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Design and Performance Analysis of Grid-Connected Photovoltaic Systems in Kalar City, Kurdistan, Iraq: A Case Study

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ABSTRACT

The Iraqi Kurdistan region possesses abundant solar energy potential, yet its energy supply relies heavily on non-renewable fossil fuels. As energy demand continues to surge, exploring alternative generation methods is imperative. In this modern era, photovoltaic systems are gaining widespread recognition for their robustness, sustainability, and practicality. Evaluating the performance of these systems is crucial for understanding various operational aspects. This study assesses the effectiveness of a 5-kW grid-connected photovoltaic system strategically installed on rooftops of residential buildings in Kalar City, Iraq. The PVsyst software, a widely used simulation tool for predicting energy output and refining system configurations, is utilized for the analysis. The software simulates the proposed PV system to predict its energy production performance, aiding in selecting the appropriate solar panel size and inverter model to meet the required load demand. The simulation results reveal that the proposed system has the potential to generate 8,814 MWh of electricity annually. Performance ratio analysis highlights December's highest PR at 90.9%, while April records the lowest PR at 79.9%, with an annual average PR of 84.5%. This performance metric underscores the system's efficiency and reliability, with superior performance during the winter months and slightly reduced performance in the summer. The study underscores the region's solar energy potential, aligning with the Kurdistan Regional Government's goals of promoting clean energy. Additionally, it demonstrates that the PV system offers a practical solution for Kalar City to meet its growing energy demands.

Keywords: Renewable energy, Solar energy, gird connected system, Photovoltaic system, PVsyst, Kalar city.

1. Introduction

The soaring prominence of photovoltaic systems for electricity generation is attributed to the diminishing availability of conventional energy resources, particularly fossil fuels. This shift has necessitated a paradigm shift towards reliable and sustainable alternatives, such as photovoltaic systems that harness the inexhaustible energy of sunlight to generate electrical power [1–3]. A notable advantage of photovoltaic systems is their cost-effectiveness, with relatively low upfront acquisition and installation costs. Moreover, these systems are environmentally friendly, emitting no harmful pollutants or hazardous gases during operation. The escalating prices of conventional fuels also contribute to the growing interest in and adoption of photovoltaic systems as a viable and sustainable alternative energy source.

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The global demand for clean and sustainable energy has experienced significant growth in recent years[4–6], primarily due to the increasing awareness and concern regarding the environmental and social consequences of fossil fuels. Among the various renewable energy sources, solar power is one of the most promising and widely embraced options[7]. However, it is essential to recognize that the performance of photovoltaic (PV) modules is subject to various influencing factors, including wind speed, ambient temperature, incoming solar radiation levels, humidity, and dust accumulation[8]. Consequently, the design and optimization of solar photovoltaic modules become imperative to maximize their efficiency and reliability under diverse conditions. Iraq's arid and hot climate, characterized by consistent warmth year-round and abundant solar energy, provides an ideal environment for solar panel installation. The region benefits from ample sunshine and minimal cloud cover, especially during the long, scorching summers, creating optimal conditions for solar energy generation. Solar panels function efficiently in sunny and arid climates like Iraq, making solar energy a practical and sustainable option for electricity production. In recent years, the use of solar panels has expanded in Iraq, driven by government initiatives that actively promote adopting photovoltaic (PV) systems through incentives and tax exemptions[9].

Solar PV modules can generate electricity for various purposes. They can connect to the grid and deliver power, serve consumers directly, or store energy in batteries or other devices for future use[10]. The recent trend is to avoid wasting excess energy and export it to the grid through net metering[11]. Grid-connected solar power systems offer users dual interaction with the grid. In times of insufficient energy production from their solar panels, users can seamlessly draw electricity from the grid. Conversely, when their solar panels generate surplus energy beyond their needs, they have the option to feed or sell this excess electricity back to the grid. This arrangement, commonly referred to as net metering[12], has gained widespread popularity globally[13]. PV technology has emerged as a financially viable means to curtail carbon emissions, driven by the declining equipment costs and the array of incentives offered globally. The International Energy Agency (IEA) reports that solar PV generation witnessed an unparalleled expansion, surging by a remarkable 270 terawatt-hours, marking a substantial 26% increase in 2022 and achieving an impressive cumulative total of nearly 1,300 terawatt-hours. Notably, this exceptional growth rate outpaced that of wind power, marking the first instance of such an occurrence[14].

The Iraqi Kurdistan region, located in the northern part of the country, faces persistent electricity shortages that impede its economic and social progress[7]. The escalating demand for electricity in this region has led to frequent daily power outages for households. Consequently, residents heavily rely on diesel generators connected via private cabling networks to power their domestic appliances. Nevertheless, this region holds substantial potential for renewable energy, especially solar energy, thanks to its sunny climate and high solar radiation levels[15]. Recognizing this valuable resource, the Kurdistan Regional Government (KRG) initiated three new solar power plant projects in 2023, with a cumulative capacity of 300 MW, which will seamlessly integrate into the national grid. These endeavors are a vital component of Kurdistan's long-term strategy to generate 900 MW of clean energy by 2030[16]. Recent academic research has explored the feasibility of solar power in the Kurdistan region. For example, Morad conducted a study[17] analyzing the potential and social awareness of implementing renewable energy sources in Kurdistan. The study revealed the region's capacity to harness renewable energy resources, yet most participants expressed the view that the public sector should spearhead renewable energy production.

This paper explores the feasibility of installing a 5-kW solar system on the currently unused rooftops of residential buildings in Kalar City, Iraq. It represents a pioneering effort in designing and analyzing a grid-connected PV system customized for rooftop installation in the city. Unlike previous studies, this research employs PVsyst software for simulating and evaluating the system's performance, offering a more comprehensive and rigorous approach. The primary objective of this study is to bridge the energy demand-supply gap in Kalar City, offering the residents a dependable and sustainable electricity source by installing PV systems on each of the 39,350 unused rooftops owned by electricity consumers in the city. Furthermore, this paper presents a meticulous design for a grid-connected PV system, carefully considering the unique climate and solar radiation conditions in the Kurdistan region of Iraq. Additionally, it provides a comprehensive performance assessment of the proposed PV system, evaluating aspects such as energy generation, performance ratio, and efficiency.

