shows that electricity generation using solar energy (PV panels) in 2000 was equal to 1.3 GW. In comparison, in 2020, it was 789 GW, which shows an 800% increase in electricity production using solar energy. Also in 2020, the amount of electricity generated using solar energy exceeded wind energy.

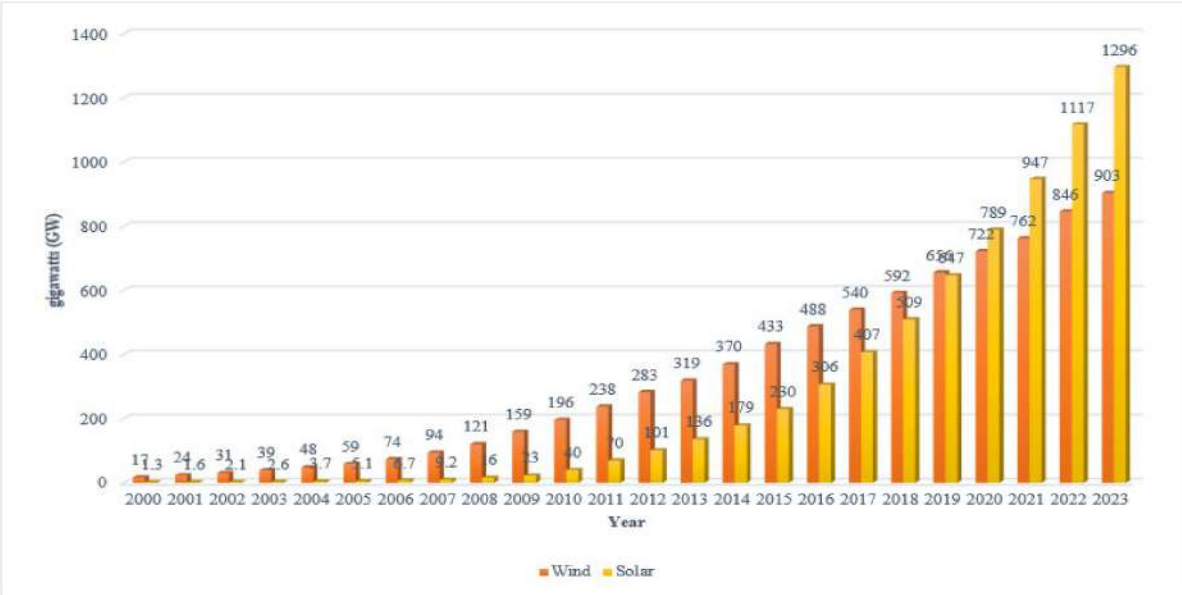
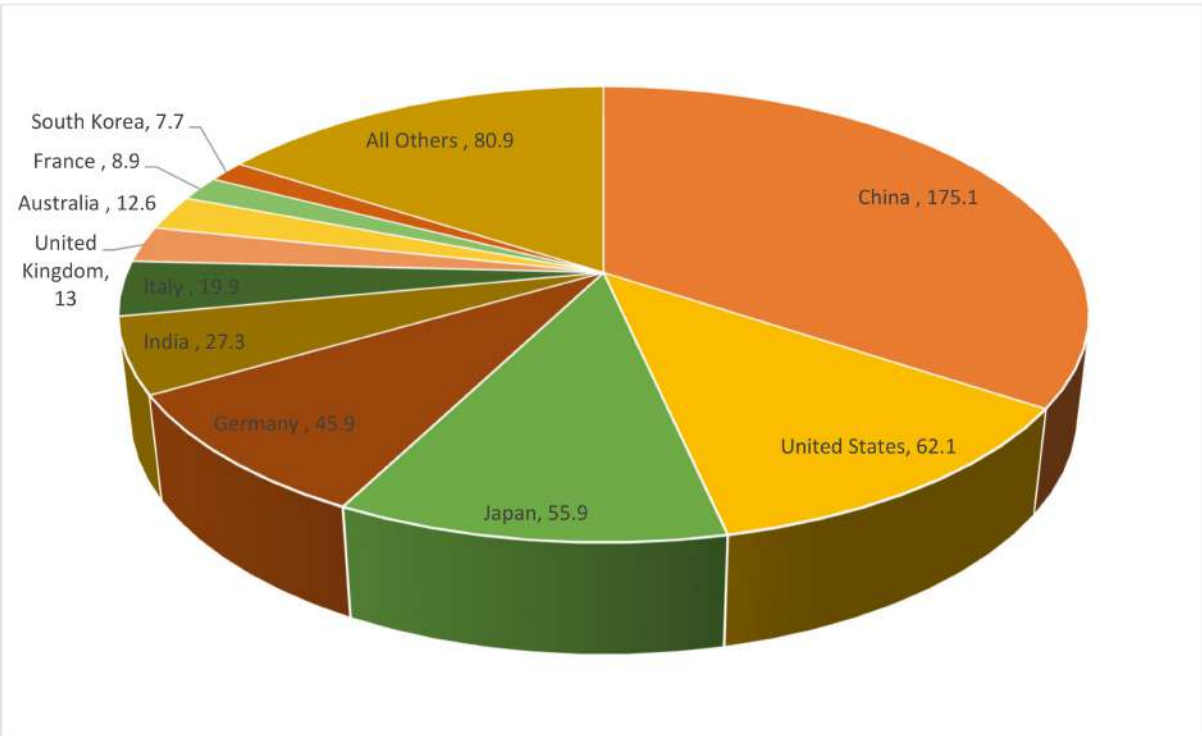


Figure 2. Generation of electricity with wind and solar energies [81].

China is the world's largest producer of electricity using solar energy. The production of electricity using solar energy in China in 2018 was equal to 175 gigawatts, which, with a significant increase in 2020, has reached about 254 gigawatts, and, according to forecasts, in 2023 will reach 448 gigawatts [82].

The amount of electricity generated using solar energy for different countries, such as China, the USA, and Japan, in 2018 is shown in Figure 3. Moreover, the increase in electricity production based on PV panels by 2023 is predicted to use about 1296 GW of solar energy [82]. As shown in this figure, the increase in electricity generation using solar energy is higher in China, the United States, and India than in other countries.



(a)

Furthermore, in 2019 and 2020, electricity generation using solar energy has been growing in the countries bordering the Persian Gulf. For example, the world's largest solar project with a production capacity of nearly 1.2 GW was inaugurated in the UAE. Approximately 3.2 million panels have been used in the project, which provides an energy demand of 90,000 people and reduces CO_2 emissions by up to one million metric tons [84]. In addition, by signing a memorandum of understanding, Saudi Arabia and Japan are making progress in developing a massive solar energy project that could see hundreds of gigawatts of solar farms built by 2030 in Saudi Arabia [85].

A solar cell transforms the energy in the photons of sunlight. The performance of solar cells hinges on spectral characteristics of sunlight, ambition temperature, and insolation. Therefore, it appears that PV technology can interrupt the perfect silicon solar cell market [86,87]. PV systems are classified into two original groups: (1) stand-alone and (2) grid-connected systems [88,89]. Considered definition, grid-connected systems are developing in China, Canada, and the US [90,91]. In urban areas, small and big PV power systems are utilized in mining, agriculture, and building industries to produce electricity for lights or produce fresh water by desalination [92–95]. A comprehensive classification of solar cells, modules, solar panels, solar array, solar PV systems, and PV effect is provided by Rabaia et al. [96].

A general schematic of a PV system is shown in Figure 4. The PV panel produced electricity in a DC output ordered by a charge controller and is stored in the battery. When needed, the energy stored in the battery is converted to AC via an inverter (DC/AC) for AC loads or otherwise, which supplies DC power directly [97–100].

