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Design and Analysis of Grid-Connected Solar Photovoltaic Systems for Sustainable Development of Remote Areas

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Abstract: This study analyses the expansion of solar energy in Iran, considering political, economic, social, and technological factors. Due to the prolonged sanctions on Iran, the development of clean energy power plants has been either halted or significantly reduced. Hence, this study aims to identify barriers to the expansion of solar energy power plants and simulate solar power plants using PVsyst (Photovoltaic system) software. The study is unique in its approach of combining technical analysis with social sciences to facilitate the implementation of solar energy expansion in remote areas. This study focuses on two specific areas with high solar radiation, namely Darab and Meybod, which are located in Fars and Yazd provinces, respectively. Solar energy can be generated in these two areas due to their unique location with high levels of solar irritation. To achieve this goal, the technical analyses focuson simulating the performance of a 9 kWp (kilowatt 'peak' power output of a system) grid-connected polysilicon(poly-Si) photovoltaic plant for Darab and a 9.90 kWp plant for Meybod. The simulation is carried out to obtain maximum electricity production and evaluate parameters such as incident radiation, performance ratio, energy into the grid, energy output at the array, and losses. The produced energy for Darab was 20.40 MWh/year, with specific production of 2061 kWh/kWp/year, and the performance ratio (PR) was 81.26%. For Meybod, production was 20.70 MWh/year, with specific production of 2091 kWh/kWp/year, and the performance ratio (PR) was 80.88%. Through the PEST analysis, it is evident that strategic planning and appropriate actions are crucial at the provincial, national, and local levels for energy systems' development. This indicates that both governments and citizens should play an active role in supporting the expansion of energy systems by planning and creating awareness among the public to embrace and adopt energy systems.

Keywords: renewable energy; photovoltaic systems; energy generation; regional areas

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1. Introduction

Solar photovoltaic (PV) electricity generation has experienced tremendous growth over recent years, due mainly to environmental concerns, global warming, reductions in PV module costs, government incentives, and a general focus on renewable energy [1]. As reported by the International Energy Agency (IEA), global solar PV generation reached 1179 TWh in 2021 up 22% compared with the previous year. The IEA also indicates that solar electricity had the second-highest absolute generation growth among all renewable energy technologies in 2021, behind wind energy [2]. In light of the significant growth in solar electricity generation [3], solar PV plants have gained critical attention in the energy market [4].

One of the best places for solar energy development is Iran because of the great solar resource availability thanks to its geographical location. It is estimated that Iran's solar irradiance is between 4.5 and 5.5 kW/m^2 with approximately 300 sunny days each year covering more than two-thirds of its land [5]. Given Iran's favorable climate and abundant solar radiation, there has been significant interest in evaluating the potential for solar power plants in the country.

Several researchers have employed various methods to identify the most suitable locations in Iran for the construction and expansion of solar power plants. For example, Azizkhani et al. [6] analysed the most suitable locations for establishing PV power stations in Iran by evaluating technical factors, economic parameters, and geographical conditions. They applied the analytical hierarchy process (AHP) model to determine the best locations to establish PV power plants. On the basis of their findings, the provinces Sistan, Baluchistan, and Fars resulted in being ideal locations for solar plant development. Gorjian, S., et al. [7] evaluated the performance of small-scale solar PV systems in Iran. The results indicate an excellent opportunity to invest in PV technology in southern Iran. Shoeibi et al. investigated a combined PV thermal system that was focused on improving the performance of the solar air heater in producing electricity to achieve CO_2 reduction. They performed four experiments using 0, 8, 16, and 24 fins and showed that the mitigation of CO_2 of the system using 24, 16, and 8 fins is, respectively, 35.1%, 22.8%, and 10.7%. In addition, they showed that when using 24 fins, the thermal efficiencies and electrical production of the PV/thermal solar air dryer was enhanced by 30.6% and 28.7%, compared with a system without fins [8].

In another study undertaken by Kannan et al. [9], a new hybrid approach based on Grey relational analysis (GRA) and the Best–worst method (BWM) was applied to determine the most suitable location for solar power production in the South Khorasan Province of Iran. Moreover, Shorabeh et al. [10] applied particle swarm optimization (PSO) and decision tree algorithms to assess and identify optimal solar power locations.

This second group of studies delved deeper into the technical aspects of solar PV power generation in Iran, exploring the performance evaluations, policies, opportunities, and barriers that may impact the growth and development of the industry. These studies aimed to provide a comprehensive understanding of the various factors that may influence the implementation and success of solar PV projects in Iran and inform decision-making processes for energy authorities and stakeholders. For instance, Mohammadi et al. [11] assessed the feasibility of building solar power plants in eight cities along the southern coast of Iran from a technical, financial, and environmental standpoint. Their findings revealed that PV plants can be developed in all cities with great success using a one-axis tracking system. In the research undertaken by Oryani et al. [12], the analytical hierarchy process (AHP) method was employed to determine the main obstacles to the adoption of renewable technologies. Their focus was on three alternatives in Iran, including wind turbines, solar PV, and biomass. The literature review and experts' viewpoints led to the identification of thirteen barriers, which were then grouped into five dimensions, namely technical; economic and financial; social, cultural, and behavioral; institutional; and political. Solaymani [13] investigated the trends in energy demand, policies, and renewable energy development, as well as the causal relationship between renewable and non-renewable energy sources in Iran. The study found that renewable energy sources do not contribute significantly to the energy supply in this country. Molamohamadi and Talaei [14] applied SWOT (strengths, weaknesses, opportunities, and threats) matrices to assess the efficiency of solar energy deployment in Iran. According to their research, Iran can develop solar systems and reduce its dependency on fossil fuels through a strategic planning process.

Another body of literature evaluates the performance of PV systems and solar plants in different Iranian locations. For example, in the study undertaken by Yazdani and Yaghoubi [15], the performance of PV systems was evaluated in the south-central area of Iran, with special emphasis placed on soiling loss, annual degradation, and economic viability. Makkiabadi et al. [16] investigated the potential of solar energy as a source of electricity production in Iran. They also assessed the construction of a 10 MW power plant in the city of Sirjan from both an economic and technical perspective. Based on their findings, Iran is not using solar energy effectively. An experimental research of modified single slope solar still was conducted by Shoeibi et al. This research, using heat pipes and thermoelectric generators, was carried out on the influence of PV/T waste heat on electricity generation and water productivity of solar stills, and it showed the electrical efficiencies, energy, and exergy for the system can be improved with this method [17].

Heirani, H., et al. [18], investigated PV industry barriers and relevant business models in light of ownership and control. In another study, Dogahe et al. [19] analysed the performance of three small-scale solar power plants in Iran.

This study aims to thoroughly examine the potential for the growth and expansion of solar electricity in two remote regions of Iran that are facing electricity shortages. By utilizing a PEST analysis, the research seeks to provide a comprehensive and well-rounded solution for the implementation of solar electricity expansion, taking into consideration the technical, political, economic, social, and technological factors that impact the development of renewable energy systems.

One of the key strengths of this study is its innovative approach, which combines technical analysis with a social sciences perspective in order to better comprehend and address the challenges that remote areas face in terms of investment and government support. By bridging the gap between technical know-how and the unique challenges of remote areas, the study provides valuable insights and recommendations for energy authorities, policymakers, and stakeholders to make informed decisions regarding the development of solar solutions. The study represents a departure from previous studies that have focused primarily on the technical aspects of designing and developing solar systems without addressing the wider social and political context. It aims to provide a comprehensive and well-rounded solution that assesses the unique challenges and opportunities of remote areas and will serve as a valuable resource for energy authorities and stakeholders as they work towards expanding and promoting the use of renewable energy solutions in these regions.

Our study addresses these issues by zeroing in on two specific areas in Iran that boast substantial potential for solar energy development and thoroughly examining the political, social, and economic barriers to the widespread adoption of these systems in these regions. Following, the key contributions of this research can be summarized into three main points.

(1) Our findings offer crucial insights for decision-makers, investors, economic agents, and stakeholders. It highlights that simply analyzing and presenting the technology for expanding solar energy in remote areas is insufficient, and a well-crafted policy is essential for attracting investment, gaining public acceptance, and obtaining support from the community. Therefore, we performed a comprehensive analysis with a policy perspective on the development of solar power production in Iran, considering four crucial elements of energy analysis: political, economic, environmental, and technological (PEST analysis).
(2) Despite the technical nature of this research, this paper delves into specific regions and highlights the prevalent issues, offering practical and efficient solutions. The in-depth analysis illustrates how strategic planning and appropriate actions are required at the provincial, national, and local levels to develop solar systems. The involvement of both government bodies and citizens is crucial in promoting the expansion of solar systems through the creation of supportive plans and raising public awareness, leading to societal acceptance and the adoption of these renewable energy systems.
(3) This study contributes to the overall understanding of renewable energy development in remote areas, providing insights and lessons learned that can be applied to other regions facing similar challenges.

