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Advancing Sustainable Opportunities with Photovoltaic Systems in Karbala, Iraq: A Proposal for a Connected PV System

Mustafa Faisal Ghlaim[1*], **Mustafa Fakhir Hussein**[1**], **Asmaa Miran Hussein**[2***], **Haneen Hayder Jasim**[3****]

[1]Department of Energy Conversion, Faculty of Mechanical Engineering, University of Kashan.

[2]Department of Electronic, Faculty of Electrical and Computer Engineering, University of Kashan.

[3]Department Applied Design, Faculty of Mechanical Engineering, University of Hilla.

Authors' Emails:
*mhmdmomo93@gmail.com,
**mostafafaker252@gmail.com,
***elecsoma@gmail.com,
****haneen_jasim@hilla-unc.edu.iq

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Abstract

Aim: The system was designed to produce 30.0 kWp of power, generating 49,622 kWh/year of energy, with a specific production of 1,654 kWh/kWp/year and a performance ratio of 81.01%.

Methods: In this study, PVsyst and Metronome software were used to design an integrated grid-connected photovoltaic system. The geographical location was determined using Metronome parameters: latitude 32.49°N, longitude 43.86°E, altitude 83 m, and time zone UTC+3. The module area is 195 m², while the cell area is 171 m².

Results: The system demonstrated its capacity to reduce carbon dioxide emissions significantly, estimated at 1,061.248 tons according to PVsyst software parameters. The results indicate good system performance and safe operation, enabling the supply of a substantial portion of electrical energy while simultaneously reducing reliance on fossil fuel sources.

Conclusion: This highlights solar photovoltaic energy systems as a viable alternative to traditional fuels.

Recommendation: The significance of the system lies in its contribution to achieving environmental sustainability goals in Karbala, Iraq.

Keywords: *Electrical energy, fossil fuels, solar photovoltaic, PVSYS software, grid-connected*

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INTRODUCTION

Background

Given its critical role in supporting equitable growth initiatives and reducing dependence on fossil fuels, photovoltaic energy represents one of the most promising alternative energy sources in Iraq. A key factor contributing to its potential is the country's high annual daily average of global solar radiation, ranging between 2,000 kWh/m² and 2,500 kWh/m² [1]. Iraq is situated in Southwest Asia, between latitudes 29° 5' and 37° 22' N and longitudes 38° 45' and 48° 45' E, forming the eastern boundary of the Arab nations. The country spans 438,320 square kilometers and shares borders with Turkey to the north, Saudi Arabia and Kuwait to the south, the Arabian Gulf to the southeast, Iran to the east, and Syria and Jordan to the west [2]. The population of Iraq is estimated at 46 million in 2024 and is projected to reach 47 million in 2025, with an expected increase to approximately 64 million by 2050 [3], [4].

The rising energy demand in Iraq is largely attributed to its growing population [5]. Currently, Iraq depends heavily on fossil fuels for electricity generation. These sources are extensively exploited, resulting in significant environmental impacts due to harmful emissions. To address these challenges, swift and effective solutions - such as easily deployable solar photovoltaic systems - are essential. [6], [7].

Integrating solar energy with the national electrical grid can help alleviate the pressure on fossil fuels, contributing to a more resilient and less fossil fuel-dependent economy [8]. Among various solar energy technologies, photovoltaic (PV) systems are the most widely used and can be efficiently integrated into the main power grid. PV systems offer multiple benefits, including a lifespan exceeding twenty years, suitability for challenging terrain, adaptability for portable installations, ease of maintenance, and grid independence in remote areas. A photovoltaic system comprises three primary components: (I) a solar energy conversion unit, (II) a converter that transforms direct current into alternating current for domestic use, and (III) a battery for energy storage, along with other components. These systems are a foundation for renewable energy due to their low cost, rapid market adoption, and sustainability [9].

Electricity generation in PV systems involves the conversion of sunlight into electricity by capturing solar energy in solar cells. This process releases electrons to produce direct current, which is subsequently converted into alternating current by an inverter for household or grid use. This mechanism is known as direct solar energy conversion [10]. In this study, a proposal for a grid-connected photovoltaic power system is proposed outlining its role in electricity generation and demonstrating safe adoption practices.