Overall**,** this paper offers valuable insights into the feasibility and potential advantages of grid-connected PV systems within the Iraqi Kurdistan region. It serves as a practical guide for designing and implementing such systems specifically tailored to the unique climate of the region.

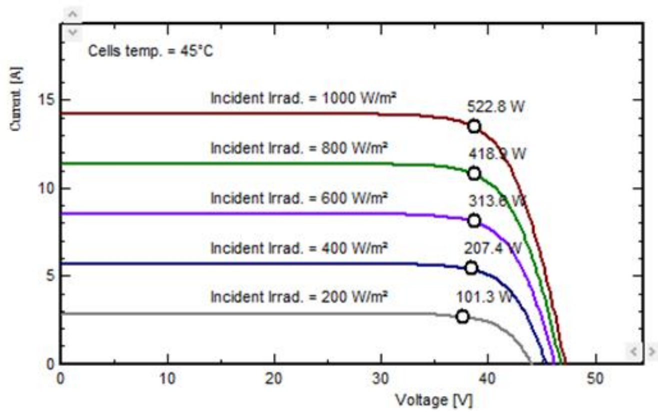
2. Grid-Connected Photovoltaic Systems: A Seamless Integration of Solar Energy and the Electrical Grid

A Grid-connected photovoltaic (PV) system harnesses the power of sunlight to generate electricity and seamlessly integrates with the utility grid. These versatile systems serve residential, commercial, and even large-scale grid-tied environments. In contrast to off-grid systems, grid-connected systems do not require battery energy storage, as they efficiently leverage the utility grid as a reliable power source. Grid-connected PV systems operate dynamically. When they generate more electricity than needed, the excess power is fed back to the grid using an inverter and a distribution board. Conversely during periods of lower energy generation, the system draws power from the grid to meet its operational requirements[7, 18]. Compared to off-grid systems, grid-connected PV systems offer several advantages, including lower upfront costs, increased reliability, and net energy metering. Net energy metering is a policy that allows grid-connected PV systems to export excess electricity to the grid, earning corresponding credits. This facilitates reduced electricity bills for PV system owners and expedites the recovery of their initial investment. Additionally, net energy metering contributes to improving the electrical grid by supporting clean and distributed power generation, ultimately enhancing overall grid stability and resilience[13]. The fundamental components of a grid-connected PV system include photovoltaic modules (PV modules), an inverter for converting direct current (DC) to alternating current (AC), and net energy metering to measure the bidirectional electricity exchange[18].

2.1 Photovoltaic Modules: The Heart of the Grid-Connected PV System

A grid-connected PV system relies on photovoltaic cells to generate DC electricity from sunlight. These cells absorb solar radiation and convert it into electrical energy that can be used on-site or fed into the grid. PV modules are made up of silicon semiconductor cells, known for their cost-effectiveness and high efficiency. When exposed to sunlight, these cells generate electricity. The power output of a single PV cell is relatively low, so multiple cells are interconnected in series and parallel configurations to create a PV module with the desired power output. Several PV modules are then connected in a series-parallel arrangement to form a PV array. The proposed grid-connected PV system will use the Longi Hi-MO6 LR5-72HTH

560W 60-cell module. This module is a high-efficiency option that utilizes monocrystalline passivated emitter and rear contact (PERC) cells. PERC cells are designed to optimize light capture while minimizing energy losses. The use of high-quality components ensures long-term performance and reliability. The Longi Hi-MO6 LR5-72HTH 560W 60-cell module has an impressive efficiency rating of 21.7%[19]. It can generate more electricity per watt of installed capacity than lower-efficiency modules. High-efficiency solar modules offer several advantages, including a reduced levelized cost of electricity (LCOE), decreased space requirements, and heightened reliability[20]. These advantages are driving the widespread adoption of high-efficiency solar modules in global markets, including regions like Kurdistan. The Longi Hi-MO6 LR5-72HTH 560W 60-cell module is a high-efficiency solar panel that can produce up to 522.8 W of power under standard test conditions (STC). The electrical specifications and power curve of the module are shown in Figure 1, which is based on the PVsyst software simulation. The power curve indicates how the module performs under different levels of solar irradiation and cell temperature. At 1000 W/m² of irradiation and 45°C of cell temperature, the module reaches its maximum power output



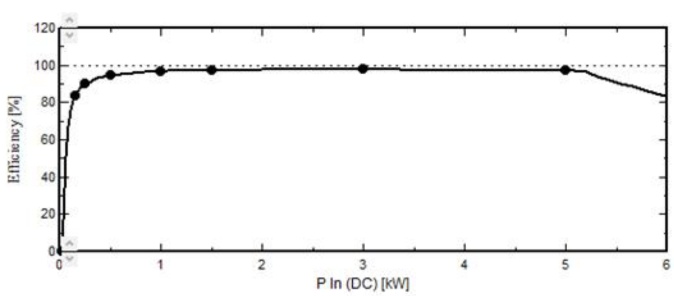
Electrical Characteristics STC : AM1.5 1000W/m² 25°C

Module Type	LR5-72HTH-560M	
Testing Condition	STC	NOCT
Maximum Power (Pmax/W)	560	418
Open Circuit Voltage (Voc/V)	51.61	48.46
Short Circuit Current (Isc/A)	13.94	11.26
Voltage at Maximum Power (Vmp/V)	43.46	39.66
Current at Maximum Power (Imp/A)	12.89	10.55
Module Efficiency(%)	21.7	

Figure 1: Displays the electrical specifications and the impact of solar irradiance on the PV electric power output for the selected PV modules.