Therefore, our research has delved into all crucial aspects of energy system implementation, considering the political, environmental, social, and technological perspectives, and this is the novelty of our work.

2. Solar energy Potential in Iran and Case Studies

According to reference [20], the Iranian government provides feed-in tariffs to entice the private sector to invest in renewable energy by offering long-term contracts which are based on the cost of generated electricity from each technology. Moreover, the government planned to install new solar power plants with a capacity of 500 megawatts (MW) by 2022. This plan, however, has been delayed and is currently under processing.

There are several reasons why Iran has a great deal of solar energy potential:

- Iran, which has 1.64 million square kilometers of land is among the best places on earth to utilize solar energy [21].
- Iran has the most favourable location to absorb solar radiation thanks to its proximity to the equator (25.2969° N).
- Iran has a vast desert area that is very suitable for PV installations.
- There are various high-potential cities in Iran. For instance, Shahdad city in Kerman province is one of the hottest and driest areas in the world. The potential for using solar energy for generating electricity is great in this country [22].
- The following are some of the main solar plants in Iran:
- A 10 MW solar photovoltaic plant has been constructed by an Italian company, Carlo Maresca Spa, in Iran in 2018. This plant is called Blu Terra 2, and it is located on Qeshm island, with an area of 20 hectares. It is expected that the plant will generate 17 GWh of energy per annum.
- The Damavand solar power plant, which offers 8.5 MW of power, was constructed by Hanau Energies in 2018.
- In South Khorasan, a solar power plant was built in 2019, equipped with a capacity of 10 MW and a site measuring 15 hectares.

Accordingly, the solar PV market is likely to dominate the market in the forecast period based on Iran's solar potential and the development of solar projects.

This research zeros in on two high-potential areas in Iran, Darab and Meybod, located in the Fars and Yazd provinces, respectively, both of which boast abundant solar radiation. The focus of this study is to provide an in-depth analysis of the potential for solar energy development in these remote areas, which are facing electricity shortages. The location of Darab is 28.75° N latitude, 54.55° E longitude, 11,524 m altitude, and is in the UTC + 3.5° N time zone. Meybod is located at 32.25° N latitude, 54.02° E longitude, 1074 m altitude, and is in the UTC + 3.5° N time zone. As depicted in Figure 1, both Fars and Yazd provinces are situated in areas where solar radiation is abundant, ranging from 3.8 to 5.4 kWh/m^2/day. These areas are suitable for the implementation of solar energy solutions and the generation of clean, renewable energy.

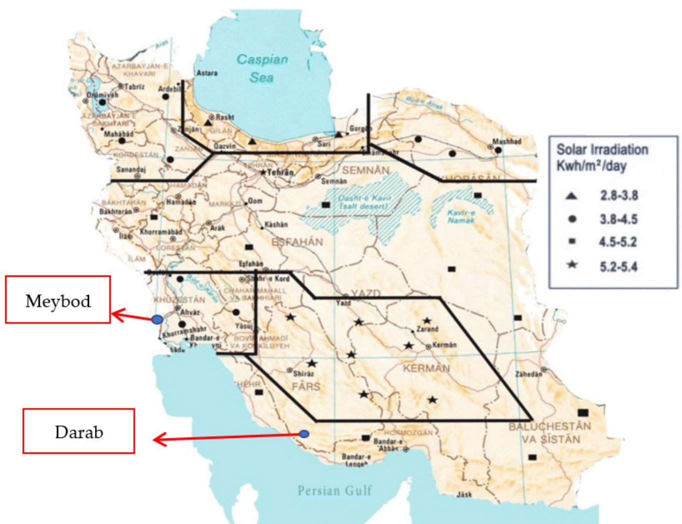

Figure 1. Location of two investigated areas.

3. Methodology

As the performance of a PV system is reliant on the type of PV modules and the geographical location in use, PVsyst was utilized for this study. Given the efficiency of PV systems in areas with ample incident solar radiation, the use of PVsyst software was suitable, as it can accurately calculate crucial metrics, such as energy production, and simulate a solar system.

To evaluate the effectiveness of solar energy, a comprehensive review of more than 400 relevant publications (including review papers and technical papers) was conducted using keywords such as Solar Systems, PV Technology, PV Systems, Solar Technology, Photovoltaic, PVsyst, and Renewable Energy. Ultimately, 48 relevant papers were selected to assess the expansion of solar energy systems. This study aims to design and model two solar photovoltaic systems for the purpose of providing thermal and electrical energy in two regions in Iran. Given the crucial need for renewable energy supply in remote areas, grid-connected solar energy will be utilized as a backup system.

We present two grid-connected photovoltaic systems. It is mandatory to use a converter in solar power systems, as the panels generate direct current (DC) electricity, but consumers require alternating current (AC) electricity. Therefore, major elements include PV modules, fuse boxes, inverters, utility meters, and the grid lines are considered for configuring the grid-connected photovoltaic system. The primary function of the PV modules is to generate DC electricity. The inverters in the systems are responsible for converting the DC voltage to AC voltage, which is then fed to the grid through a utility meter and fuse box. The inverter continuously produces a sinusoidal output, and in grid-connected PV systems, it is designed to operate in phase with the grid.

Figure 2 shows the general schematic of the proposed model that can be changed and improved for a real model on the basis of the final condition.

As illustrated in the figure, the photovoltaic (PV) arrays harness solar energy, which is then transformed into electricity by the inverter. The generated electricity then flows through the fuse boxes and utility meters before being fed into the grid.

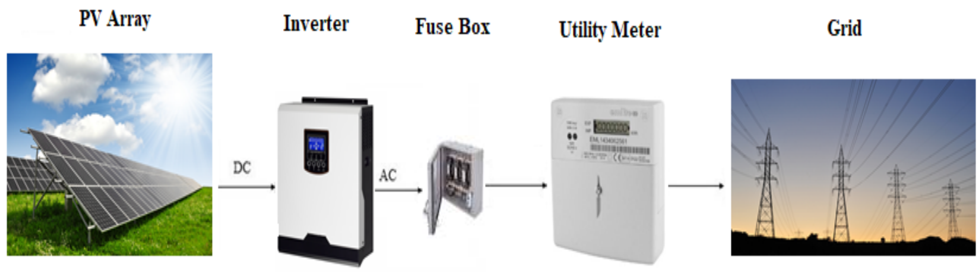

Figure 2. General schematic of the proposed model.

Moreover, Figure 3 outlines the research methodology sections for this study. The methodology consists of five key sections, which include:

Mathematical Description of the Proposed System

This section outlines the key formulas used in the analysis and simulation of solar power plants with PVsyst software, drawing upon References [23–25]. These formulas provide a deeper understanding of how calculations are performed and results are obtained.

The three types of inverters commonly used in PV systems are [23]:

1. String inverters
2. Central inverters
3. Micro inverters

String inverters have limited capacity, but they have the advantage of being compact and easy to install and maintain.

A transformer is a device that transmits electric power from one alternating-current circuit to one or more other circuits by changing the voltage level but not the frequency.