Objectives

1. Outline the connected photovoltaic energy sources in Iraq
2. Understand the importance of renewable energy in enhancing the energy sector
3. Provide a connected, sustainable, and easy-to-install system for integration with the electricity grid
4. Mitigate the impact of fossil fuels by reducing harmful emissions

LITERATURE REVIEW

This section presents a survey of solar photovoltaic systems from multiple perspectives and objectives, noting the limited studies that precisely examine the importance of photovoltaic systems in Iraq. One study highlights the significance of solar energy by exploring sun-tracking technologies and reviewing global optimization strategies for PV systems. It confirms the abundance and eco-friendliness of solar energy, emphasizing that dual-axis tracking systems outperform single-axis and fixed systems in efficiency and benefits [11].

Another study evaluates the reliability of standalone PV systems, focusing on their long-term performance and the necessity for consistent electricity delivery, particularly in rural areas. The use of robust methodologies enhances the quality and reliability of these systems [12]. Another study discussed the design of a PV system for an average household in Al-Hilla Governorate, Iraq. It emphasizes solar energy reliance and the usage of independent PV systems for various applications, noting their importance in overcoming power delays and supporting remote development projects [13].

An analysis of off-grid PV systems for rural families in Diyala Governorate demonstrates their effectiveness over fossil fuels, suggesting their viability as long-term energy solutions in areas lacking electricity infrastructure [14]. A study provided a load estimation for off-grid solar PV systems, showing their reliability in renewable energy generation with minimal maintenance requirements [15]. A review of Iraq's solar energy potential highlights the capability of PV systems to reduce reliance on the national grid. While the systems meet performance standards, the main challenge is the accumulation of airborne dust over time [16]. The study focused on optimizing PV systems to match seasonal trends in Karbala, Iraq, and proposes cost-effective strategies for maximizing solar irradiation. It evaluates two PV approaches and a 690-kW system designed for office applications. Key considerations include a seasonal inclination angle, an albedo of 0.25, and a horizontal axis system. Results show improved efficiency and reduced costs by using more affordable materials [17].

One study underscores the technical and economic feasibility of PV systems, comparing integration with diesel systems in Sebha, Libya, where energy demand is 61,894 kWh/day. It reports that a 15.6 kW PV system requires 86 modules, 16 batteries (12 V, 375 Ah), an 18.9 kVA inverter, a 48 VA inverter, and a 60-amp, 24 V regulator. Despite high costs, long-term gains position PV systems as viable alternatives to diesel power [18]. A study assessing the performance of standalone PV systems in rural communities concludes that they are among the most effective energy options in remote areas, serving as alternatives to national grid power in representative zones [19].

Research on standalone battery systems reveals their potential to enhance electricity access in rural areas, helping alleviate energy poverty in developing countries worldwide [20]. Another study outlines the design and optimization of standalone PV systems for rural communities in Shalateen, Egypt. It confirms their efficiency in supplying electricity to families far from the national grid, advocating broader adoption [21]. Another study highlighted the crucial role of PV systems in addressing environmental challenges and supporting the energy sector, especially through grid-connected systems. A system with a maximum capacity of 584 kW using 1,095 modules over 2,994 m² is estimated to save between 13,636 and 23,117 tons of CO_2. PV systems offer sustainable energy sector solutions by 2050 [22]. Lastly, a study proposes methods for standalone PV systems suitable for off-grid users. It offers technical guidance on site selection and system components, targeting individuals seeking independent energy sources for personal consumption [23].

METHODOLOGY

In this study, PVSYS software was used to design a photovoltaic system in Karbala. The project was implemented at a site located at latitude 32.49°N and longitude 43.86°E. Metronome parameters were utilized to perform simulations that display solar radiation levels, temperature patterns, and sunrise rates specific to the location. The primary objective of this project was to

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emphasize the significance of photovoltaic systems in Iraq. The selected site in Karbala was identified as part of an effort to find rapid and sustainable energy solutions. Additionally, the PV Systems software was used to generate analytical results due to its high efficiency in data analysis.

RESULTS OF THE PROPOSED SYSTEM

The location of Al Qattarah in Karbala, Iraq, was selected for the implementation of the system, considering the essential conditions required for its successful deployment. Weather data from Metronome 8.1 was utilized, providing key information on radiation levels, as well as precipitation and temperature patterns at the site. Figures 1 through 4 were analyzed to illustrate the most critical aspects of the grid-connected photovoltaic system.