2.2 Inverter: The Heartbeat of Grid-Connected PV Systems

In the intricate symphony of a grid-connected photovoltaic (PV) system, the inverter plays a pivotal role. It transforms the direct current (DC) power generated by the solar modules into alternating current (AC) electricity, a form that is seamlessly compatible with the electrical grid and perfectly suited for powering various household appliances and devices. As the central hub of the PV system, the inverter ensures a smooth synchronization between the electricity generated by the solar panels and the grid, facilitating the uninterrupted flow of power. Any significant malfunction in this core component could lead to a complete system shutdown, emphasizing the importance of selecting a top-tier inverter[21]. For this research, we have chosen the SolarMax 5.0 kW 150-950 TL 5ES-T inverter, a distinguished product from SolarMax Technology. Renowned for its commitment to innovation and efforts to make solar energy more accessible and affordable, SolarMax Technology is a prominent leader in the industry. These inverters, celebrated for their outstanding quality, have become a staple in most solar PV system projects in the Kurdistan region[22]. Figure 2 elegantly presents the efficiency curve of the chosen SolarMax inverter, along with its input and output specifications.



Input side (DC PV field)

Minimum MPP Voltage	150	V
Min. Voltage for PNom	200	V
Maximum current per MPPT	12.9	A
Nominal MPP Voltage	720	V
Maximum MPP Voltage	950	V
Absolute max. PV Voltag	1000	V

Output side (AC grid)

Grid voltage	400	V
Nominal AC Power	5.00	kW
Maximum AC Power	5.00	kW
Nominal AC current	7.20	A
Maximum AC current	7.20	A

Figure 2: illustrating the efficiency of the chosen inverter and its input/output specifications.

2.3 Net energy metering: A Transformative Paradigm

Net metering, a ground-breaking and pivotal concept, revolutionizes the energy landscape by enabling a two-way exchange of electricity between end consumers and the national grid through advanced bidirectional meters. This innovation empowers consumers to feed surplus solar energy back into the grid, transforming them into active participants in the energy ecosystem. Grid-connected net metering has emerged as a widely adopted and effective strategy, catalyzing the widespread adoption of solar power systems. Under net metering, homeowners and businesses can offset their conventional electricity consumption with clean solar energy, accumulating credits for any surplus electricity they contribute to the grid. This symbiotic relationship aligns with the overarching goal of enhancing the sustainability of the energy infrastructure[23].

In a significant step towards enhancing energy efficiency, the Ministry of Electricity in the Kurdistan Region launched a pioneering initiative in August 2019, strategically deploying state-of-the-art smart net metering units in various regional locations[24]. These intelligent meters accurately measure and seamlessly transmit the amount of electricity households generate through their solar panels, contributing to the grid's energy supply. The integration of smart meters aligns with the global trend of digitization and innovation in the modern energy landscape. Notably, Directive Number 3 of 2021, promulgated by the Ministry of Electricity, authorizes the seamless integration of electricity generated from solar sources into the national electricity grid[16].

3. Climatic and solar radiation conditions in Kalar

Kalar, located at coordinates 34°63'45" N latitude and 45°32'20" E longitude, is the administrative center of the Garmian region in Kurdistan, northern Iraq[25, 26]. It has an elevation ranging from 300 to 355 meters above sea level and encompasses an area of approximately 32 square kilometers[26]. Kalar's climate is warm and dry, with summer temperatures occasionally exceeding 50°C[27]. The city benefits from abundant sunshine throughout the year, boasting an average of 10.46 sun-hours and 300 sunny days annually[28]. Solar radiation is the primary factor influencing the performance of a grid-connected PV system. The efficiency of a PV system is directly linked to the amount of solar radiation it receives. The city of Kalar stands out with a high potential for solar energy production compared to other cities in the Kurdistan region of Iraq, boasting an annual average solar radiation of about 5.17 kWh/m²/day, as illustrated in Figure 3[15]. This abundant solar resource makes Kalar an ideal candidate for deploying a strategically placed grid-connected photovoltaic system. Such an initiative aims to alleviate the persistent electricity shortages that afflict the city, particularly during the scorching summer season.

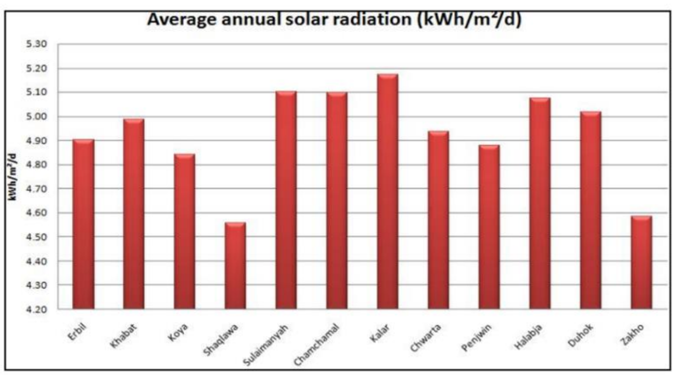


Figure 3: Average annual solar irradiance in different cities of Kurdistan[15].

4. The Soaring Demand for Electricity in Kalar

The Iraqi Kurdistan region has witnessed a meteoric rise in electricity demand, resulting in frequent daily power outages for households. Consequently, residents rely heavily on private neighborhood diesel generators connected through private cabling networks to power their appliances. In 2022, the Kurdistan Ministry of Electricity achieved a power production rate of 3,500 megawatts, while peak power demand reached 7,187 megawatts. These figures highlight the mismatch between supply and demand in urban areas of Kurdistan, posing a significant challenge to the region's development and stability.