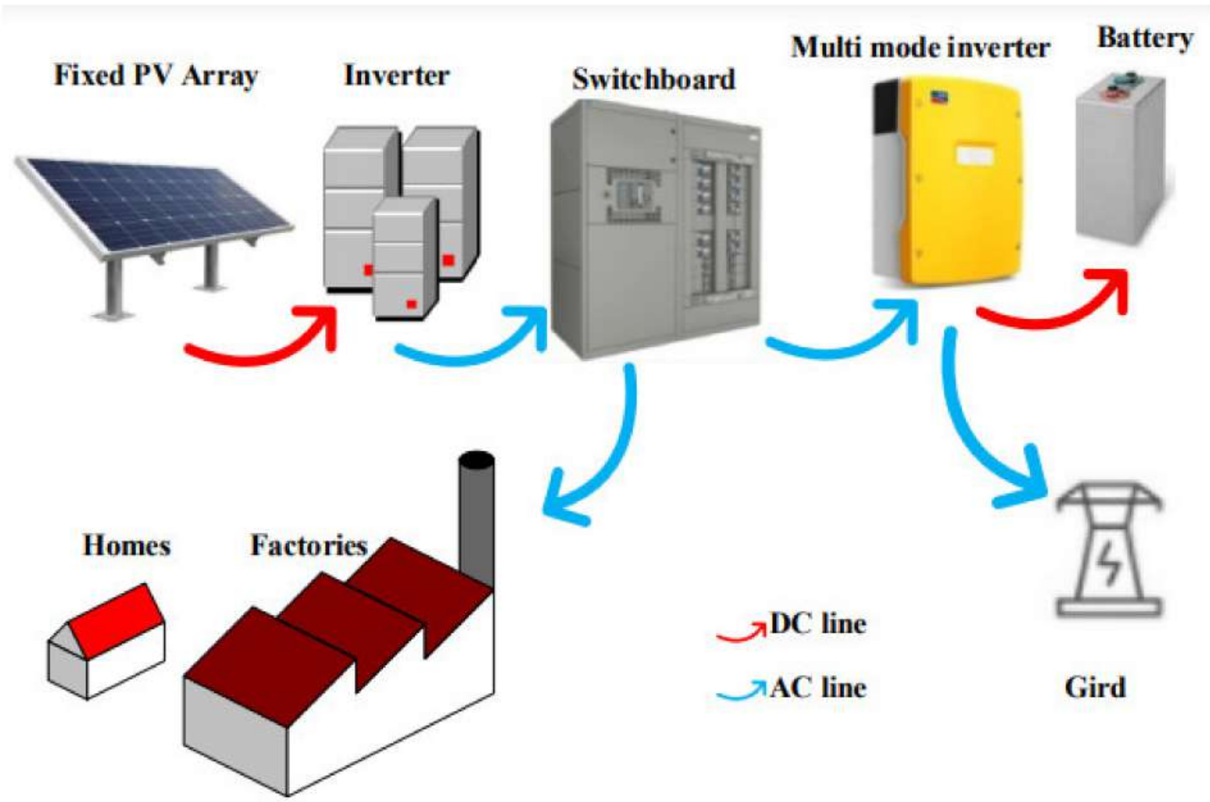


Figure 4. Basic Schematic of a PV system [97].

In recent decades, the development of PV cells (a single solar cell), PV panels (a collection of single cells connected), and PV arrays (several individual PV panels electrically connected), as well as solar power plants have been proliferating. Basic schematics of a PV cell, PV panel, and PV array are shown in Figure 5 [101].

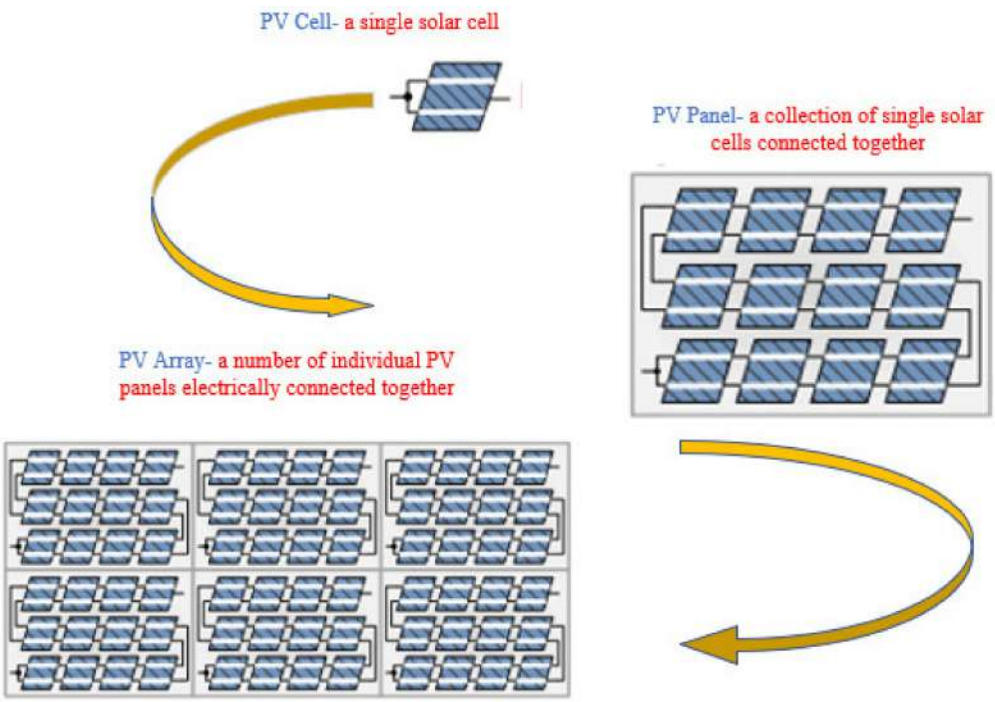


Figure 5. PV cell, PV Panel, and PV array.

One problem preventing countries from using solar panels to generate electricity in recent years is their low efficiency. Therefore, many researchers have worked and studied changing the type of solar cells and increasing their efficiency in recent years. Figure 6 shows a schematic of different types of solar cells.

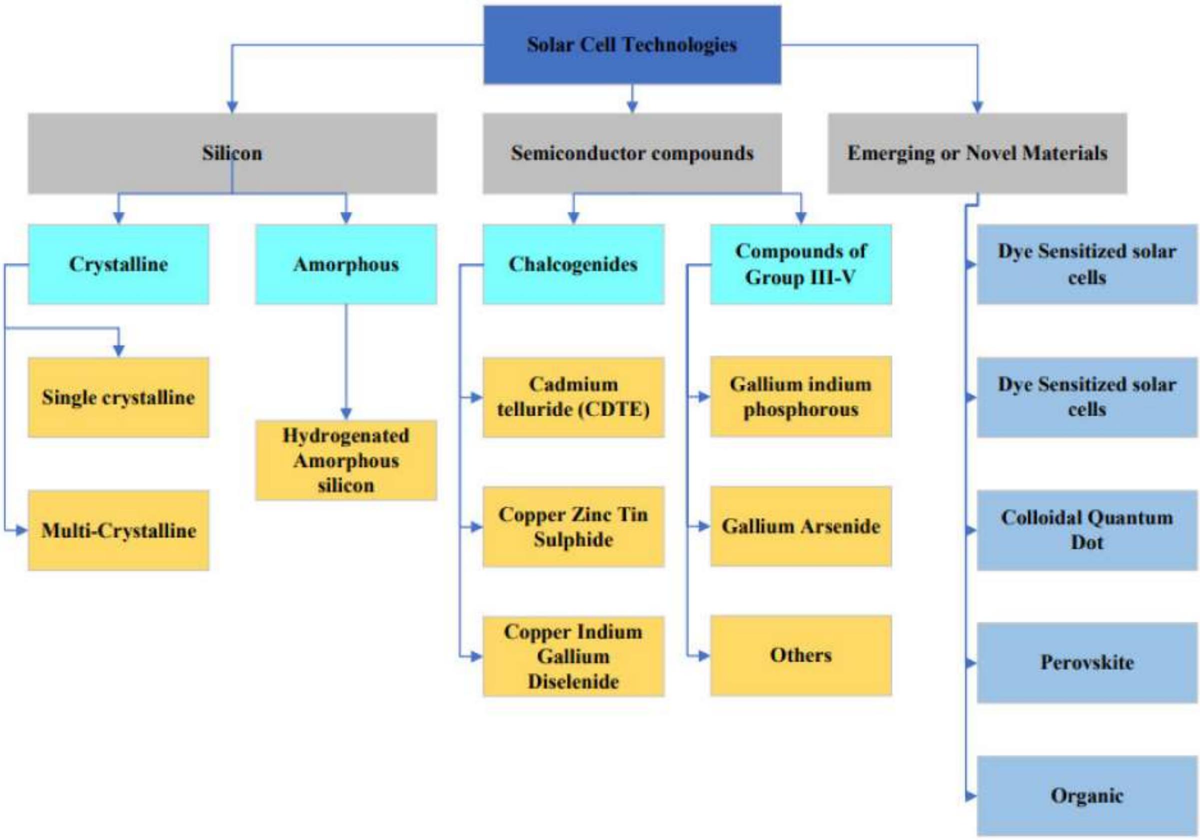


Figure 6. Technologies of solar cells [102].