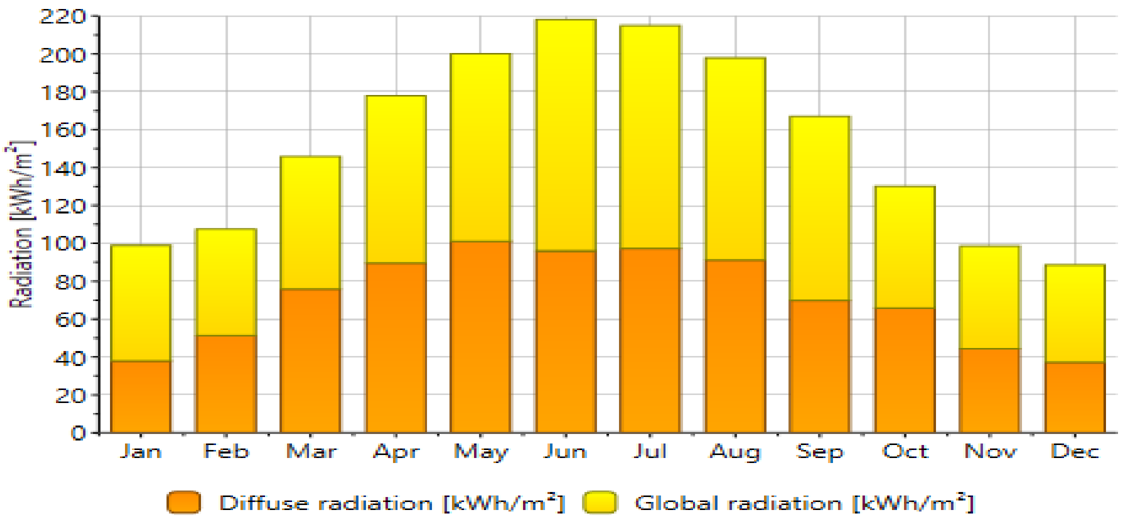

Figure 1. The Radiation for Al Qattarah

Figure 1 illustrates the rates of diffuse radiation and global radiation. When comparing the months of February and June with June and July, it is evident that solar radiation levels are significantly higher in June and July. Therefore, these months represent the periods during which the highest rates of solar radiation can be achieved.

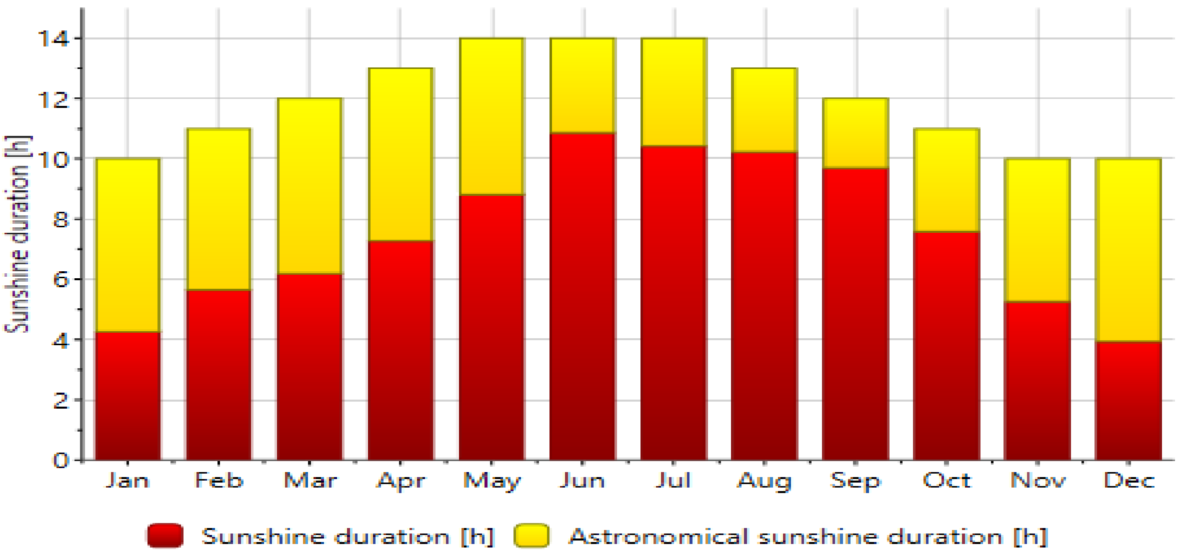

Figure 2. Sunshine Duration for Al Qattarah

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Figure 2 presents the rates of sunshine duration and astronomical sunshine. It is observed that the month of June records the highest values for both sunshine duration and astronomical sunshine when compared to the other months, indicating optimal solar exposure during this period.