A significant challenge faced by numerous households and businesses within the Kurdistan Regional Government (KRG) is the disparity between electrical power supply and demand. Kalar, a city with 39,350 electricity consumers, is among the cities that grapple with this challenge in Kurdistan, Iraq. The city receives only 1.6% of the total electricity production in the region, leading to frequent blackouts during the day[29]. Kalar's power supply is derived from two primary sources: local distribution networks and neighborhood generators. According to the Directorate of Electricity in the city, there are currently 126 neighborhood generators in operation, each with a capacity exceeding 210 kV for power generation. While these generators serve as backup electricity sources during power outages, they also exhibit certain drawbacks, such as high noise levels and significant CO2 emissions.

Table 1 presents data for 2022, including the monthly average energy supplied, demand, and average shedding time in hours, sourced from the Directorate of Electricity of Kalar[30]. With an average power supply of a mere 44.7 MW and an average demand of 63.5 MW, Kalar faced an average shortage of 18.1 MW in 2022. The most notable disparity between electricity supply and demand transpired during the winter months, reaching its zenith at 25 MW in late January. In total, the city received approximately 762 MWh of energy supply from the grid, maintaining an average of 16 hours of primary power supply throughout the year 2022.

Table 1: Monthly average energy supplied, demand, and average shedding time in the city of Kalar.

Month	Av. Load Supply/ MW	Av. Demand / MW	Av. Sheading time /hrs.
January	48.4	72.8	11:17
February	44	62.4	10:08
March	42	56.8	9:05
April	42.8	47.6	3:04
May	40.4	56.8	6:00
June	47.2	73.2	8:49
July	52	79.2	8:15
August	50.8	82.4	8:55
September	48.8	68.8	6:19
October	40.4	54.4	5:11
November	36.4	47.2	5:26
December	44	60.4	6:33
Average	537.2	762	7:25

5 Solar PV System Configuration

The primary components of a solar PV system configuration are visually represented in Figure 4. These components include rooftop solar panels for electricity generation, an inverter responsible for converting DC power into AC power, and a bidirectional meter between the PV system's AC output circuits and the electric utility grid. This innovative system enables the AC power generated by the PV system to either supply the household's energy needs or feed any surplus power into the grid, especially during daylight hours. Conversely, at night or when the electrical load exceeds the PV system's capacity, the required additional power for the AC load is drawn from the utility electric grid. This system essentially eliminates the need for a power storage battery, as any excess electricity generated by the PV array is seamlessly integrated into the utility grid. This option provides a compelling approach for transitioning towards the incorporation of solar power as a strategy to address energy crises. The configuration of a PV system offers a harmonious convergence of convenience, efficiency, and sustainability. By harnessing solar energy to produce clean electricity, it addresses household energy needs while simultaneously contributing to the grid and reducing dependence on fossil fuels.

A beautiful metaphor envisions a symphony orchestra in which each instrument plays a unique and essential role in creating a harmonious melody. The configuration of the solar PV system can be likened to an orchestra, where each component works in concert to generate and deliver clean electricity. The rooftop solar panels represent the violins, serenading the sun with melodies and capturing its energy. The inverter acts as a conductor, transforming the DC power generated by the panels into AC power that can be used by the household. The bidirectional meter serves as the bridge connecting the PV system to the electric utility grid, enabling the seamless flow of electricity in both directions. Together, these components create a beautiful and sustainable symphony for solar energy, offering a glimpse into a brighter future where clean energy is accessible to all.

PVsyst, a specialized software tool, harmoniously blends engineering prowess with the suns power to streamline the design and simulation of grid-connected PV systems. Leveraging its extensive weather database, PVsyst generates comprehensive simulation reports that provide a rich tapestry of insights into system performance[31]. In this study, PVsyst version 7.4 was used to model a 5-kW grid-connected PV system, orchestrating a symphony of nine modules and one inverter into a single string. The resulting system, occupying an area of 23 square meters, is a testament to PVsyst's ability to foster optimal system design and accurate performance predictions. PVsyst is a powerful tool used by engineers to advance the transition to clean energy. With its sophisticated and efficient design and simulation capabilities, PVsyst plays a crucial role in paving the way towards a more sustainable future[31]. The layout and essential settings for the project are depicted in Figure 5. The tilt angle was set at 33°. In this simulation, Longi Solar 560 Wp 36V silicon monocrystalline PV solar cells were utilized along with a dual Maximum Power Point Tracker (MPPT) SolarMax inverter. The planned power input was 5.0 kWp (nominal), with 9 modules in series and 1 string. Once all the variables have been accurately declared in the variant section, the system assists in determining the compatibility of the PV modules and the inverter. Subsequently, the simulation can be initiated if there are no errors

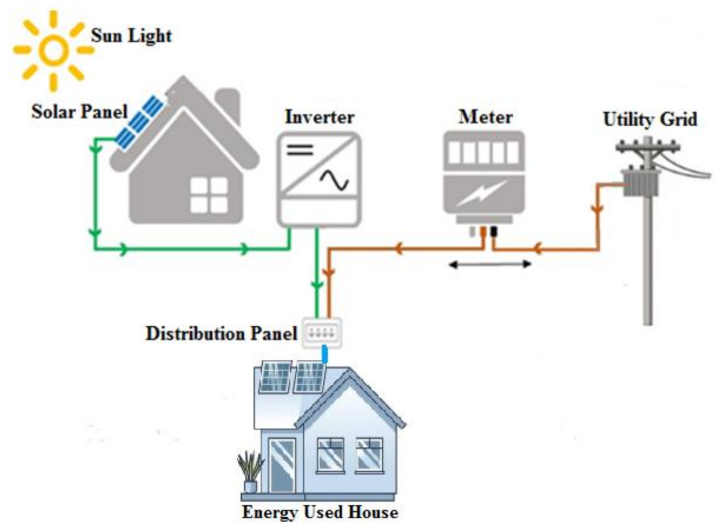


Figure 4: The Schematic diagram of the Configuration System Provided by the software.