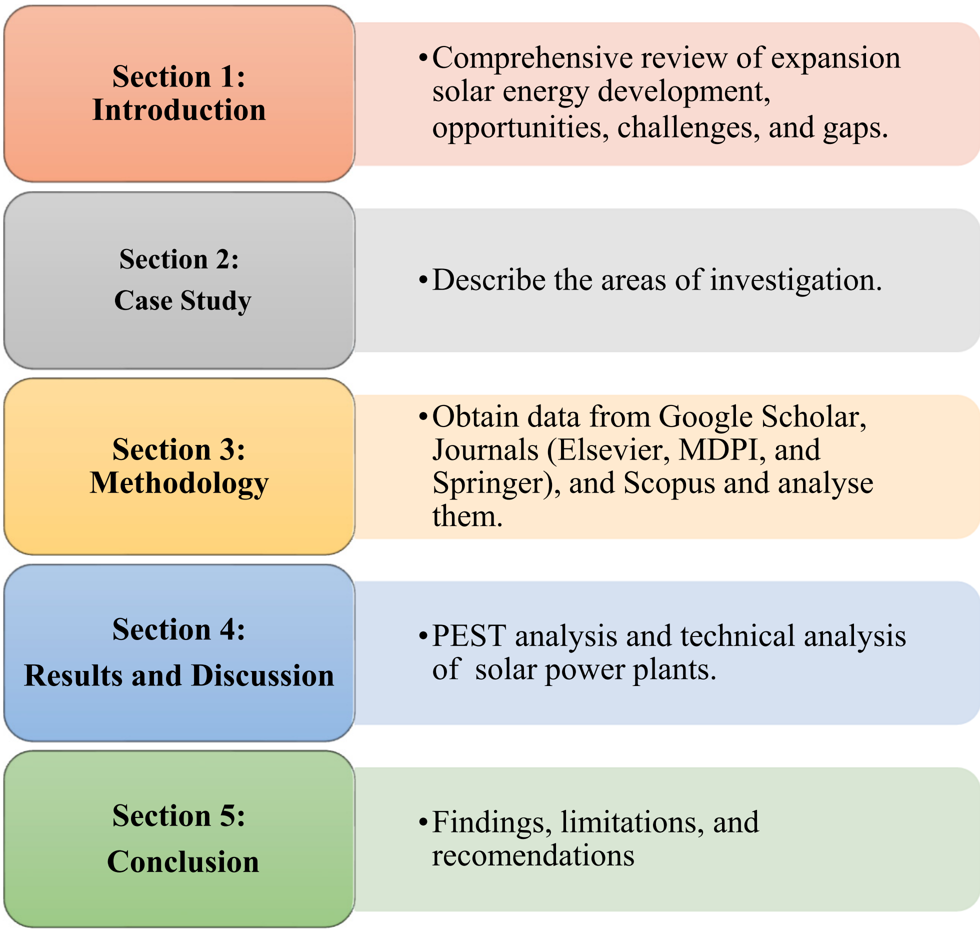

Figure 3. Research Methodology.

In addition, to evaluate the performance of solar PV plants, several parameters must be calculated, such as array yield (YA), reference system yield (YR), final system yield (YF), performance ratio (PR), and the capacity utilization factor (CUF) [24].

Array yield can be defined as a matrix efficiency, which refers to the daily output energy in DC based on the nominal power (kWh/KWp/day). In other words, the array yield reflects the DC generated from the PV array over time (days, months, and years) to the rated PV array power.

$$Y_A = \frac{E_{DC}}{P_O} \quad (1)$$

Reference yield is a measure of the maximum number of sun-hours in a day, calculated as the total in-plane solar insolation (kWh/m^2) divided by the reference irradiance (kW/m^2) of the array. The reference radiation, assumed to be 1000 W/m^2 in STC, represents the amount of energy required to produce the nominal power (Pnom) of the array for one hour. Y_R in the equation represents the expression for incident energy (kWh/m^2/day) in the plane of the array [25]:

$$Y_R = \frac{H_t(\mathrm{kWh/m^2})}{I_A(\mathrm{kW/m^2})} \quad (2)$$

Final yield refers to the number of hours required for the solar PV system to produce the net energy at the rated power. It is calculated by dividing the net AC energy output of the system on a yearly, monthly, or daily basis by the peak power capacity of the PV panels:

$$Y_F = \frac{E_{AC}}{P_P} \quad (3)$$

The performance ratio is calculated by dividing the final yield by the reference yield. This ratio provides insight into the efficiency of the system, as it shows the percentage of energy lost due to various factors, such as solar panel degradation, soiling, shading, temperature, and other internal losses. In real-world conditions, the performance ratio represents the actual performance of a solar PV plant compared with its potential performance.:

$$PR = \frac{Y_F}{Y_R} \quad (4)$$

The capacity utilization factor (CUF) can be described as the ratio of annual solar PV energy output to capacity-equivalent output over the same period:

$$CUF = \frac{E_{AC}}{P_P} \times 8760 \quad (5)$$

A PV panel's efficiency (η_{PV}) can be calculated as follows:

$$\eta_{PV} = \frac{E_{DC}}{G_i \times A_{PV}} \times 100\% \quad (6)$$

The efficiency of the inverter (η_{inv}) in the PV solar plant can be calculated by dividing the AC power produced by the inverter by the DC power produced by the PV array, which is given as

$$\eta_{inv} = \frac{P_{AC}}{P_{DC}} \times 100\% \quad (7)$$

In the solar PV plant, the general efficiency of the PV system is calculated by dividing the power output generated by the array by the total in-plane solar insolation, which is given as

$$\eta_s = \frac{E_{AC}}{G_i \times A_{PV}} \times 100\% \quad (8)$$

The performance of a solar PV plant is influenced by various loss parameters that can occur throughout the system. To accurately evaluate the losses associated with the plant, it is crucial to calculate both the array capture loss (LA) and loss system (LS).

Array capture loss (LA) refers to heat losses caused by a rise in PV cell temperature, accumulation of dust in PV arrays, irradiation with variable intensity, partial shading, maximum power point errors, and inconsistencies. Thus, array capture loss (LA) can be calculated by subtracting the reference yield from the array yield:

$$L_A = Y_R - Y_A \quad (9)$$

The loss system (LS) refers to DC and AC cable losses, calculated by subtracting the array yield from the final system yield. This includes inverter losses in grid-connected systems or battery losses in standalone systems:

$$L_S = Y_A - Y_F \quad (10)$$

4. Results and Discussion

In this section, a comprehensive examination of the potential for solar energy development is conducted in Iran using PEST analysis. The research takes into account four important aspects of energy analysis: political, economic, social, and technological. This analysis provides a deep understanding of the challenges and opportunities for implementing solar energy systems in Iran. The study also includes an examination of renewable energy development in Iran, particularly solar energy, and the barriers to its expansion. Moreover, the research identifies potential solutions to overcome these barriers and improve the adoption of renewable energy in Iran. The technical aspect of solar energy systems is also analyzed and simulated using PVsyst software.

4.1. PEST Analysis

The adoption of renewable energy systems in Iran requires a comprehensive and well-rounded approach that takes into account various political, economic, social, and technological factors. The PEST analysis is an important tool that can help decision-makers and energy experts understand the impact of these factors on the implementation of renewable energy projects. By considering the PEST analysis, policymakers and energy experts can ensure that the implementation of renewable energy systems is successful and results in positive outcomes. In recent years, numerous studies have been conducted in Iran that provide insight into the factors that impact the development of renewable energy systems and provide valuable recommendations for the successful implementation of renewable energy projects. These studies are a testament to the importance of considering the PEST analysis in the development of renewable energy systems in Iran.

For instance, Zahedi et al. conducted a strategic study on the renewable energy policy in Iran and emphasized the importance of solar energy in achieving energy sustainability and optimization. They noted that the development of solar energy could effectively address the electricity shortage during crucial times [26]. Another study by Zarezade et al. focused on implementing solar dryers in Yazd province and highlighted the benefits of using solar energy systems in reducing physical effort and human resources [27]. These studies demonstrate the potential for the effective use of solar energy in Iran and its positive impact on the country's energy sustainability and efficiency.

In a study conducted by Banirazi Motlagh et al., the potential of residential solar energy systems to minimize urban air pollution in Tehran was explored through an integrated value model. The results showed that solar energy development not only provides electricity but also can reduce CO_2 emissions compared with traditional systems that rely on fossil fuels for electricity production [28]. Vaziri Rad et al. conducted a case study in Iran to explore the techno-economic feasibility of a hybrid power system for rural electrification, with a focus on cost-effective hydrogen production. Their research concluded that the development of renewable energy systems is the best long-term solution for electricity production in remote areas [29]. Jahangir et al. also investigated the implementation of a hybrid renewable energy system on the basis of the Homer software-based solution for rural electrification in Fars province, Iran, with a specific emphasis on economic analysis. Their results showed optimal systems range from USD 0.128 to 0.223/kW h for the COE. They also showed the most optimal economic solar system for this hybrid system is photovoltaic panels with a capability of 80.7 kW [30]. Moreover, Maleki et al. developed an optimization model in order to the electrification of a remote area in Namin city of Iran. The results indicated that the most cost-effective system is the grid-independent hybrid photovoltaic/fuel cell/wind turbine system for supplying electrical energy [31].

Dehghani et al. analyzed the roles of stakeholders and the challenges in utilizing solar energy, highlighting the importance of stakeholder acceptance for successful electricity generation [32]. Kalbasi et al., using PVsyst and Meteonorm software packages, conducted a potentiometric study on the construction of a 20 kW power plant in various cities in Iran. The results indicated that solar cells with advanced technology resulted in lower costs, with monocrystalline cells being the most cost-effective option. Additionally, the results revealed that ventilation had less impact on monocrystalline solar cells compared with other types [33]. Mohammadnejad, M., et al. reviewed Iran's overall energy situation and its focus on sustainability. They analyzed solar energy as a major source of energy in Iran [34].