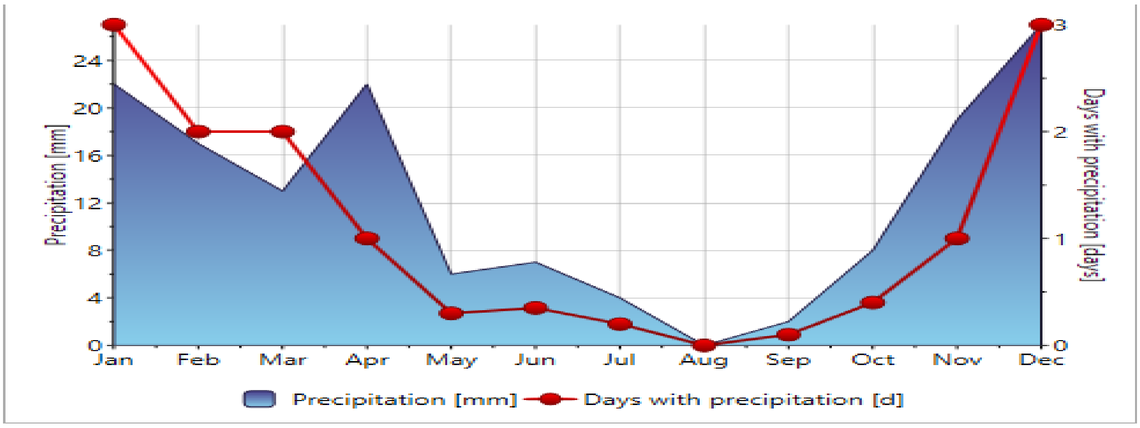

Figure 3. Precipitation for Al Qattarah

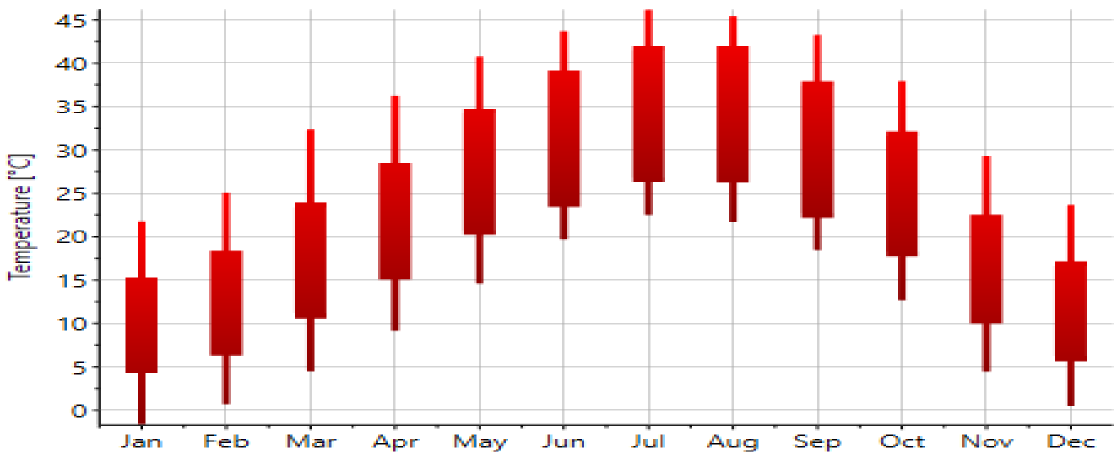

Figure 4. The Rate of Temperature for Al Qattarah

The photovoltaic system is designed as a grid-connected type where table (1) shows the system details in detail.