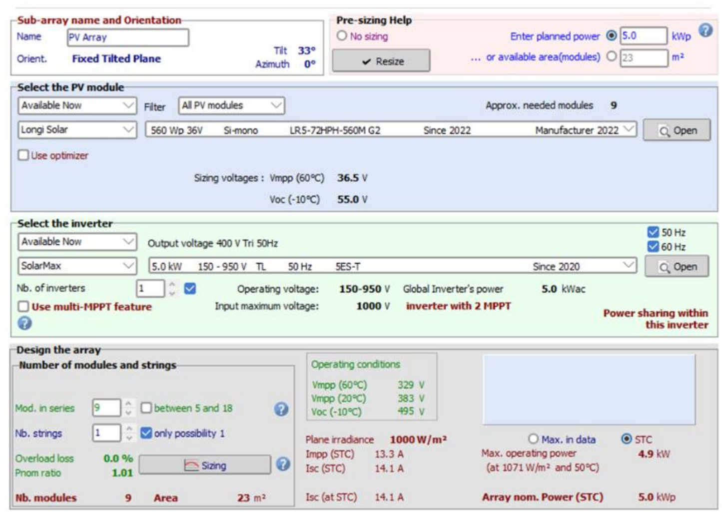


Figure 5: The proposed System setting and layout.

Figure 6. Shows the optimal tilt and azimuth angle for the proposed PV system. The optimal tilt angle for solar panel installation is a delicate balance, carefully crafted to maximize sunlight absorption throughout the year. Like a dancer swaying to the rhythm of the sun, solar panels must be positioned at the perfect angle to capture its rays and convert them into clean energy. At the Kalari Nwe neighborhood site, the software-recommended optimal tilt angle aligns with the area's annual average latitude at 33 degrees. This angle ensures that solar panels are optimally positioned to face the sun directly, with their surfaces perpendicular to its rays during the midday peak. Moreover, the suggested ideal azimuth angle of zero degrees implies that the panels should be oriented southward to receive maximum exposure to the sun's radiant energy.

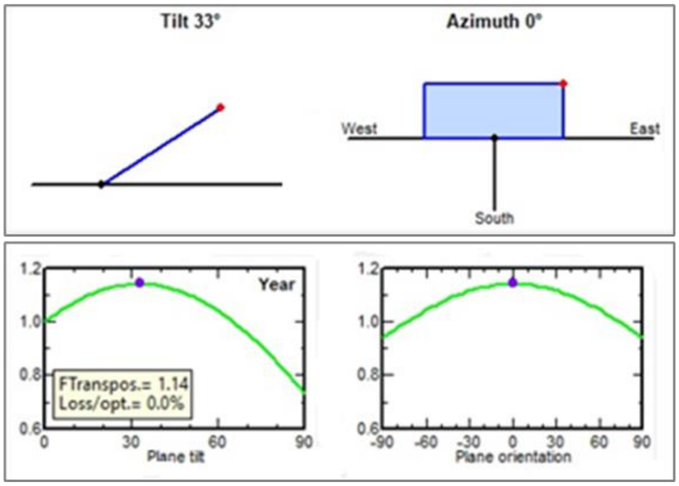


Figure 6: The optimal tilt and azimuth angle for the proposed PV system.

Figure 7 offers a mesmerizing glimpse into the sun's daily journey across the city, its path traced like a golden arc across the sky. This crucial tool in solar energy analysis enables engineers and researchers to choreograph the perfect dance between solar panels and the sun. By closely examining the curve, they can identify the key moments of the day when the panels will receive the highest levels of direct sunlight. Consequently, the orientation and tilt angle of the panels can be adjusted with precision to enhance energy output and overall efficiency. This meticulous alignment with the sun allows solar panels to convert sunlight into a harmonious source of clean energy, catering to the energy needs of both homes and businesses. The carefully calculated and precisely implemented optimal tilt angle serves as evidence of the ingenuity and commitment of engineers and researchers working towards a more sustainable future for everyone.

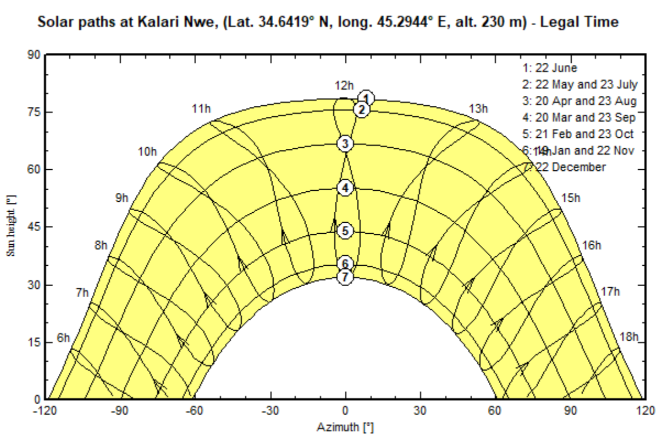


Figure 7: Sun path moving direction.

5 Simulation and results

PVsyst seamlessly integrates meteorological data by utilizing algorithms specifically designed to precisely simulate the performance of solar PV systems. The default partner in this collaboration is Meteonorm, a trusted global data provider. However, alternative sources such as NASA-SSE, PVGIS, and Solcast offer unique advantages depending on user needs. NASA-SSE, a satellite-based data source, is particularly valuable in regions where Meteonorm data is unavailable or inaccurate, providing high-resolution solar irradiance and temperature data. Nevertheless, NASA-SSE data may incur higher costs and require more computational resources for accurate simulations. In contrast, PVGIS, a web-based tool, offers solar irradiance and temperature data tailored to Europe, the Middle East, and Africa, utilizing reliable ground-based station data. It serves as a valuable alternative to Meteonorm in these regions, accessible for free with user-friendly features. However, it is important to note that PVGIS is not available for all regions and has less frequent updates compared to Meteonorm data. Solcast, a commercial data provider, delivers solar irradiance and temperature data with global coverage, making it a strong alternative for regions where Meteonorm data might lack accuracy or availability. Solcast data is known for its frequent updates and can be tailored to meet specific user requirements, such as incorporating historical data or forecasting future trends. However, Solcast data is associated with higher costs and greater computational demands than Meteonorm data[32, 33].