Fazelpour et al. conducted an analysis of a 45 kW photovoltaic power plant for Qeshm Island in Iran using the PVsyst software. The findings showed that the performance ratio of the photovoltaic power plant was 86.1%, and it had the potential to produce 50.6 MWh per year [35]. Farangi et al. conducted an analysis of grid-connected photovoltaic power systems on the basis of the new energy policy in Iran. They explored various energy policies in the country, including new incentives and supporting policies for renewable energy resources. Furthermore, they simulated two different scales of grid-connected PV power systems using the RETScreen software to better understand the impact of these policies [36].

4.2. Obstacles to the Growth of Renewable Energy in Iran

The Iranian economy heavily relies on oil, which has resulted in significant hindrance to its growth, particularly in the realm of renewable energy, due to the long-standing sanctions imposed on the country [7,37]. These restrictions have resulted in limited access to global financial resources, equipment, and human capital, impacting not only the growth of renewables but all economic sectors [38]. The lack of investment and technology transfer has hindered Iran's ability to fully embrace and develop clean energy sources. This has resulted in a dependency on traditional energy sources, with limited progress in transitioning towards a more sustainable energy mix.

The domestic policies in Iran have had a greater impact than sanctions on the country's economy, particularly in the realm of renewable energy. The fluctuation in the exchange rate leads to an increase in expenses for projects, as they are paid in foreign currency while the cost of goods and services also rises. This creates a mismatch between the expenses, which are in euros, and the incomes, which are in rials. The resulting economic instability and inconsistent policies discourage investors from entering the market. Additionally, even if resources are available, if the regulations and rules do not align with the investors' needs and conditions, the range of issues becomes even wider [39–41].

The studies conducted by Razmjoo et al. [42] and Ghouchani et al. [43] delved into the various barriers affecting the growth and development of renewable energy in Iran. They emphasized the need for a comprehensive energy strategy and proper planning to ensure the country's successful implementation of renewable energy. Furthermore, Atabi et al. [44] conducted an investigation into the major barriers hindering the deployment of photovoltaic technology in Iran. Technical limitations, the absence of a robust roadmap, inadequacies in regulations and laws, as well as specific weather conditions that pose a challenge for installing PV panels, were identified as the most significant barriers. Addressing these barriers and providing solutions to overcome them is crucial for advancing photovoltaic technology in Iran.

Therefore, on the basis of the findings of recent studies conducted in Iran, it can be concluded that strategic planning and appropriate measures at the provincial, national, and local levels are crucial for the development of energy systems, particularly solar energy. It means governments can play a key role in supporting the expansion of energy systems through planning and sensitizing the public to accept and adopt energy systems [45]. In addition, the government's participation as an effective mediator among national, community, and other local stakeholders for developing public–private projects is crucial in line with the expansion of energy systems [46]. On the other hand, the public can have a direct role in the expansion of solar energy systems. This means that people can increase the utilization of the new energy systems as a device for producing the energy required [47]. In order to achieve the desired goals and outcomes, it is vital to establish a collaborative effort between the government authorities at the national and local levels and the general public. With joint efforts and cooperation between these stakeholders, the targets of expanding solar energy can be achieved more efficiently and effectively [48].

4.3. Characteristics of PV Module and Intervals

In this section, we aimed to analyze and simulate the potential of solar systems in two specific areas using PVsyst software. The objective was to demonstrate the energy production capacity and performance of these systems in the selected areas.

Designing and implementing a successful solar power plant requires carefully selecting various components, including PV modules, inverters, foundations, cables, fuses, switches, and other components. The efficiency and performance of the plant depend on the proper selection of these components. In this study, we have meticulously chosen appropriate PV modules and inverters to maximize energy production for the two areas under consideration. To provide a clear understanding of the components utilized, Table 1 presents the characteristics of the selected PV modules and inverters, which are consistent in both areas.

Table 1. Characteristics of PV module and inverters for two investigated areas.

PV Module	**Darab**	**Meybod**
Manufacture	Generic	Generic
Model	Mono 300 Wp 60 cells	Mono 300 Wp 60 cells
Unit Nom. Power	300 Wp	300 Wp
Number of PV modules	33 units	33 units
Nominal (STC)	9.90 kWp	9.90 kWp
Modules	3 Strings × 11 In series	3 Strings × 11 In series

Moreover, characteristics of inverters with inverter model 3 kWac, total power 9 kWp, and operation voltage 125–440 V for two areas were investigated.

For the two models, the Pnom ratio (DC-AC) was 1:10. In the array losses section, we considered array losses for two areas. Table 2 shows the module quality loss (MQL), module mismatch losses (MML), and strength mismatch losses (SML) for the two areas.

Table 2. Array losses for the Darab and Meybod areas.

Darab	**Calculated**	**Meybod**	**Calculated**
MQL	−0.8%	MQL	−0.8%
MML	2.0% at MPP	MML	2.0% at MPP
SML	0.1%	SML	0.1%

In addition, incidence effect (IAM) loss factors for two investigated areas are presented in Table 3. (Incidence effect (IAM): Fresnel AR coating, n (glass) = 1.526, n (AR) = 1.290.)

Table 3. Incidence effect (IAM) loss factor for two investigated areas.

0°	**30°**	**50°**	**60°**	**70°**	**75°**	**80°**	**85°**	**90°**
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

4.4. Analysis of Systems Production

In order to determine the various indicators associated with the global incident energy in the solar collectors, normalized production was calculated for both areas under study. As a result, normalized indicators, such as collection loss, system loss, useful energy produced, and performance ratio, were obtained and evaluated on the basis of the simulation study, as shown in Figure 4. The simulation results for the Darab area indicate a high level of solar energy production, with a total of 20.40 MWh/year generated. The specific production of 2061 kWh/kWp/year demonstrates the efficiency of the system, while the performance ratio of 81.26% highlights its effectiveness. These results suggest that Darab is a promising location for solar energy development. Figure 4 illustrates the normalized production per installed kilowatt peak (kWp) and the performance ratio for the Darab area. The results show that the Darab area produces an average of 5.65 kWh/kWp/day (inverter output), with a daily loss system of 0.2 kWh/kWp/day. The performance ratio of 0.813 yf/year demonstrates good production efficiency in this area. The figure also highlights the highest and lowest production of useful energy in January and July, respectively.

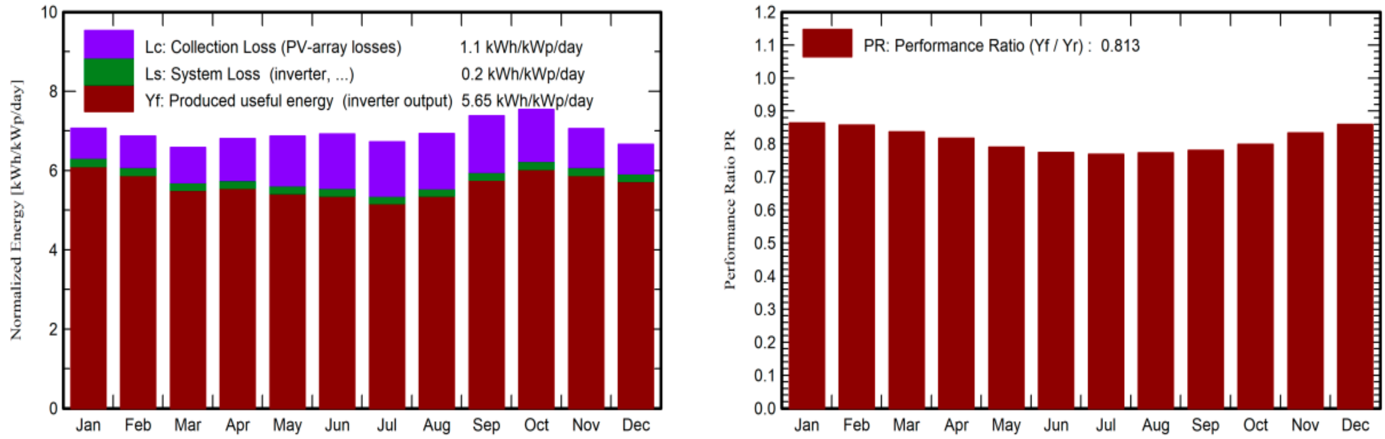

Figure 4. Normalized production and performance ratio for the Darab area.