As shown in Figure 7, the ideal behavior of PV cells can be modelled as a diode. Based on the theory of electronics in solar cells (Figure 7), when the sun shines on the solar cell, the load current can be extracted in the following [103]:

$$I = I_L - I_0 \left[\exp\left(\frac{q(V + IR_S)}{AkT} \right) - 1 \right] - \frac{V + IR_S}{R_{SH}} \tag{1}$$

where the junction current of the diode (I_d) [104],

$$I_d = I_0 \left[\exp\left(\frac{q(V + IR_S)}{AkT} \right) - 1 \right] \tag{2}$$

where I, I_L, I_0, q, k, T, R_S, and R_{SH} are the load current, the PV current, the reverse saturation current, electronic charge, Boltzmann constant, absolute temperature, series resistance, and parallel resistance, respectively.

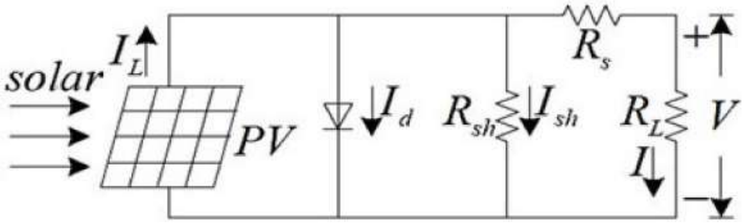


Figure 7. The equivalent circuit of the solar cell.

A solar cell's energy conversion efficiency (η) [104]:

$$\eta = \frac{P_m}{ExA_c} \tag{3}$$

where P_m, E, and A_c are maximum power point, input light irradiance, and the surface area of the solar cell, respectively.

3. Solar Energy in Iran

Iran is located near the equator and southwest Asia, with an area of about 1,600,000 km^2. In some cities of Iran, there are about 300 sunny days. For example, the hottest city in the world is the city of Shahdad, in Kerman province [105,106]. Sunlight and stormy winds can be seen in all cities of Iran [103]. This part of the world has desirable conditions for the beneficial utilizing of solar energy. Iran has good opportunities for the spread of waterpower, and it is an ideal country for the use of solar energy [107,108]. A careful study revealed that the average global radiation of Iran is about 19.50 (MJ/m^2)/day [109,110].

The amount of forthcoming global radiation (∼2000 (kWh/m^2)/year) in Iran and other countries near the equator, such as the UAE and Saudi Arabia, is highest globally. Hosseini and Hosseini [111] studied a case study in Dehloran city located in the west of Iran to show how to utilize solar energy instead of gas and oil resources. Mostafaeipour et al. [112] studied the possibility of using solar energy in several regions of Iran. Their results showed that cities in central and southern regions could receive higher quantities of solar horizontal radiation. Southern Khorasan, Khuzestan, Yazd, and Kerman provinces catch considerable solar radiation values [113].

As shown in Figure 8, desirable cities with annual daily global radiation are located in the provinces of Kerman, Fars, Isfahan, and Yazd, in Iran. All large and small solar power plants are now located in these four provinces. Of course, other cities in Iran, such as Chaharmahal Bakhtiari, have an excellent ability to absorb solar energy. In recent years several solar power plants have been built in this province. The all-high fiord of the Yazd province is described by a high annual direct normal radiation of 2511 kWh/m^2 [114–116].

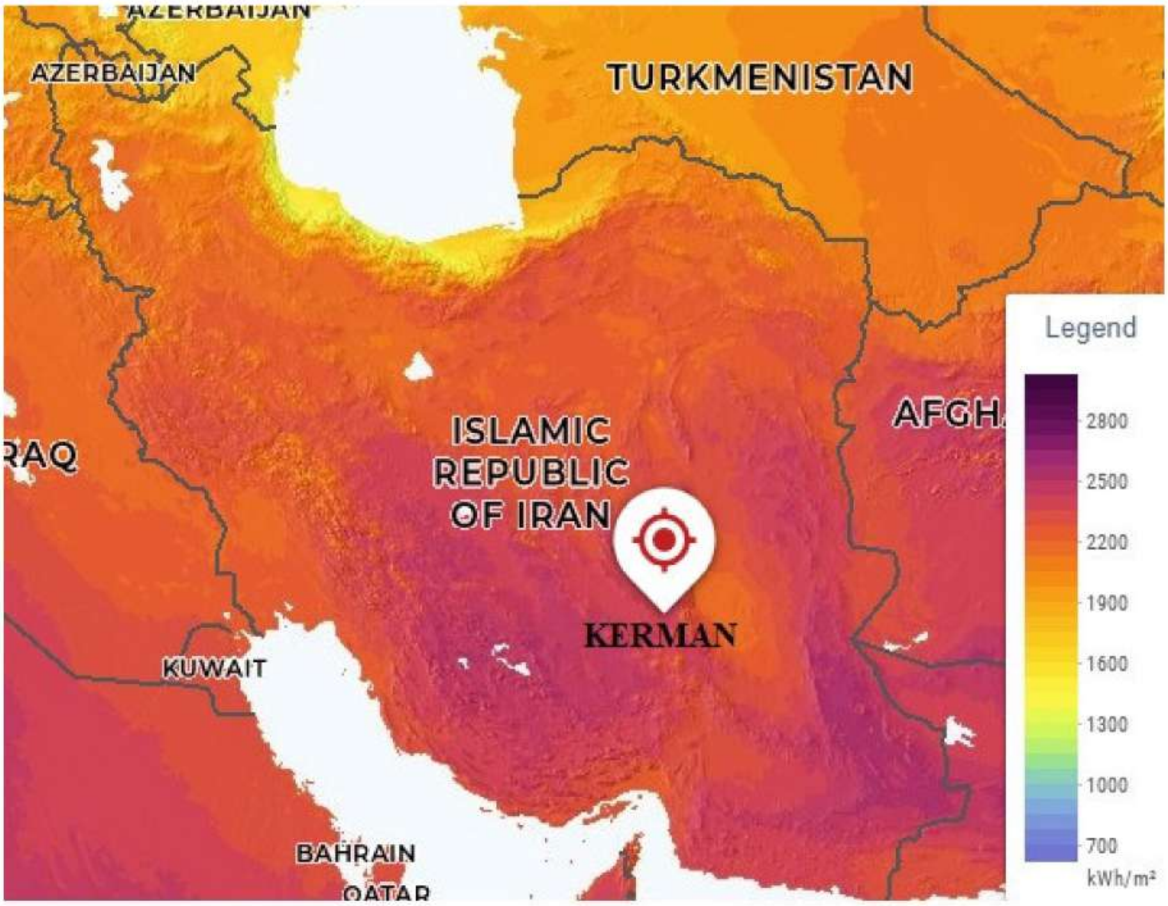


Figure 8. Map of annual, global, solar irradiation of Iran [113].

4. Solar Power Plants in Iran

Iran has an extensive fossil source, and most of its power plants run on oil and gas. In recent years, environmental pollution has occurred in large cities like Tehran, Tabriz, and Isfahan. Also, with the expansion of industry and agriculture in Iran, the need for electricity is expanding. There is a shortage of electricity in the big cities of Iran now in the summer. Therefore, the Iranian government has been looking to establish solar power plants to provide electricity to their villages and cities in recent years. At present, the advantages of using clean energy against pollution and the high consumption and environmental costs of fossil fuels have led Iranians to use clean energy and fuel [117–122]. The renewable power plants' geographical map is shown in Figure 9 [123].