The meteorological file, a harmonious symphony of crucial parameters, plays a vital role in solar PV simulations. Horizontal global irradiance and average ambient temperature serve as the foundation of this symphony, while horizontal diffuse irradiance and wind velocity can be optionally included to enhance the accuracy of the results. Table 2 presents the meteorological data collected for the Kalari Nwe-Kalar City site, sourced from the Meteonorm 8.1 database, which encapsulates the latest and most up-to-date climate periods. This database was integrated into PVsyst software starting from version 7.4, ensuring that simulations for this site reflect the most recent climate conditions.

Table 2: The average monthly meteorological data for Kalari New neighborhood.

Month	GlobHor KWh/m^2	DiffHor KWh/m^2	T-Amb C^o	Windvel m/s
January	89.8	33.31	8.56	1.8
February	98.6	50.64	11.48	2.2
March	138.1	65.61	16.34	2.5
April	171	85.18	21.10	2.6
May	192.5	99.29	27.25	2.4
June	226	86.07	31.99	2.6
July	220.7	91.54	35.01	2.6
August	198.9	84.97	34.56	2.3
September	172.8	56.01	29.75	2.0
October	129.2	56.25	24.45	1.7
November	96.2	36.17	14.19	1.6
December	82.1	30.96	10.07	1.6
Year	1815.9	776.00	22.19	2.2

The simulation parameters and main results are depicted in Figure 8. According to the simulation, the PV system has the capacity to generate 8814 kWh/year of electricity, corresponding to a performance ratio of 0.845. This ratio represents the relationship between the actual and theoretical energy outputs of the system. The provided values affirm that the proposed PV system exhibits high efficiency and reliability.

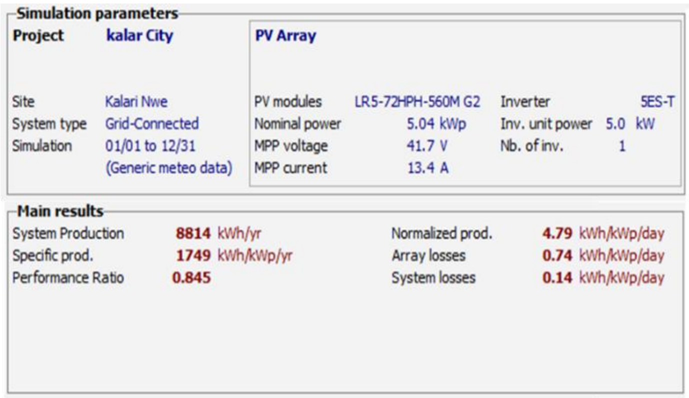


Figure 8: The simulation parameters and main results of the proposed PV system.

Table 3 presents a mesmerizing dance between grid-injected energy, performance ratio (PR), and weather conditions for the proposed photovoltaic (PV) system. June emerges as the prima ballerina, showcasing the highest energy injection of 841 kWh, while December takes a graceful bow with the lowest energy injection of 617.7 kWh. Throughout the year, the system elegantly produces 8814 kWh of electricity, showcasing its ability to supply clean energy to both homes and businesses. The analysis of the Performance Ratio (PR) reveals an intriguing relationship between module temperature and relative humidity. In January, characterized by cooler temperatures, the PR gracefully reaches its peak at 90.9%. However, in July, marked by warmer temperatures and lower humidity, the PR takes a more subdued step, hitting its lowest point at 79.9%. The annual average PR of 84.5% highlights the system's resilience and ability to perform consistently under varying weather conditions. The inverse correlation between PR and system temperature is evident in the data, underscoring the significant influence of weather on PV system performance. As module temperature increases, the efficiency of the solar cells decreases, resulting in a lower PR. Similarly reduced relative humidity can also lead to a decrease in PR, as it can impact the cooling of the solar cells. Despite these challenges, the proposed PV system dances gracefully with the elements, generating clean and reliable energy throughout the year. Its performance is a testament to the ingenuity of engineers and researchers striving to create a more sustainable future.

Table 3: The Energy Injected into the Grid and Its Performance Ratio.

Month	E-Grid KWh	PR ratio
January	651.4	0.909
February	594.0	0.900
March	719.8	0.872
April	772.6	0.854
May	774.2	0.833
June	841.0	0.807
July	832.5	0.799
August	817.1	0.800
September	820.5	0.810
October	716.4	0.844
November	656.9	0.885
December	617.7	0.907
Year	8814.2	0.845

Figure 9 depicts the arrow loss diagram generated by PVsyst software. Beneath the golden rays of the sun, the solar PV system performs its graceful dance, generating clean energy to power our homes and businesses. However, hidden beneath its elegant exterior is a symphony of losses, each vying to reduce its energy output. The arrow loss diagram, a visual masterpiece, captures the delicate balance between gains and losses within the PV system. It reveals the intricate interplay of optical, array, and system losses, each playing a unique role in shaping the system's overall performance. Optical losses result in a reduction of sunlight reaching the PV modules, thereby diminishing their energy output. The primary contributors to optical losses are reflection and absorption. To mitigate their impact, it is recommended to employ high-quality modules, optimize orientation, and prevent shading. Array losses pose as concealed adversaries, diminishing the energy output of the PV system. Various factors contribute to these losses, including mismatched modules, wiring issues, and resistance. Mitigating these losses requires careful selection of compatible PV modules, an appropriate string inverter, and high-quality wiring to optimize energy flow within the system. System losses, the final frontier of energy efficiency, manifest as inverter losses, wiring losses, and miscellaneous losses. However, using a high-efficiency inverter, minimal wiring losses, and appropriate components can minimize their impact. By analyzing the arrow loss diagram with a keen eye and implementing strategic adjustments, engineers can mitigate the major sources of loss, unlocking the full potential of solar PV systems to deliver clean and abundant energy.