Table 1. System Summary

Grid-Connected System	Measurements
Number of modules	30.0 units
Pnom total	30.0 KWp
Quantity of inverters	5 units
Pnom total	21.00 Kwac
Pnom ratio	1.429
User's needs	Unlimited load (grid)
Tilt/Azimuth	30 / 0°

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PV module

Manufacturer	Generic
Model	Mono 250 Wp 60 cells Bifacial
(Original PVsyst database)	
Unit Nom. Power	250 Wp
Number of PV modules	120 units
Nominal (STC)	30.0 kWp
Modules	10 string x 12 In series
At operating cond. (50°C)	
Pmpp	26.98 kWp
U mpp	330 V
I mpp	82 A

Total PV power

Nominal (STC)	30 kWp
Total	120 modules
Module area	195 m²
Cell area	171 m²

Inverter

Manufacturer	Generic
Model	4.2 kWac inverter with 2 MPPT
(Original PVsyst database)	
Unit Nom. Power	4.20 kWac
Number of inverters	10 * MPPT 50% 5 units
Total power	21.0 kWac
Operating voltage	125-500 V
Pnom ratio (DC:AC)	1.43
No power sharing between MPPTs	

Total inverter power

Total power	21 kWac
Number of inverters	5 units
Pnom ratio	1.43

Thermal Loss factor
Module temperature according to irradiance
Uc (const) 20.0 W/m²K
Uv (wind) 0.0 W/m²K/m/s

DC wiring losses
Global array res. 68 mΩ
Loss Fraction 1.5 % at STC

Module Quality Loss
Loss Fraction -0.8 %

Module mismatch losses
Loss Fraction 2.0 % at MPP

IAM loss factor
Incidence effect (IAM): Fresnel smooth glass, n = 1.526

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.998	0.981	0.948	0.862	0.776	0.636	0.403	0.000