The most significant number of solar power plants are installed in provinces of Kerman (with 4 to 10 MW solar power plants), Yazd (with 5 to 10 MW solar power plants), and Fars (with 7 to 10 MW solar power plants). In recent years, central cities of Iran such as Tehran (about 37.57 MW), Hamedan (about 31.4 MW), and Isfahan (about 13.45 MW) have also designed and built several solar power plants. The amount of power of solar power plants in the provinces of Iran is shown in Figure 10, where Yazd, Fars, and Kerman provinces with a capacity of 68.5, 98.8, and 54 MW, respectively, are the top provinces producing electricity from energy in Iran [124].

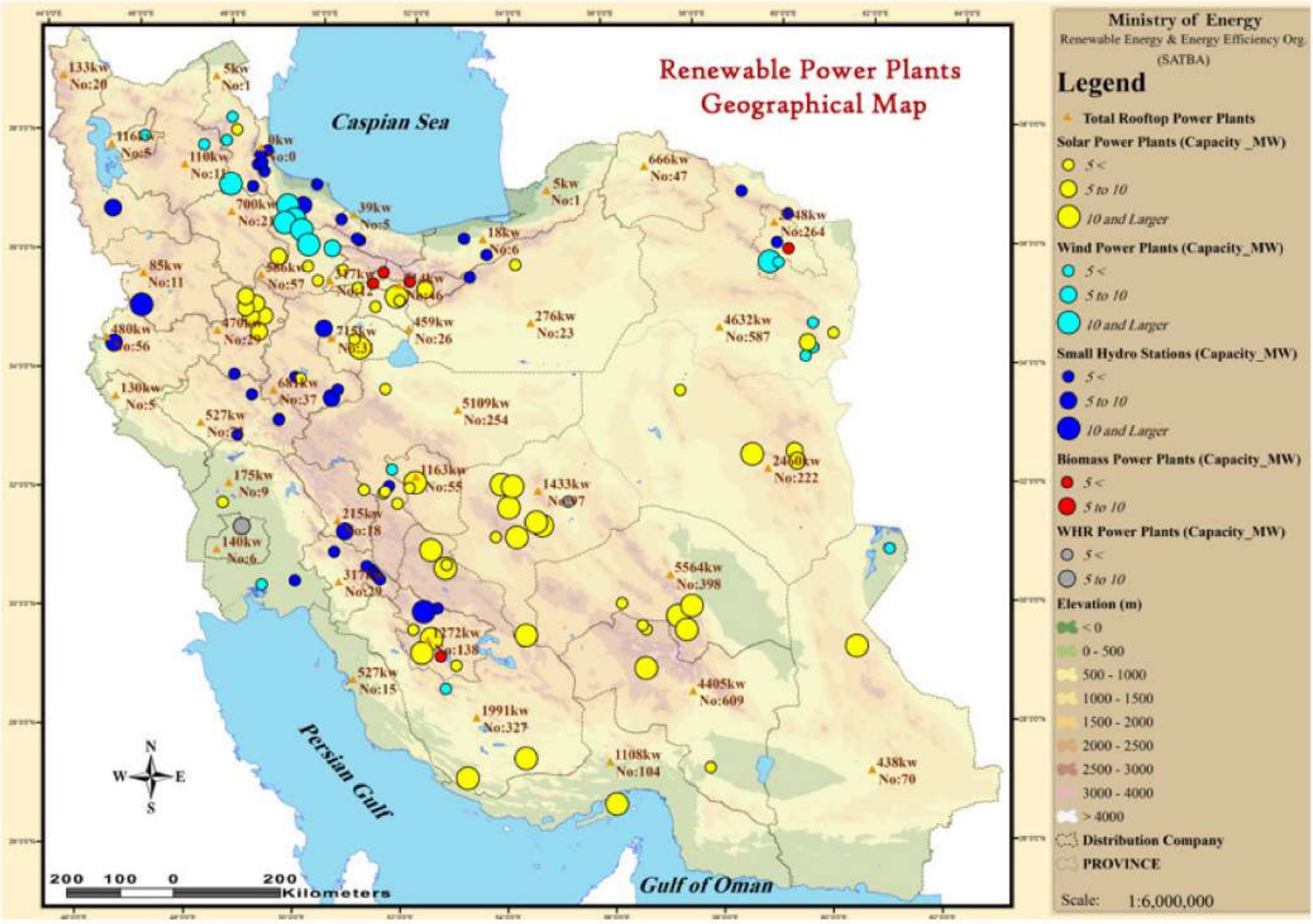


Figure 9. Geographical map of renewable power plants [123].

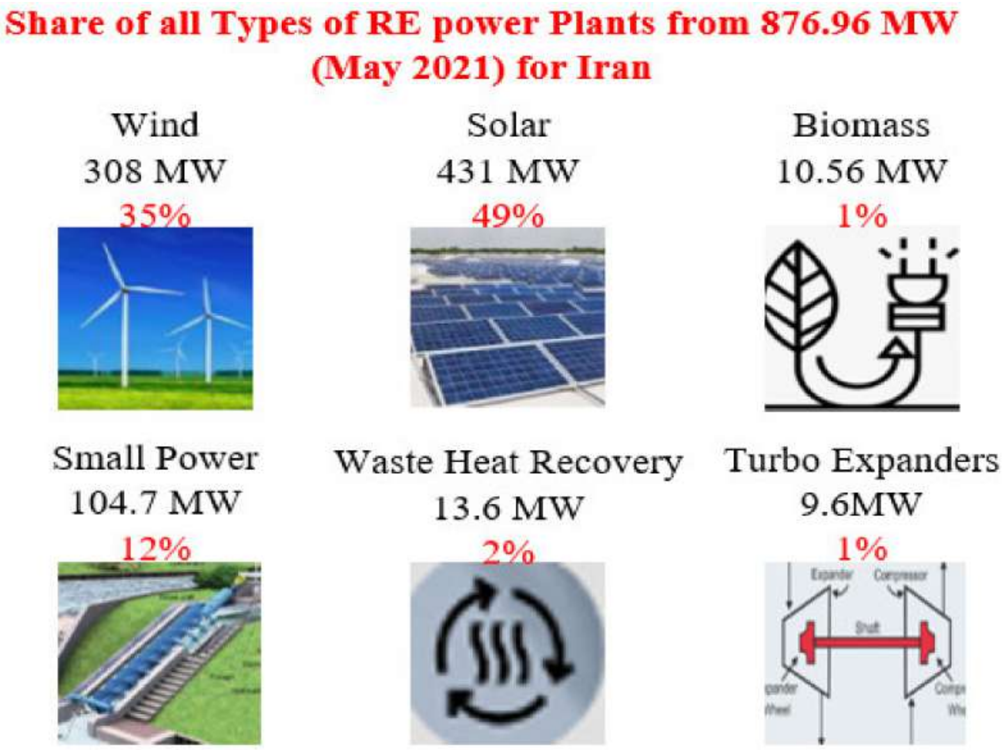


Figure 10. Share of all types of RE power plants [125].

Renewable Energy & Energy Efficiency Organization (SATBA) reported that now 131 renewable power plants on a scale of MW with a total capacity of 876.69 MW have been put into operation. In addition, another 821 MW is under construction. Of these, there are 63 solar power plants with 433 MW and 20 wind power plants with about 308 MW (Figure 10). The rest of the power plants include small hydropower plants with a total capacity of 104.7 MW, biomass with a total capacity of 10.56 MW, and heat loss recovery from industrial processes with a total capacity of 13.6 MW [125].

As shown in Figure 11, about 178 million kWh of generated electricity is produced by renewable power plants in June 2021. As it turned out (Table 1), about 49% of electricity was generated by solar energy [126,127]. One of the critical points is that about 4277 thousand tons less CO_2 have been prevented. Moreover, a study of technical and economic assessment of the integrated solar combined cycle power plants in Iran was analyzed by Hosseini et al. [23].