Moreover, the normalized productions, such as losses system (Ls), collection losses, performance ratio, and produced useful energy per installed kWp/day, were evaluated in Figure 5 for the Meybod area. The energy produced was 20.70 MWh/year, specific production was 2091 kWh/kWp/year, and the performance ratio PR was 80.88%. Figure 5 shows the normalized production (per installed kWp), and performance ratio for the Meybod area. Based on the results for the Meybod area, produced useful energy (inverter output) is 5.72 kWh/kWp/day, while the loss system is 0.2 kWh/kWp/day. In addition, the performance ratio is 0.809 yf/year. Furthermore, Meybod produces the most and least useful energy in September and May, respectively.

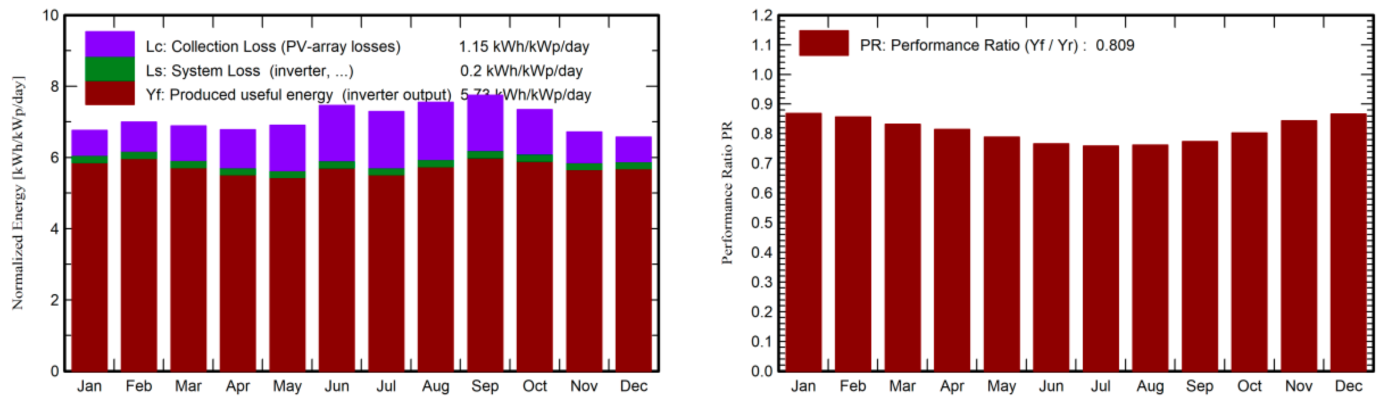

Figure 5. Normalized production and performance ratio for the Meybod area.

One of the critical factors in optimizing solar energy production is the tilt angle of the panels, which is dependent on the path of the sun in the location of the solar panel. By tilting solar panels to the right angle, we will be able to receive more solar energy, which means we can produce more electricity. Figures 6 and 7 illustrate the daily input–output for a fixed tilt angle in the Darab area. The EGrid parameter (kWh/day) was used to determine the optimum tilt angle for both monthly and yearly periods.

In addition, Figures 8 and 9, demonstrates the system output power distribution for two areas investigated. These graphs for different conditions show changes based on kWh/Bin.

Tables 4 and 5 display the balance and main results for the Darab Meybod areas. As shown in the table, different units are included. The total energy injected into the grid for Meybod was higher at 20.701 MWh compared with Darab, which had a total of 20.404 MWh. However, the total global horizontal irradiation in Darab was higher at 2236 kWh/m^2 compared with Meybod, which was at 2222 kWh/m^2.

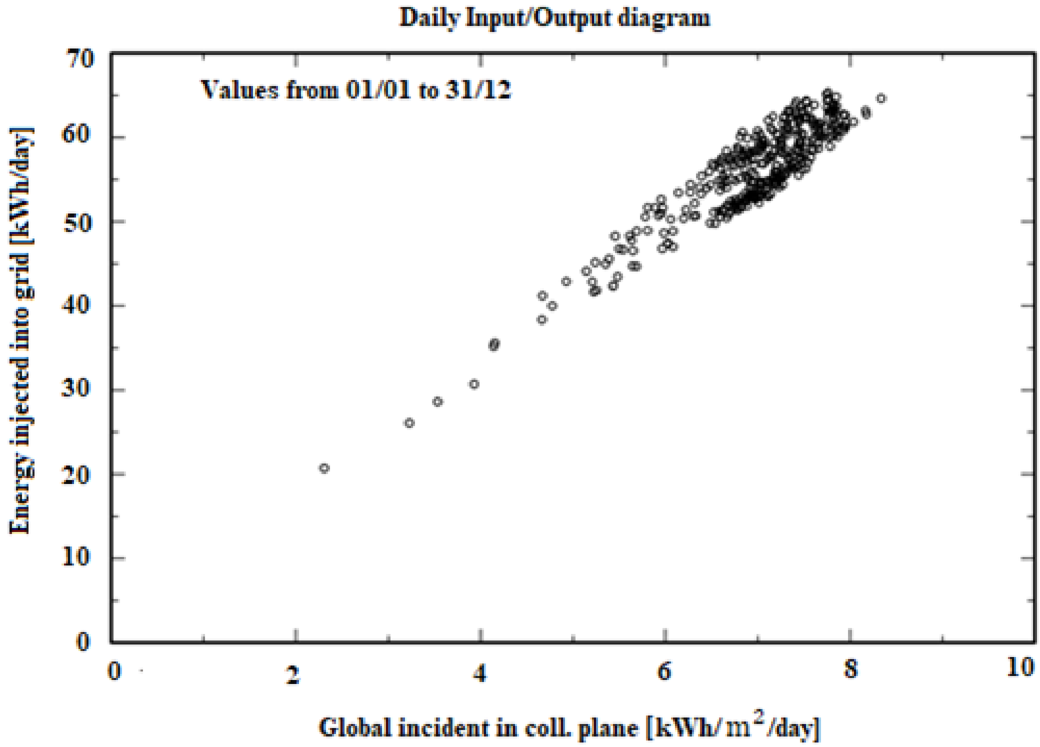

Figure 6. Daily input/output diagram for the Darab area.

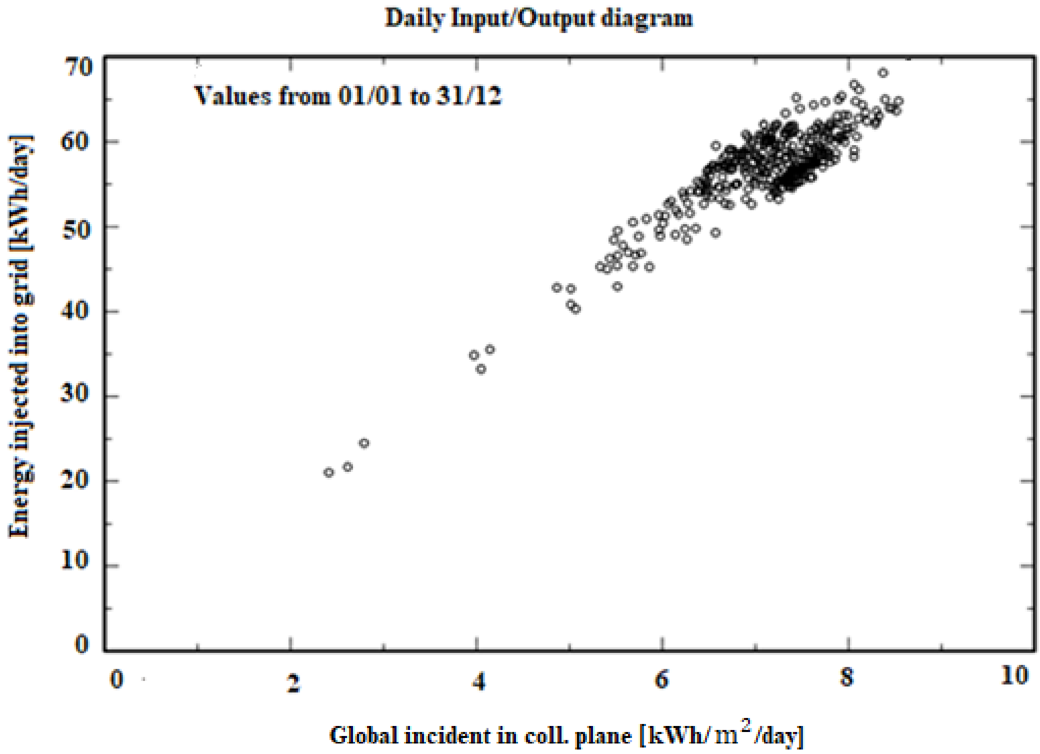

Figure 7. Daily input/output diagram for the Meybod area.