Figure 5. PV Array Characteristics and Array Losses

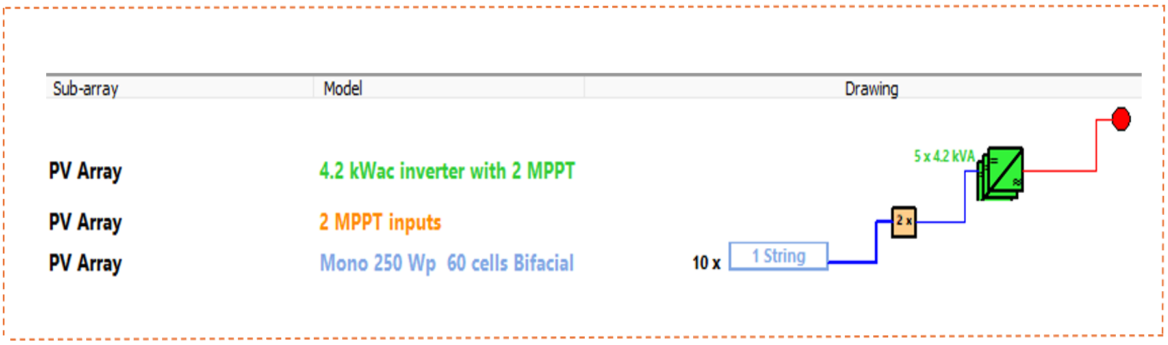

Figure 6. Layout of Setup of PV System

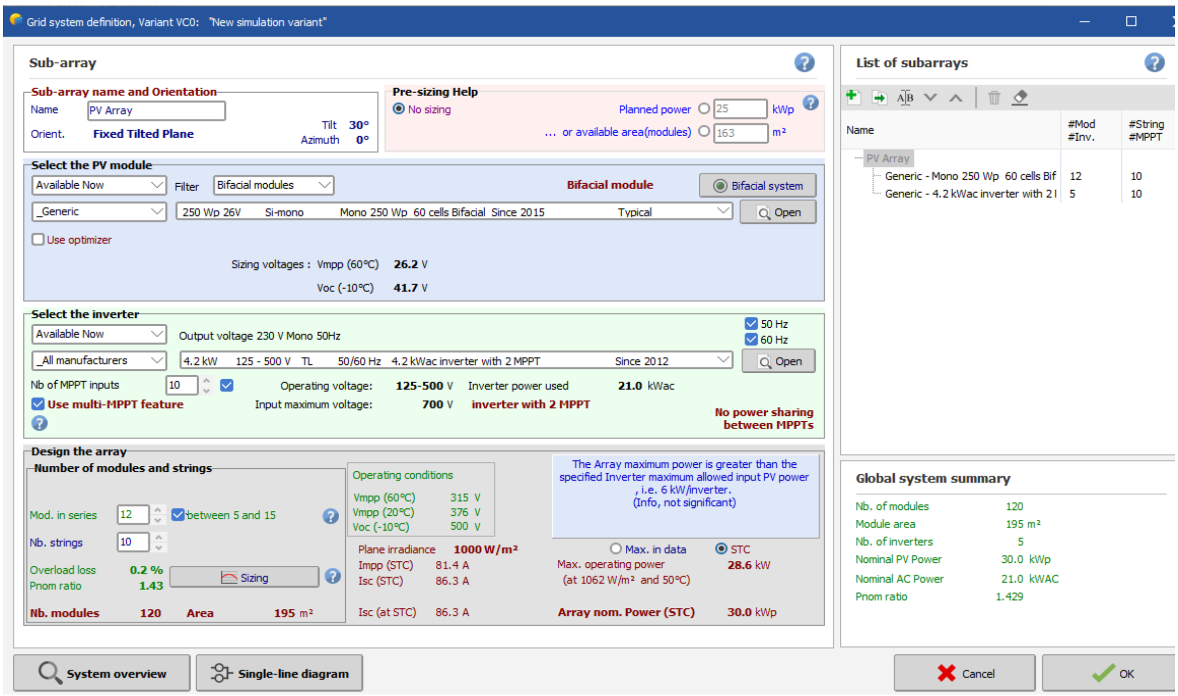

Figure 7. Single Line Diagram

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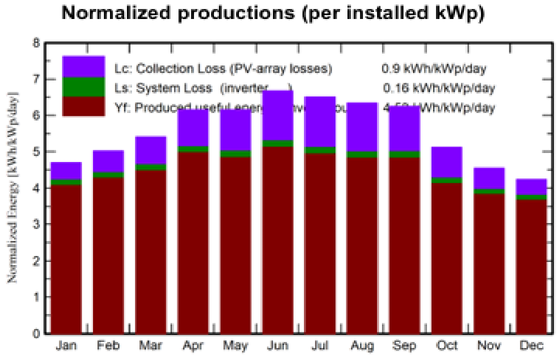
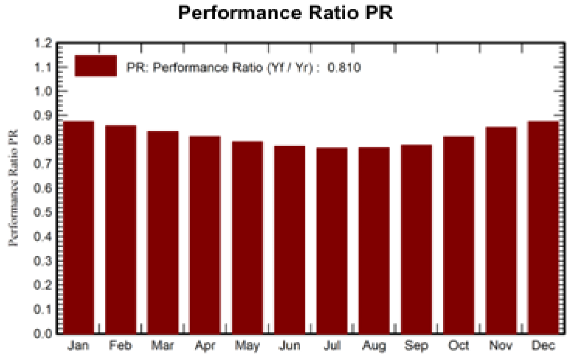
Figure (7) shows the characteristics of a single line for the system where the PV module in operation is of the type (Mono 250Wp 60 cells Bifacial) as this type was used to obtain the best performance for the system. The number of (Inverter is 4.2Kwac inverter with 2 MPPT) and the (String is 12 Mono 250Wp 60 cells Bifacial).

System Production

Produced Energy	49622 kWh/year	Specific production	1654 kWh/kWp/year
		Perf. Ratio PR	81.01 %





Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	97.2	38.2	9.16	145.7	143.0	3958	3822	0.875
February	107.7	50.3	11.87	140.6	137.9	3747	3618	0.858
March	146.0	76.2	17.14	167.9	163.9	4347	4198	0.833
April	177.1	89.2	21.75	184.7	180.1	4663	4503	0.813
May	198.7	100.1	27.57	190.7	185.4	4695	4531	0.792
June	216.3	96.5	31.44	200.1	194.4	4807	4640	0.773
July	214.4	96.5	34.15	201.7	196.1	4792	4625	0.764
August	194.9	92.9	34.05	196.5	191.5	4675	4514	0.766
September	166.9	71.5	29.88	187.5	182.9	4528	4373	0.777
October	128.5	64.4	24.66	158.8	155.5	4005	3869	0.812
November	97.0	45.3	15.91	136.3	133.5	3602	3480	0.851
December	86.9	38.2	10.85	131.5	129.0	3573	3450	0.875
Year	1831.6	859.3	22.43	2041.9	1993.1	51392	49622	0.810