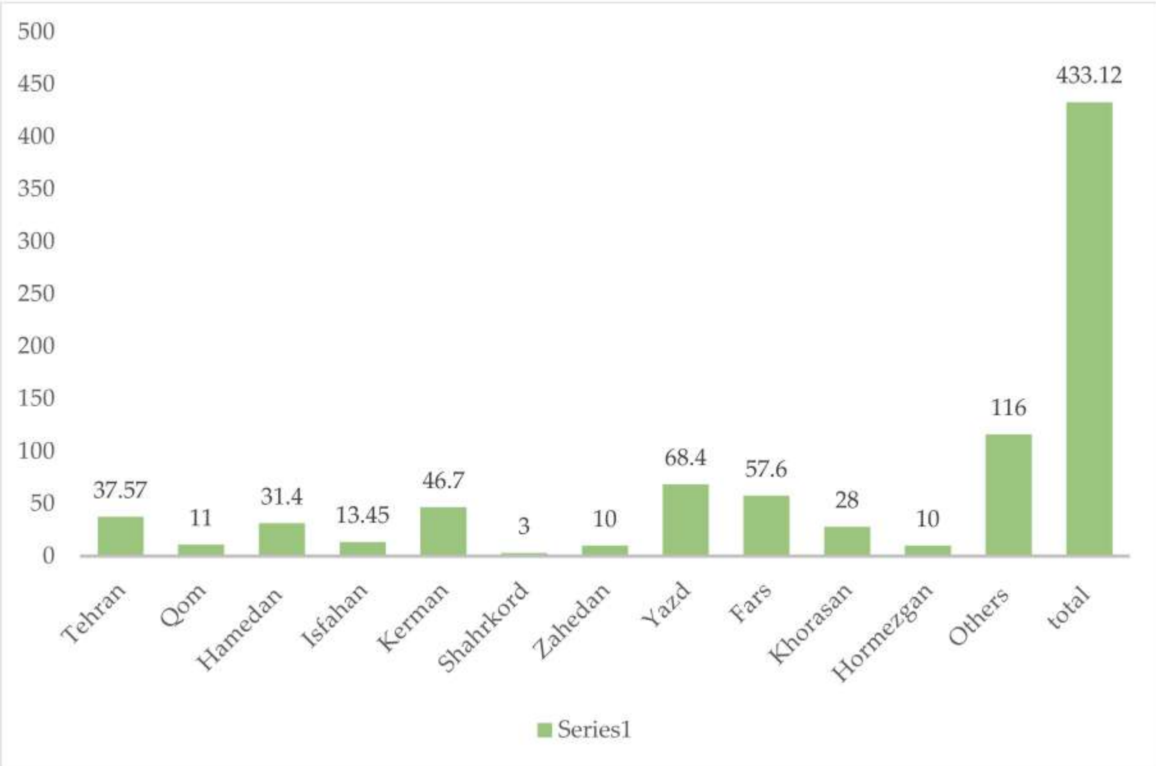


Figure 11. The number of solar power plants in the provinces of Iran [126].

Table 1. Electricity production in June 2021 and the cumulative (until July) in Iran.

Cumulative (Till July 2021)		June 2021
6377	Generated Electricity from Renewable Energy (RE) (million KWh)	178
1811	Fossil Fuel Conservation (Million cubic meter natural gas)	51
1403	Water Conservation (million liter)	39
4277	Prevention CO_2 (thousand ton)	115
27	Prevention of air pollutants (thousand ton)	0.8

Their study showed that increasing steam turbine capacity by 50% and 4% improvement in total efficiency are other advantages of Integrated Solar Combined System with

67 MW solar power plant. In addition, theoretical and technical potential evaluation of solar power generation in Iran was studied by Ghasemi et al. [128]. Their study was about Sistan and Baluchestan provinces, and their results showed that about 14% of the province is suitable for constructing solar power plants.

Electricity generated by solar farms in the cities of Iran is shown in Figure 11. The capacity of large solar farms in Iran is about 433 MW, and the provinces of Yazd, Fars, and Kerman are about 68.4, 57.6, and 46.7 MW of electricity produced by solar farms, respectively.

Kerman is the most important city in the southeast of Iran. Due to sunlight on more than 300 days of the year, Kerman province is located in the center of the golden trapezoid of the country's solar energy, unique natural space. Furthrermore, adequate infrastructure, which is a significant advantage, can make this province a clean energy supply and attract foreign investors [129–132]. The use of solar plans to meet the needs of Iranian villagers and nomads is increasing. One of the small solar power plants in Kerman can be seen in Figure 12a [133].

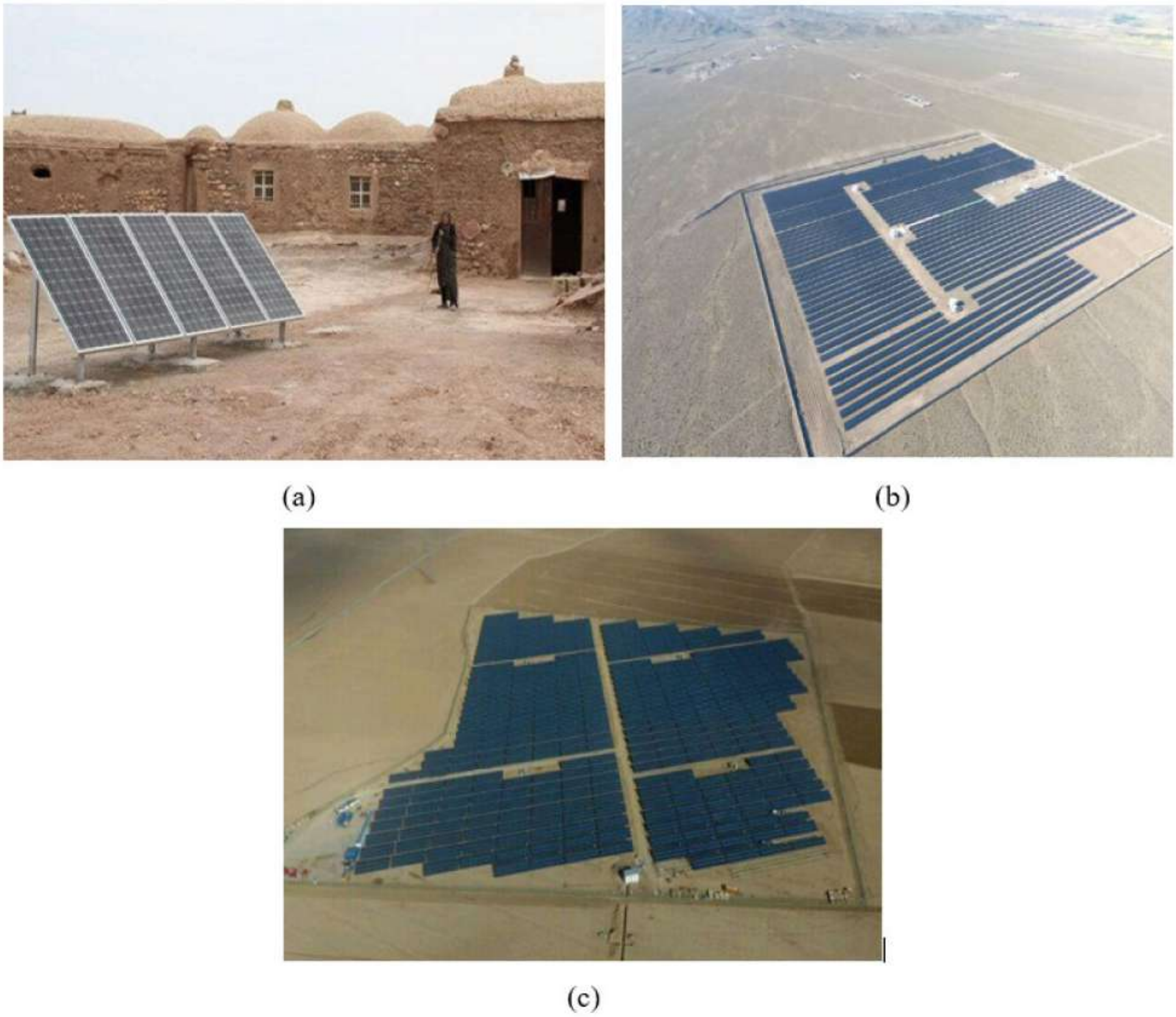


Figure 12. (**a**) A small solar plant in Kerman, (**b**) an installed PV power plant in Kerman with a 10 MW capacity, and (**c**) an installed solar power plant in Hamedan with a capacity of 7 MW [126].