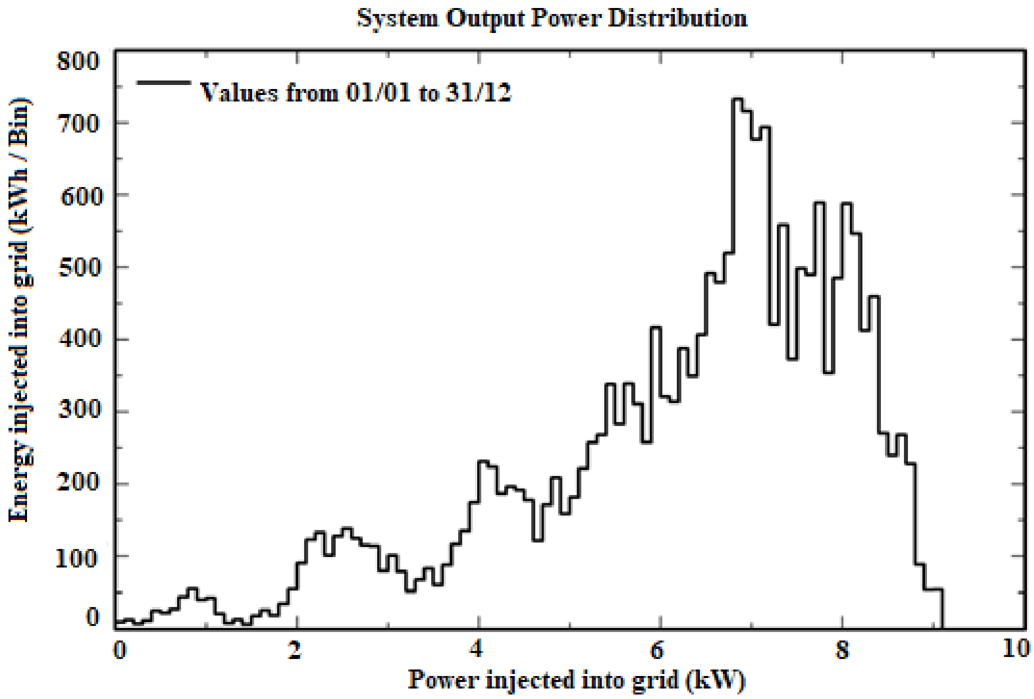

Figure 8. System output power distribution for the Darab area.

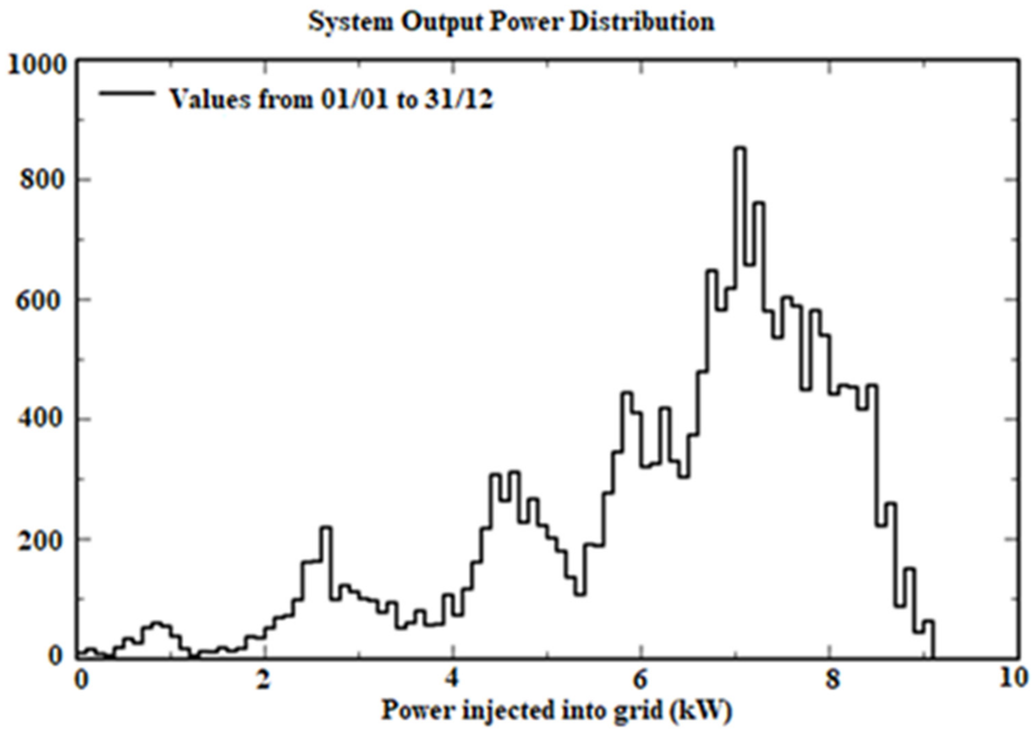

Figure 9. System output power distribution for the Meybod area.

Table 4. Balance and main results for the Darab area in 2022.

	GlobHor kWh/m^2	DiffHor kWh/m^2	T_Amb °C	GlobInc kWh/m^2	GlobEff kWh/m^2	EArray MWh	E_Grid MWh	PR Ratio
January	138.2	21.30	7.49	219.1	219.1	1.939	1.875	0.864
February	140.4	31.77	9.94	192.2	192.2	1.688	1.631	0.857
March	177.0	54.63	14.17	203.9	203.9	1.750	1.690	0.837
April	201.5	63.01	19.03	204.0	204.0	1.710	1.652	0.818
May	235.0	65.75	25.96	212.8	212.8	1.725	1.665	0.790
June	241.3	66.11	29.96	207.7	207.7	1.651	1.593	0.775
July	234.3	73.79	32.28	208.4	208.4	1.644	1.586	0.769
August	220.9	70.39	30.80	214.9	214.9	1.702	1.645	0.773
September	199.4	40.72	26.53	221.3	221.3	1.772	1.712	0.781
October	179.3	29.06	21.27	233.8	233.8	1.915	1.850	0.799
November	141.7	24.43	13.45	211.6	211.6	1.809	1.747	0.834
December	127.2	20.30	9.19	206.6	206.6	1.819	1.757	0.859
Year	2236.0	561.27	20.06	2536.3	2490.2	21.122	20.404	0.813

Table 5. Balance and main results for the Meybod area in 2022.

	GlobHor kWh/m^2	DiffHor kWh/m^2	T_Amb °C	GlobInc kWh/m^2	GlobEff kWh/m^2	EArray MWh	E_Grid MWh	PR Ratio
January	126.3	21.53	7.46	209.6	207.7	1.863	1.801	0.868
February	135.8	23.30	10.30	195.7	193.2	1.716	1.658	0.851
March	176.4	45.51	15.89	213.3	209.9	1.818	1.755	0.836
April	195.1	65.34	20.83	203.4	198.9	1.698	1.640	0.815
May	230.6	62.25	26.89	214.1	208.7	1.731	1.671	0.788
June	254.9	48.41	31.54	223.9	218.0	1.758	1.697	0.766
July	250.0	54.13	33.89	225.9	220.0	1.756	1.695	0.758
August	235.2	44.22	31.63	234.0	228.5	1.827	1.765	0.762
September	203.0	34.35	27.44	232.5	228.0	1.842	1.780	0.773
October	168.3	26.14	21.41	227.7	224.4	1.873	1.810	0.803
November	127.9	23.01	12.86	201. 4	199.2	1.742	1.683	0.844
December	117.2	17.93	8.44	203.8	201.5	1.808	1.746	0.866
Year	2220.0	466.12	20.77	2585.3	2537.3	21.430	20.701	0.809

PV array characteristics and array losses for two studied areas were presented in Table 6. Some important items belonging to these characteristics, such as module area, cell area, Uc, and Uv, are shown in this table.

Table 6. PV array characteristics and array losses for two studied areas.

Total PV Power	Darab/Meybod	Thermal Loss Factor	Darab/Meybod
Module area	53.7 m^2	Uc (Const)	20.0 W/m^{2}K
Cell area	46.9 m^2	Uv (Wind)	0.0 W/m^{2}K/m/s
Total	33 modules	-	-

The array loss diagrams, which provide insight into the various losses obtained from the simulated studies, are displayed in Figures 10 and 11. These diagrams show the resulting energy flow and the incident irradiation energy that includes all possible losses that may occur during the conversion process from solar energy to electric energy. These figures showcase the loss breakdown for both systems analyzed. These diagrams demonstrate the key factors to be taken into account when installing a photovoltaic plant. As can be seen, there is an obvious loss for the Darab area from 24.66 MWh to 20.40 MWh, and from 25.13 MWh to 20.70 MWh for the Meybod area. In addition, as seen in these Figures, the global horizontal irradiance in the Darab area is 2236 kWh/m^2, while in the Meybod area, it is 2221 kWh/m^2, indicating a favorable potential for solar energy production. The PV conversion efficiency at STC for the two areas is 18.45%.