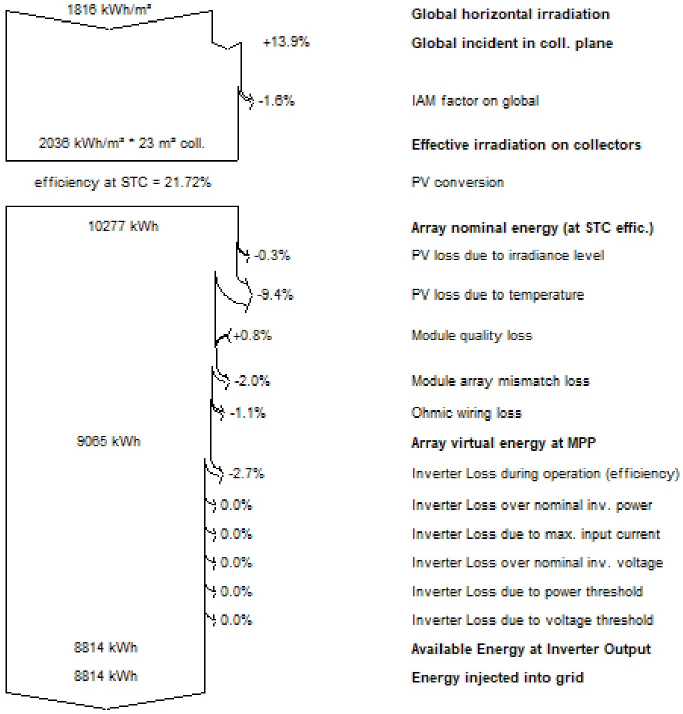


Figure 9: Arrow Losses Diagram for the Proposed PV System.

The performance ratio (PR) is a critical measure of PV system efficiency and reliability. It represents the ratio of the actual energy output to the theoretical maximum, expressed as a percentage. Figure 10(a) depicts a beautiful dance of the PR throughout the year at the designated site within Kalar City. The system exhibits a higher PR during the winter months, from October to April, due to cooler temperatures and lower solar angles. Conversely, the PR decreases during the summer months, from June to September, due to higher temperatures and solar angles. This seasonal variation in PR is aligned with the criteria specified in the IEC 61724-1:2021 standard for PV systems. Figure 10(b) presents a normalized monthly production assessment conducted by PVsyst, considering PV-array losses, system losses, and the production of useful energy. The graph is visually appealing, with three distinct colors representing each component. The purple color represents collection losses, or PV array losses, which average 0.74 kWh/kWp/day. The green color symbolizes system losses, which amount to 0.14 kWh/kWp/day. Finally, the brown color denotes the production of useful energy, which registers at a commendable 4.79 kWh/kWp/day. June records the highest energy production, while December records the lowest output. Overall, the system consistently demonstrates remarkable energy production throughout the year. The dance of the PR and the normalized monthly production assessment in Figure 9 offer a fascinating glimpse into the inner workings of the PV system. The seasonal variation in PR is a reminder of the importance of weather conditions in PV system performance. However, the PV system demonstrates its high performance and dependability by consistently generating energy throughout the year. This serves as a testament to the efficiency and reliability of the PV system, as well as the ingenuity of the engineers and researchers who designed it.

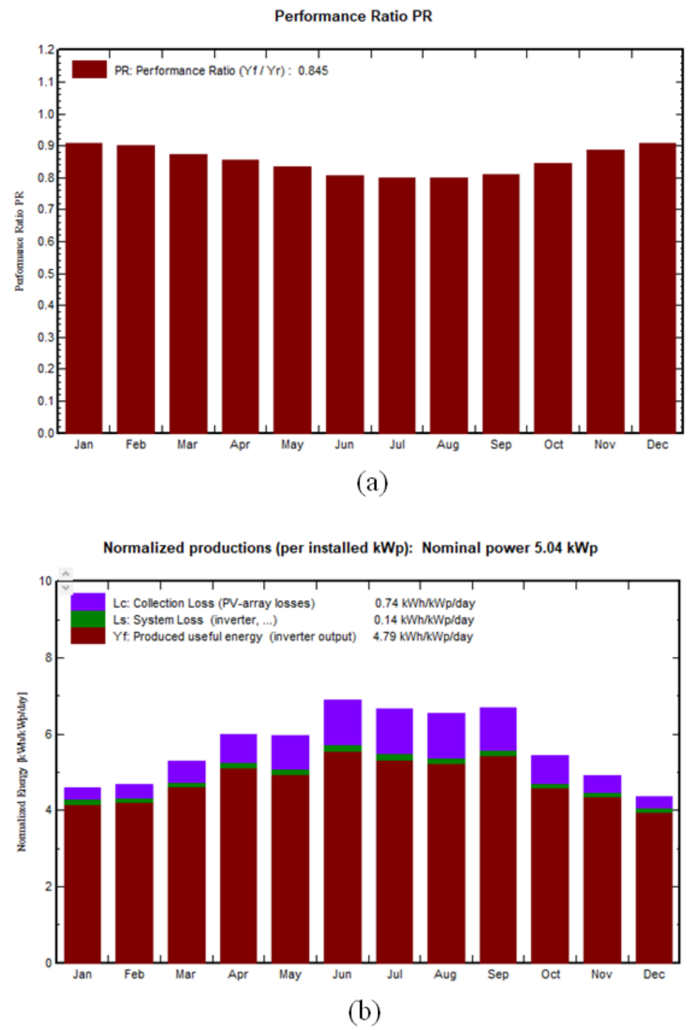


Figure 10: presents the outcomes of the performance assessment for the PV system. (a) displays the Performance Ratio (PR) of the system, while (b) demonstrates the Normalized Monthly Production (NMP) of the system.