According to the Renewable Energy & Energy Efficiency Organization (SATBA), a 10 MW power plant in Kerman province in Baft was connected to the grid [134]. The power plant is constructed in an area of 20 ha, using specialist and localized equipment by the private sector. It is estimated that by starting this solar plant, 9598 tons of environmental pollutants will be prevented, and 3060 cubic meters of water consumption will be reduced annually. In addition, the power plant will also save 3.95 million cubic meters of natural gas, annually, in Iran's electricity production [135,136]. One of the largest solar power plants in Iran is located in Kerman province (Figure 12b). Mahan Solar Power Plant is designed to produce 20 megawatts per day. In total, 76,912 solar panels have been installed in this power plant, and about 21,000 bases have been hammered, and the amount of foreign investment in this project is US$27 million. Furthermore, this power plant will be converted to 100 megawatts in the future [137,138].

Kerman province has been considered one of Iran's most proper provinces with the highest solar radiation. Eight solar power plants with a total capacity of 48.7 megawatts have been constructed and are running at the moment. In Kerman province, 926 solar rooftops with a capacity of 8228 kW have been installed [139]. In recent years, much research has been done to evaluate the possibility of electricity generation from solar energy in Kerman province [140–142]. For example, a comprehensive approach to design and improve a solar chimney power plant in Kerman Province was studied by Gholamalizadeh and Mansouri [143]. All large solar power plants in Kerman province are presented in Table 2.

Table 2. Solar power plants in Kerman province (PV power plant).

Capacity (MW)	City	Solar Plant
100 (Under Construction)	Bam	Bam
20	Kerman	Noor Mahan
10	Baft	Baft
1	Bardsir	Arya

Fars, a province located in the southwest of Iran, has an area of 122,400 km^2 [144]. The total capacity of renewable and clean power plants in Fars is 84.52 MW, which includes ten solar power plants with a cumulative capacity of 67.6 MW, a biomass power plant with a capacity of 1.065 MW, a wind power plant with a capacity of 0.66 MW, and two hydroelectric power plants with a capacity of 12.25 MW, as well as 331 small scale solar systems (roof) with a cumulative capacity of 2021 kW.

In Fars, there are several solar power plants with a capacity of 10 MW. Moreover, a list of high-power solar power plants in Fars is presented in Table 3. Renewable energy researchers in Fars are trying to show the people and the government the potential of converting solar energy into electricity [145–147].

Table 3. Solar power plants of Fars province.

Capacity (MW)	City	Solar Plant
20 (Two plants with 10 MW)	Abadeh	Abadeh
10	Shiraz	Karno
10	Eghlid	Eghlid
4	Sarvastan	Sarvastan
10	Shiraz	Lohar
0.25	Shiraz	Shiraz

In other provinces such as Isfahan, Tehran, Yazd, Hamedan (Figure 12c), and Khuzestan, a large solar power plant with a maximum capacity of 20 MW has been built. Table 4 lists several solar power plants in other cities of Iran [148].

Table 4. Installed solar power plants in Iran.

Capacity (MW)	City	Solar Plant
0.51	Tehran	Molard
1	Arak	Arak
7	Hamedan	Amirkabir
7	Hamedan	Persian Golf
10	Isfahan	Zarigheh
17	Yazd	Yazd
10	Alborz	Taleghan
10	Tehran	Komord
2	Zanjan	Kohok
7	Zanjan	Abhar
1	Isfahan	Sanat
1	Isfahan	Negar
10	Khozestan	AZIN
5	Mashhad	KHAF
1.5	Sharkord	SIMAN

Several other researchers across Iran have tried to cover the power consumption of industrial plants by technical and economic studies of various solar power plants [149,150]. For example, the techno-economic of PV systems capacity in Shiraz was studied by Yazdani and Yaghoubi [151]. In this analysis, a typical one MW solar plant was made in the software of PVsyst. The economic study displayed that enterprise in a PV system without any particular government help is economically advantageous, as the net present amount and Internal Rate of Return (IRR) were found to be US$1,367,499 and 17.09%, respectively.

A comprehensive study on the applications of different data-driven approaches in the performance modeling of solar units is introduced by Alhuyi Nazari et al. [152]. They are also in other studies on solar energy [153,154], reviews on the applications of multi-criteria decision-making approaches for power plant site selection.

In addition to the installed solar power plants, several research cases have been conducted to design solar power plants for Iran's climatic conditions and to study them technically and economically. Table 5 shows the research cases that have dealt with this issue and explains their details.

Table 5. Designed solar power plants for different regions in Iran.

Reference	Plant Type	Region	Capacity	Economical	Further Notes
Shahnazari and Lari [155]	Parabolic Trough Concentrating Solar-thermal Power (CSP)	Yazd	62 to 398 MW_e for different configurations	Cost of produced electricity was 13.5 to 50 Euro per MWh for different configurations	The benefit of integrating a solar field into a combined cycle plant was proved when compared to a standalone Solar Electricity Generating System (SEGS).
Asnaghi and Lajevardi [156]	Solar Chimney Power Plant (SCPP)	12 cities	10 to 28 MWh/month	Not mentioned	The output of the SCPP system in southern regions of Iran is far more than in other regions.

Table 5. *Cont.*

Reference	Plant Type	Region	Capacity	Economical	Further Notes
Ghasemi et al. [128]	PV collectors and Concentrating Solar-thermal Power (CSP)	14 cities of Sistan and Baluchistan province	7419 TWh/year for CSP and 8758 TWh/year for PV system	Not mentioned	Geographical and technical potentials were also evaluated to choose the best region for establishing a power plant.
Hirbodi et al. [24]	Parabolic trough and Solar Tower Power Plant (STPP)	Soth-central regions of Iran	20, 50,100 and 200 MW_e	The best price was obtained as 11.3 c/KWh_e and the best solar-to-electricity efficiency was 14.7%	Environmental aspects, including reduction of CO_2 emission and fossil fuel-saving, were also evaluated.
Hosseini et al. [23]	Parabolic trough Integrated Solar Combined Cycle System (ISCCS)		67 MWe	The Levelized Energy Costs (LEC) of ISCCS-67 is 10 and 33% lower than the combined cycle and gas turbine	They found that an ISCCS-67 saves 59 million dollars in fuel consumption and reduces about 2.4 million tons of CO_2 emission during the 30-year operating period.
Rafat et al. [157]	A hybrid Multi Effect Desalination (MED) and solar power plant	Shiraz	500 KW	Not mentioned	The maximum energy efficiency of 14% was obtained. The maximum of 9.87 Kg/s fresh water was estimated to be produced. The best GOR was 6.82.
Besarati et al. [158]	PV and CSP	50 cities in Iran	5 MW	Not mentioned	The highest capacity factor was obtained as 26.1% for Bushehr. Environmental aspects were also investigated.
Asanghi [122]	Solar Chimney Power Plant (SCPP)	Five cities in Iran	1–2 MW/year	Not mentioned	A power plant with the chimney height of 350 m and collector diameter of 1000 m was capable. Abadan was found as the best city for the plant.

4.1. Case Study (Sirjan City)

Sirjan is one of the cities of Kerman province, geographically located at 29°6′ N and 58°20′ E, and at 1760 m above sea level. The curves of the solar radiation and wind speed for Sirjan city for each month in 2018 are presented in Figures 13 and 14, respectively [3].

Figure 13. Average monthly radiation (MJ/m^2) in Sirjan city [3].