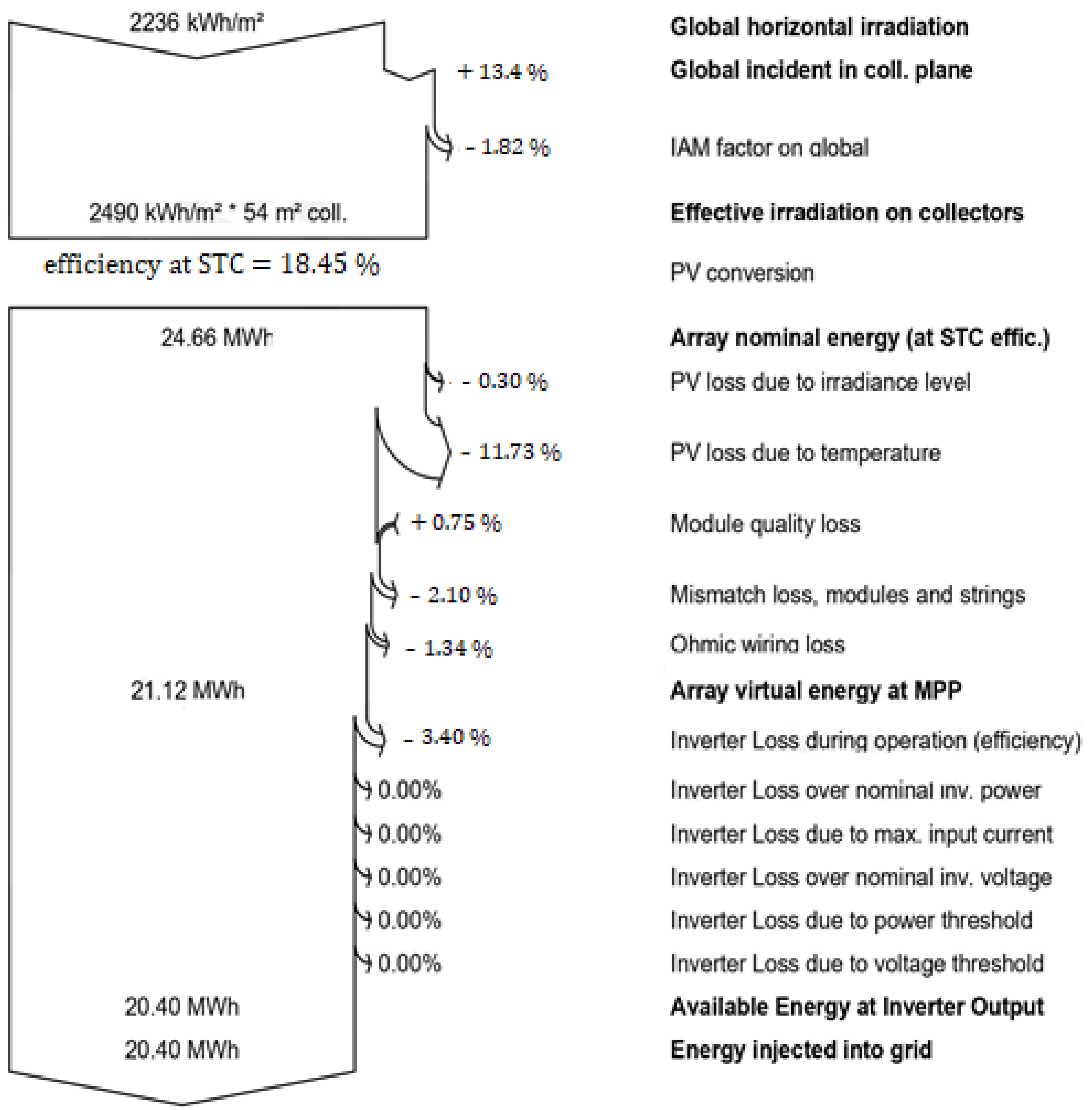

Figure 10. Loss diagram for the Darab area.

Additionally, for each area, there are other different losses to consider. For example, the PV loss during the irradiance level for the Darab is −0.30%, and for the Meybod, it is −0.29%. The PV loss due to temperature is −11.73% for the Darab and −12.09% for the Meybod. Moreover, the inverter losses during operation (efficiency) were −3.40% for both areas.

The layout and important settings for the project are displayed in Figure 12. For both areas, the tilt angle was set at 33°, and generic 300 Wp 27v PV modules were selected. The planned power input was 10.0 kWp (Nominal), with 11 modules in series and 3 strings.

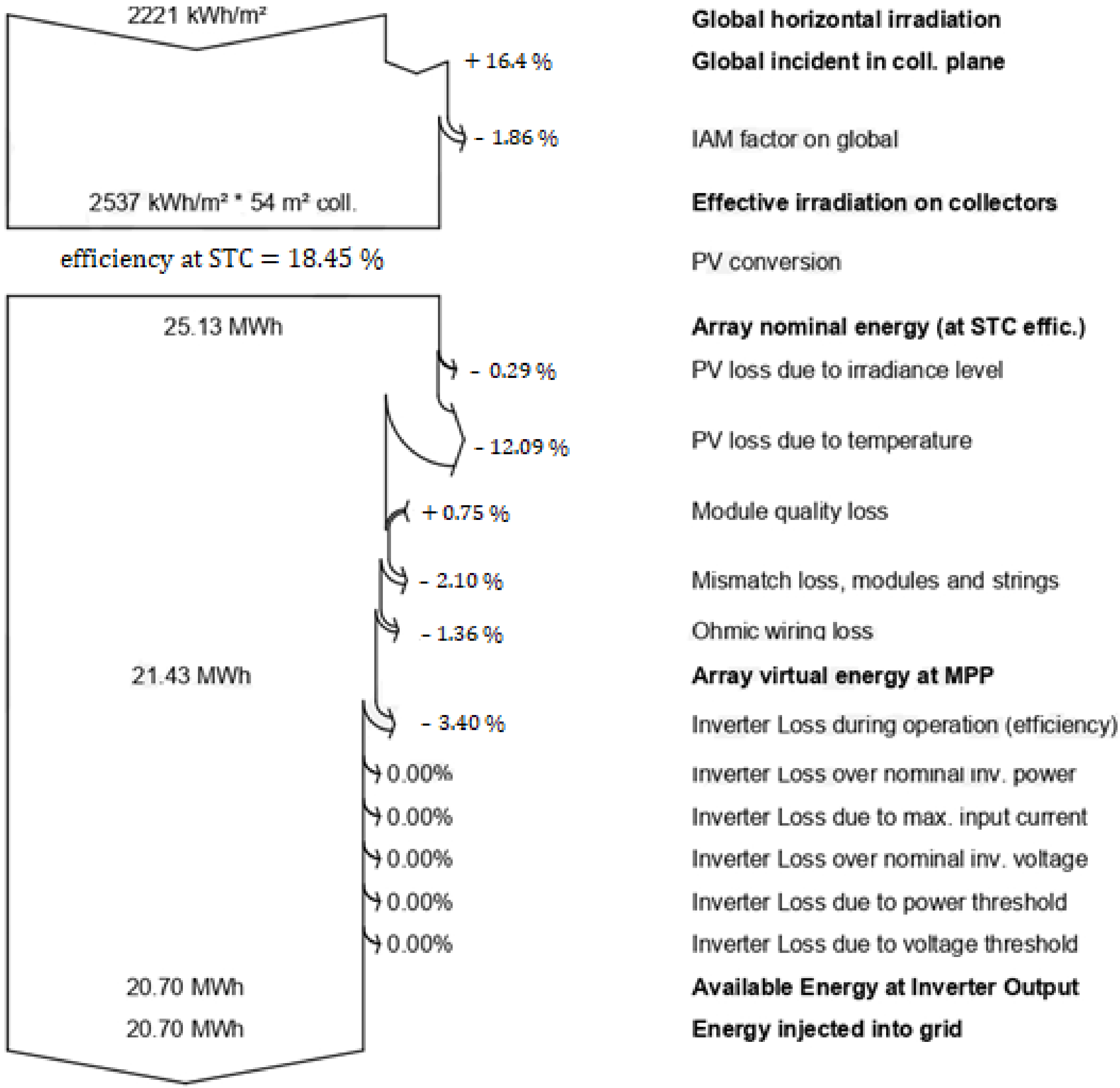

Figure 11. Loss diagram for the Meybod area.