Figure 8. Main Results

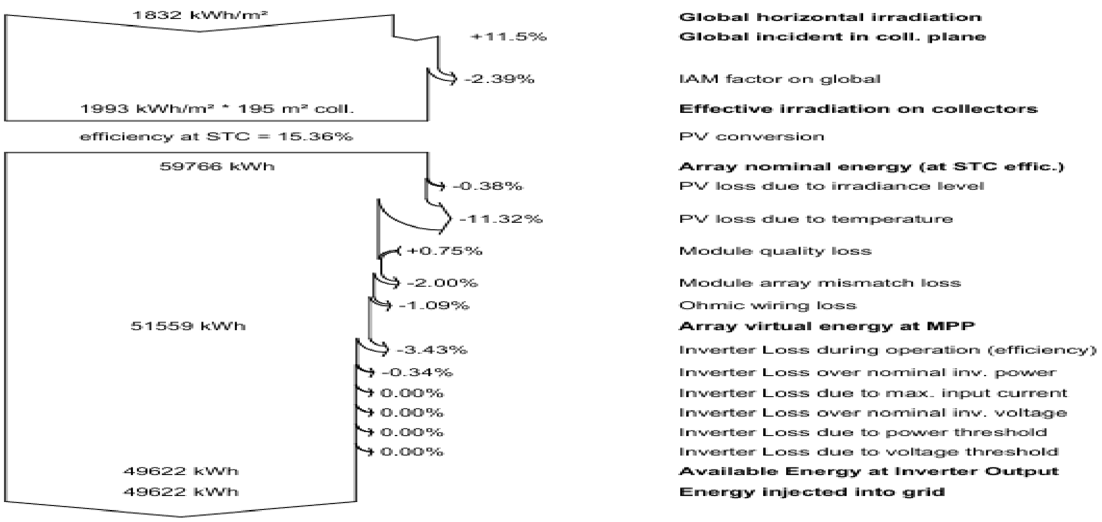


Figure 9. Loss Diagram

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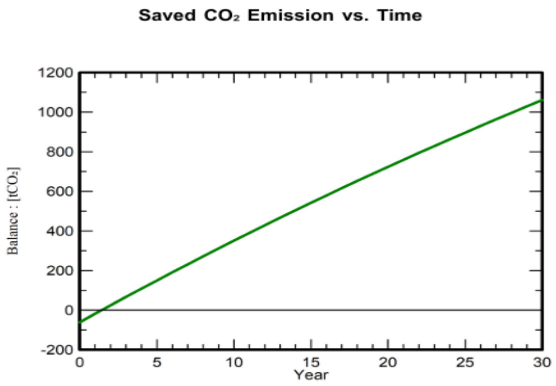
Total: 1061.2 tCO_2

Generated emissions
Total: 61.21 tCO_2
Source: Detailed calculation from table below

Replaced Emissions
Total: 1293.7 tCO_2
System production: 49.62 MWh/yr
Grid Lifecycle Emissions: 869 gCO_2/kWh
Source: IEA List
Country: Iraq
Lifetime: 30 years
Annual degradation: 1.0 %



System Lifecycle Emissions Details

Item	LCE	Quantity	Subtotal [$kgCO_2$]
Modules	1713 kgCO2/kWp	30.0 kWp	51382
Supports	5.80 kgCO2/kg	1200 kg	6955
Inverters	574 kgCO2/units	5.00 units	2871

Figure 10. The CO_2 Emission Balance

Conclusion

Solar photovoltaic energy represents one of Iraq's abundant natural resources, made possible by the country's favorable climatic conditions. However, despite this potential, its utilization remains limited due to various challenges. The primary reason is Iraq's wealth in fossil fuel resources such as oil and gas, which has led to a stronger focus on conventional energy sources. In this study, a grid-connected photovoltaic system was proposed for a selected site in Karbala using the PVsys software. The system demonstrated high performance, ease of implementation, and strong potential for successful adoption. By integrating this system into the national electricity grid, the electricity sector can be significantly improved, helping to enhance the energy supply. Furthermore, this system presents a viable solution to address Iraq's ongoing electricity shortages.

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