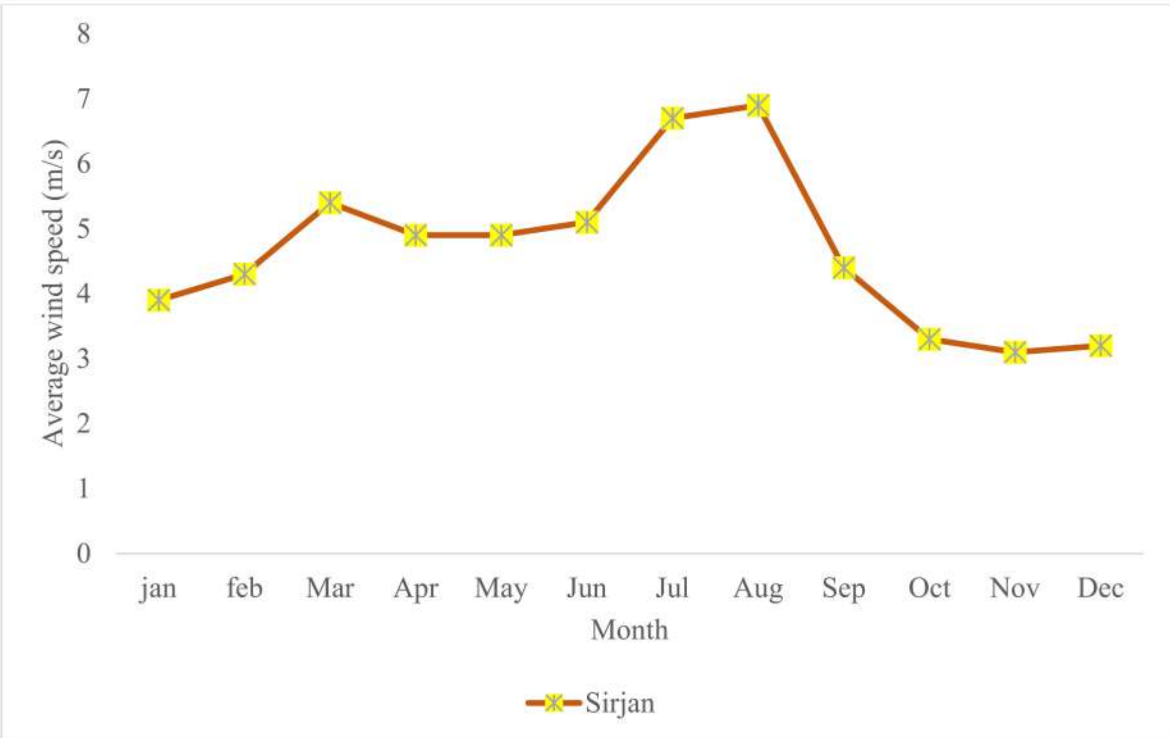


Figure 14. Average wind speed (m/s) in Sirjan city [3].

The following data have been extracted to build a 10 MW-solar power plant in the Balord region of Sirjan. The design location of the solar power plant in Sirjan is shown in Figure 8.

The location must first be examined in terms of solar radiation and wind speed to design a solar power plant. By comparing the amount of wind and the intensity of solar radiation of Sirjan, it has been determined that this city has the potential to invest in the construction of a solar power plant. In this design, 25,000 PV panels with a capacity of 400 watts have been used. About 15 hectares of land are needed to build this solar power plant.

As shown in Figure 15, each array requires 5000 arrays of 50 solar panels. Both arrays are placed next to each other, forming 25 rows in each block. In each block, a 2.5 MW transformer and inverter are used to convert DC to EC.

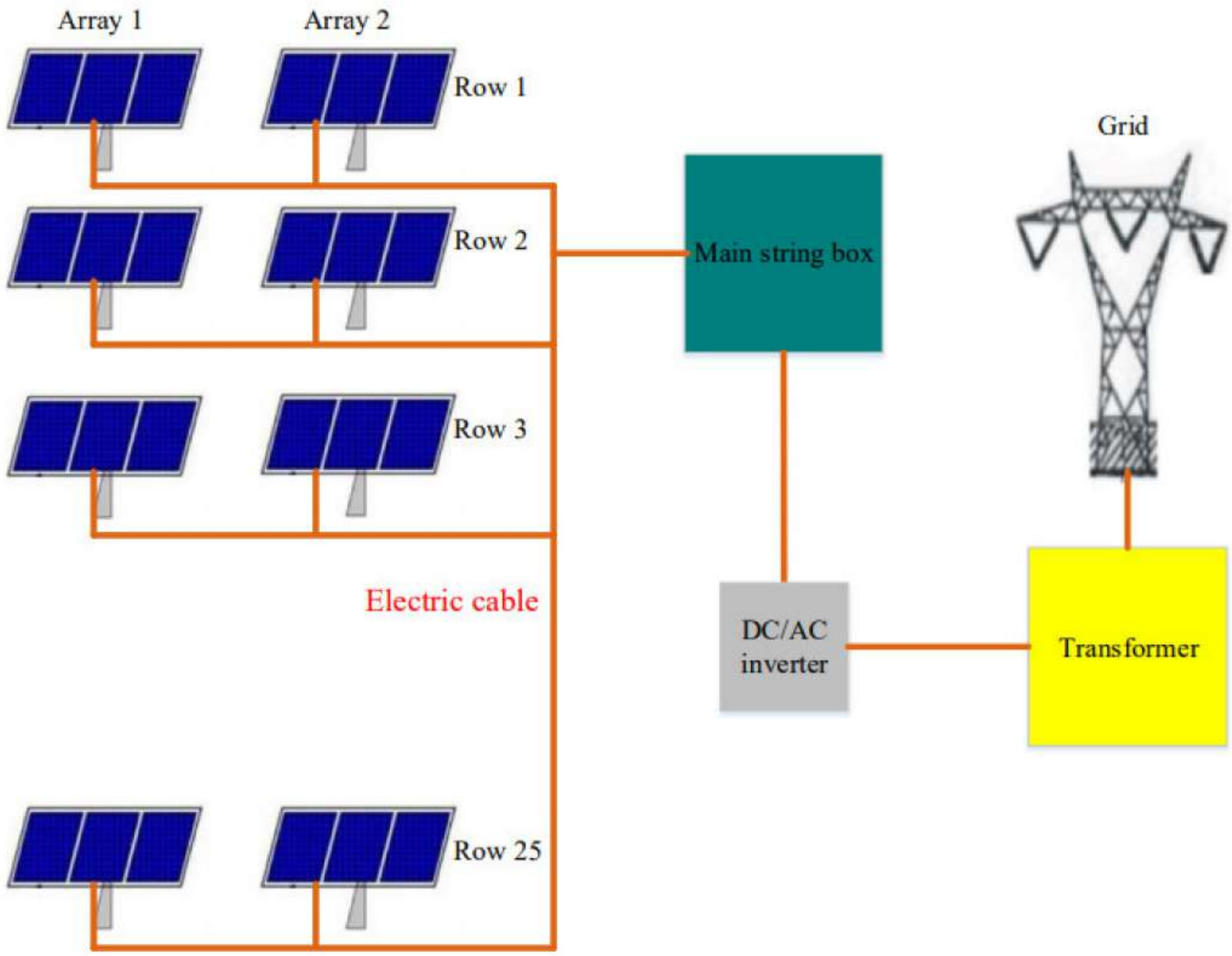


Figure 15. Layout of a block in 10 MW solar power plant.

4.2. Economic and Technical Study of a 10 MW Power Plant in Sirjan City

In the city of Sirjan, about 1900 to 2000 kWh/m^2 solar energy (horizontal global irradiation) is received. The effective irradiance on the solar plant is about 2030 kWh/m^2. Therefore, in a 10MW solar power plant in Sirjan, about 20,489 MWh nominal array energy. By calculating of array soloing, module quality, module array mismatch, and inverter loss, this solar power plant can produce 16,047 MWh per year.

To analyze the construction of a 10 MW solar power plant, it is necessary to first extract fixed costs (CAPEX costs) such as land, landscaping, and purchasing equipment. Table 6 shows a 10 MW solar power plant's fixed cost by examining the Iranian and foreign markets.

Table 6. CAPEX costs of a 10 MW solar power plant.

Costs	Total Price (US$)
Land	240,000
Landscaping	750,000
Construction	630,000
Technology, equipment, installation and testing	10,400,000
Facilities	2,400,000
Unforeseen (10%)	1,600,000
Pre-operation costs	120,000
Total	16,140,000

After extracting the fixed costs, about $100,000 is the current cost to build this solar power plant. One of the most important parts is the sale of electricity. At the present time, in the summer, Iran government pays $40.0 per Megawatt.

Considering the 300 sunny days in the city of Sirjan, Table 7 below shows the production capacity of this power plant in each season; according to the sales rate in each season, the annual income of this power plant can be extracted. As shown in Table 7, a 10-megawatt solar power plant sells for about $893,868 a year.

Table 7. Sales cost of a 10 MW solar power plant.