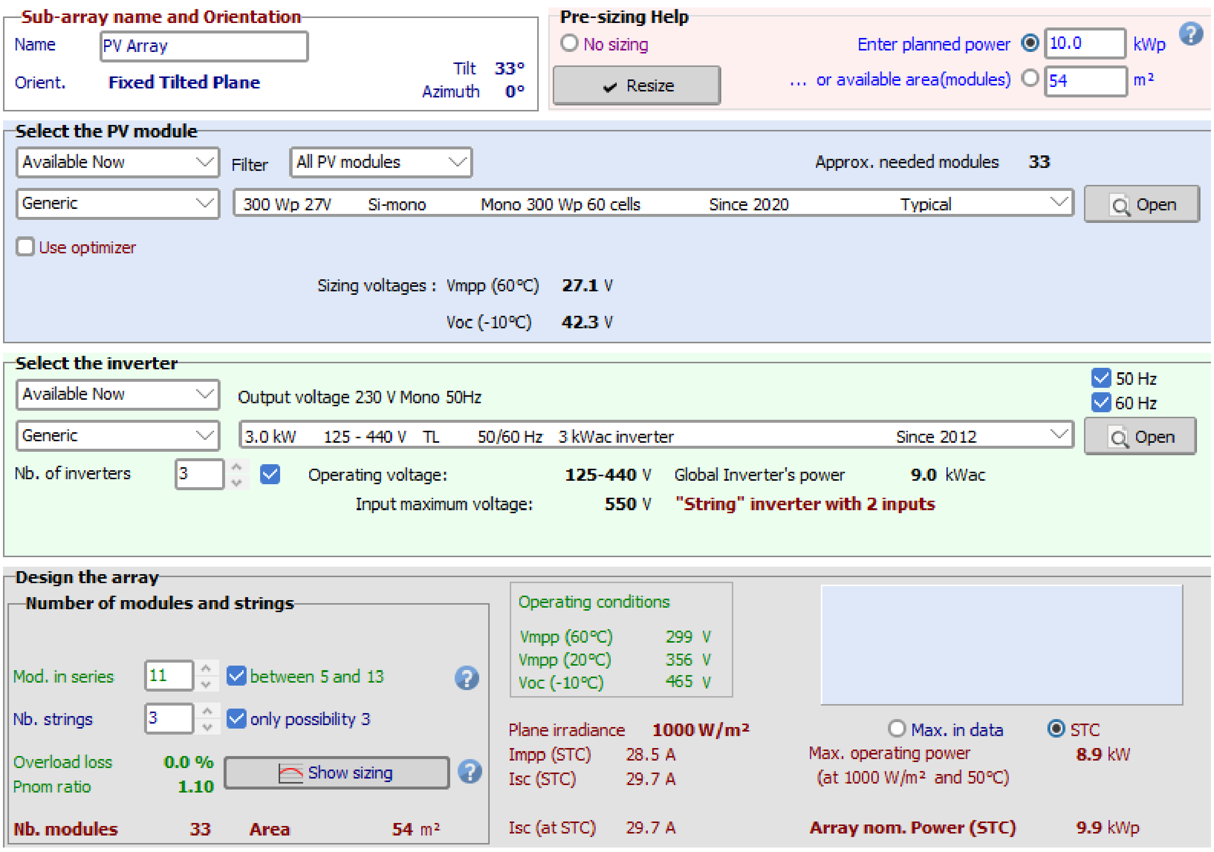

Figure 12. Project page layout and important settings.

5. Conclusions

The implementation of renewable energy-based power plants in Iran has been hindered by long-term sanctions, resulting in a slow growth or even stagnation of the industry. This study was a comprehensive research effort that utilized PVsyst software to analyze the obstacles to the growth of solar energy power plants and simulate the potential performance of solar power plants in two remote regions of Iran.

The location of Iran, particularly the Fars and Yazd provinces, holds immense potential for harnessing solar energy, making them ideal candidates for this research aimed at exploring the feasibility of generating electricity from solar panels. With abundant sun exposure, these regions were selected for their exceptional solar energy potentials. This study aimed to identify two regions in Iran with high potential for solar energy production and examine the challenges and opportunities in implementing renewable energy solutions in these remote areas. Through a PEST analysis, we evaluated the political, economic, social, and technological factors that impact the development of solar energy systems in Iran. It was concluded that strategic planning and collaboration between government authorities and local communities at the provincial, national, and local levels are essential for successfully implementing renewable energy solutions. In addition, the government's role as a mediator among stakeholders, promoting public–private partnerships, and raising awareness among the public regarding the benefits of renewable energy systems, will be crucial in ensuring the expansion of renewable energy solutions in these regions. The role of the public is crucial in the expansion of solar energy systems. By actively participating in the implementation process, they can drive the growth and development of renewable energy. To ensure that the goals are met, it is important to have a strong collaboration between the public and both local and national government authorities. Before implementing renewable energy systems, conducting a comprehensive PEST analysis can help identify and address any barriers that may arise, leading to a successful and sustainable expansion of e.g., solar energy.

The technical performance of two PV plants located in the Darab and Meybod areas of Iran was analyzed. The simulation focused on maximizing energy production and evaluating various performance parameters, such as incident radiation, performance ratio, energy input into the grid, energy output at the array, and losses. The PV plant in Darab had a capacity of 9 kWp, while the one in Meybod had a capacity of 9.90 kWp. The results showed that the produced electricity in Darab was 20.40 MWh/year, with a specific production of 2061 kWh/kWp/year and a performance ratio (PR) of 81.26%. Meanwhile, the production in Meybod was 20.70 MWh/year, with a specific production of 2091 kWh/kWp/year and a performance ratio (PR) of 80.88%.

The contribution and policy implications of this research can be summarized as follows:

(1) This study highlights the potential for solar power production in the Fars and Yazd provinces in Iran, making it a valuable resource for meeting the energy needs of remote regions.
(2) The PEST analysis conducted in this study helps identify and evaluate the political, economic, social, and technological factors that impact the development of solar energy systems in Iran.
(3) The study highlights the need for strategic planning and collaboration between government authorities and local communities to implement renewable energy solutions successfully.
(4) The study highlights the government's role as a mediator among stakeholders and the importance of raising awareness among the public regarding the benefits of renewable energy systems.
(5) The simulation of two PV plants in Iran's Darab and Meybod areas was conducted using PVsyst software, evaluating the performance parameters such as incident radiation, performance ratio, the energy input into the grid, energy output at the array, and losses. This study provides valuable insights into the technical performance of PV plants. It can serve as a reference for energy authorities and other stakeholders in evaluating the potential of other areas in Iran for implementing clean energy solutions.
(6) This study provides valuable insights for policymakers and stakeholders involved in the development of clean energy solutions in Iran and other similar regions, enabling them to make informed decisions to drive the growth and expansion of renewable energy.

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Data Availability Statement: For the paper, we used weather data that can be obtained directly from PVsyst software belonging to the 2022 year.

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

Nomenclature

Apv	Array photovoltaic for system
CUF	Capacity utilization factor
HDI	Horizontal diffuse irradiation
GHI	Global horizontal irradiation
EA	Effective energy at the output of the array
Eac	Net AC power output system on a yearly, monthly basis
Edc	Daily output energy in DC
EG	Energy injected into grid
GE	Effective global, corr. for IAM and shadings

GI	Global incident in coll. plane
Ht	Total in-plane solar insolation
IAM	Incidence effect
IEA	International Energy Agency
LA	Array capture loss
LC	Capture losses, in kWh/kWp/day
LS	Losses system, in kWh/kWp/day
MML	Module mismatch losses
MQL	Module quality loss
MPP	Maximum power point
η_{inv}	Efficiency of the inverter in the PV solar plant
η_{pv}	PV panel's efficiency
η_s	General efficiency of the PV system
Pac	AC power produced by the inverter
Pdc	DC power produced by the PV array
PEST	Political, environmental, social, and technological
Pnom	Ratio of DC:AC
Po	Nominal power
Ps	polysilicon(poly-Si)
Pp	Daily basis by peak PV power
PR	Performance ratio
PV	Photovoltaic
PVsyst	Photovoltaic system
RES	Renewable energy source
SML	Strength mismatch losses
STC	Standard testing condition
SWOT	(strengths, weaknesses, opportunities, and threats)
Tamb	Ambient temperature
YA	Array yield
YF	Final system yield
YR	Reference yield

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