Season	Number of Days	Daily Capacity (MWh)	Seasonal Capacity (MWh)	Sales Rate (US$/KWh)	Sales Cost (US$)
Spring	93	66	6138	0.036	220,968
Summer	93	80	7440	0.04	297,600
Fall	90	70	6300	0.036	226,800
Winter	90	55	4950	0.03	148,500
Total	366		24,828		893,868

The IRR is a measurement utilized in financial analysis to evaluate the profitability of possible investments. IRR is a discount rate that makes the Net Present Value (NPV) of all cash flows equal to zero in a discounted cash flow analysis. The formula and calculation for IRR can be utilized by the following equation:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1 + IRR)^t} - C_0 \tag{4}$$

where C_t, C_0, and t are net cash inflow during the period, total initial investment costs, and the number of time periods, respectively.

A preliminary investigation revealed that the cost of purchasing solar panels is about US$10.7 million. Now, by calculating the investment cost and the current cost (such as the cost of power, energy, and maintenance), it is determined that IRR is equal to 21.05. The design information of a 10 MW solar power plant in Sirjan city is given in Table 8.

Table 8. Design information of a 10 MW solar power plant in Sirjan.

Description	Unit	Amount
City		Sirjan
Longitude	North	29°6′ N
latitude	East	58°20′ E
Power plant capacity	Megawatts	10
Area	square meters	150,000
Number of solar panels	number	25,000
Dimensions of each panel	square meters	2
Cost of purchasing panels	US$	10,700,000
The cost of building a power plant	US$	16,140,000
Purchase price	US$	893,868
IRR	%	21.05

4.3. Technical Analysis with HOMER

After extracting the costs, this solar system's technical and economic analysis can be provided using Homer software. Firstly, this design's discount rate, inflation rate, annual capacity shortage, and project lifetime are 10, 15, 5, and 20, respectively. The amount of electricity production on a daily and monthly basis is shown in Figures 16 and 17. As shown in Figure 16, the highest energy production in this power plant is in spring (starting from the 90th day) and summer (ending on the 270th day). As can be seen in this figure, solar energy production starts at 7 am and continues until 6 pm. Electricity generation in June, July, and August in Sirjan have are the highest, at 1.1, 1.05, and 0.95 KWh, respectively. Furthermore, the average gird sales in different months are shown in Figure 17.

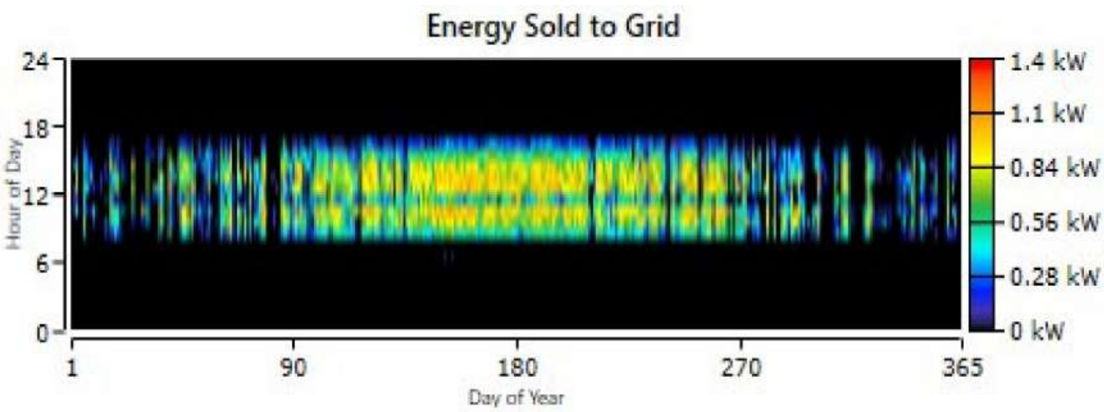


Figure 16. Daily electricity production in one year in Sirjan.

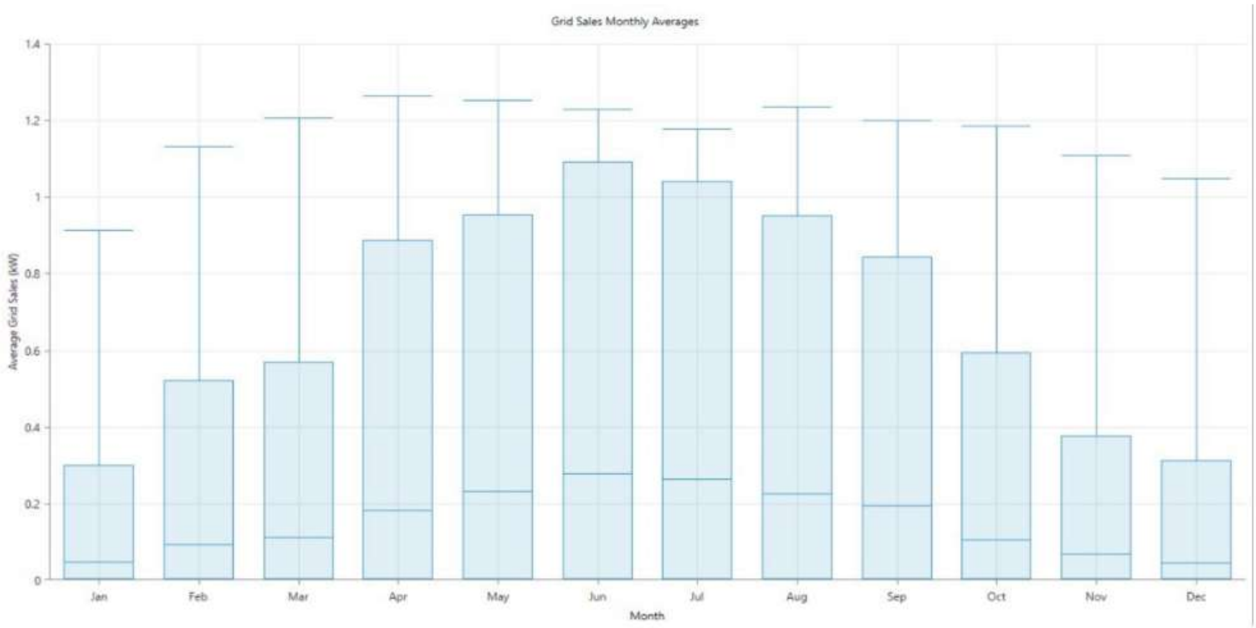


Figure 17. Monthly electricity production in one year in Sirjan.

5. Conclusions

The use of solar energy has increased globally, and countries are trying to meet their electricity needs in the industrial and agricultural sectors by solar power plants. It is predicted that by 2013, about 1296 GWh of the world will produce electricity using PV panels. In Iran in 2020, only about 900 megawatts of electricity will be produced with solar energy, which is very low compared to the global average.

In that case, we will find that the use of solar energy in Iran is deficient. However, the map of the solar global annual irradiation of Iran has shown that Iran's southern cities are in the best position to receive solar radiation (it reached 2000 kWh/m^2 in some places). Therefore, the public, private, and mining companies should enter this sector and generate electricity using renewable energy, such as solar energy.

In Fars, Kerman, and Isfahan provinces, there is a potential to meet the needs of industry and agriculture using solar energy. Economic analysis showed that about US$16.14 million is needed to build a 10 MW solar power plant in Sirjan. It has also been shown that the return on profit takes place in four years, and it can be concluded that investors can build a solar power plant.

Author Contributions: Conceptualization, M.M., S.H.; Methodology, M.M., A.T., H.H.; investigation S.H., M.S., M.K.; resources M.M., A.T., H.H.; data curation S.H.; writing-original draft preparation M.M., A.T., M.S., M.K.; writing-review and editing S.H., H.H., M.M.N., G.P.; visualization M.M., M.M.N.; supervision G.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not Applicable.

Informed Consent Statement: Not Applicable.

Data Availability Statement: Not Applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

A	Surface area (m^2)
C_0	Total initial investment costs (&)
C_t	Net cash inflow during the period (&)
E	Input light irradiance (W/m^2)
I	load current (A)
I_L	Photovoltaic current (A)
I_0	Reverse saturation current (A)
q	Electronic charge
T	Absolute temperature (K)
P_m	Maximum power point (W)
q	Electronic charge
R_S	Series resistance (Ω)
R_{SH}	Parallel resistance (Ω)
k	Boltzmann constant
IRR	Internal rate of return
NPV	Net present value
η	nergy conversion efficiency

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