The daily input-output relationship graph (Figure 11) shows the relationship between the solar radiation input, energy production, and energy delivered to the grid of a solar energy system. The graph illustrates a strong correlation between energy production and solar radiation input, indicating a notably high overall efficiency of the system. However, there are some losses in the system, which can be minimized by cleaning the solar panels regularly, using a high-quality inverter, and using efficient transmission lines. Additionally, battery energy storage systems (BESS) and smart energy management systems (SEMS) can address daily variations in energy production and optimize energy production. By implementing these strategies, the solar energy system can be made even more efficient and effective.

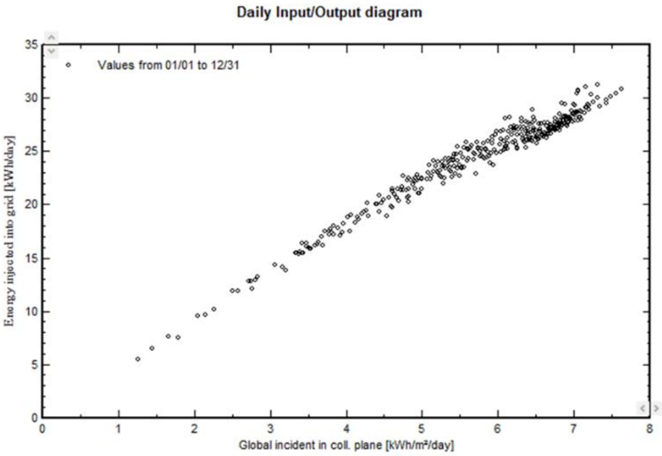


Figure 11: shows the daily diagram between input and output energy for the proposed PV system.

Conclusion

This study's primary objective was to provide a reliable and sustainable energy source for Kalar City by reducing the gap between load demand and supply. Despite the notable challenge posed by the installation cost of a grid-connected photovoltaic (PV) system, a new policy has been introduced to assist citizens in acquiring small loans specifically for the purchase and installation of rooftop solar units. To address the energy challenges in Kalar City, Kurdistan, Iraq, a solution was pursued through the design of a 5-kW grid-connected PV system using PVsyst software. This system was custom-tailored for electricity consumers in Kalar city. After meticulous consideration, a suitable PV module and inverter were carefully selected to optimize the system's performance. The optimal solution for meeting the household's energy requirements throughout the year involves nine PV panels with a capacity of 560W each and one grid-tie inverter of 5kW. This proposed system is expected to generate 8814.2 kWh of clean electricity annually, with the highest energy production occurring in June and the lowest energy production happening in December. The performance ratio analysis revealed that the highest PR was recorded in January, while the lowest PR was obtained in July. These findings underscore the significant benefits of installing solar panels on the rooftops of residential buildings in the city. On average, the proposed system can generate approximately 346.8 MWh of electricity from solar energy per hour, covering over 60% of the load demand during peak seasons. In other seasons with lower demand, excess electricity can be produced to meet the needs of other Kurdish cities. Solar PV systems offer a clean and sustainable energy solution that can benefit all cities in Kurdistan by reducing their reliance on diesel generators and enhancing the performance and reliability of the electricity sector.

This paper has scrutinized various technical and policy challenges and opportunities related to the integration of high levels of solar PV into the grid. To ensure the successful integration of high-penetration solar PV into the grid, policymakers must thoughtfully consider the technical and policy measures outlined in this paper. Energy planners should also integrate strategies for incorporating solar PV systems into their grid planning and operations.

Conflict of interests

None

References

1. M. K. Mat Desa *et al.*, "Silicon back contact solar cell configuration: A pathway towards higher efficiency," *Renewable and Sustainable Energy Reviews*, vol. 60. Elsevier Ltd, pp. 1516–1532, Jul. 01, 2016. doi: 10.1016/j.rser.2016.03.004.
2. N. Belakhdar, M. Kharbach, and M. E. Afilal, "The renewable energy plan in Morocco, a Divisia index approach," *Energy Strategy Reviews*, vol. 4, pp. 11–15, 2014, doi: https://doi.org/10.1016/j.esr.2014.06.001.
3. R. de Arce, R. Mahía, E. Medina, and G. Escribano, "A simulation of the economic impact of renewable energy development in Morocco," *Energy Policy*, vol. 46, pp. 335–345, 2012, doi: https://doi.org/10.1016/j.enpol.2012.03.068.
4. "The Sustainability Trends Report. Generation Investment Management," 2023. Accessed: Sep. 20, 2023. [Online]. Available: https://str2023.generationim.com/chapters/introduction
5. Geoff Stapleton and Susan Neill, *Grid-connected Solar Electric Systems*, 1st Edition. 2011. doi: https://doi.org/10.4324/9780203588628.
6. A. M. Salih Hassan and D. Al Kez, "A Novel Technique for Smoothing Wind Farm Output Power Intermittency," *Passer journal of basic and applied sciences*, no. 13, pp. 187–204, Dec. 2022.
7. K. Ali, D. Hameed, and S. Qadir, "10 kW Grid-Connected PV System Cost and Environmental Analysis for Government Offices: Darbandikhan Technical Institute as a Case Study," *UKH Journal of Science and Engineering*, vol. 4, no. 2, pp. 157–165, Dec. 2020, doi: 10.25079/ukhjse.v4n2y2020.pp157-165.
8. P. Dwivedi, K. Sudhakar, A. Soni, E. Solomin, and I. Kirpichnikova, "Advanced cooling techniques of P.V. modules: A state of art," *Case Studies in Thermal Engineering*, vol. 21, 2020, doi: 10.1016/j.csite.2020.100674.
9. Y. Al-Maleki, "Overview of Iraq's Renewable Energy Progress in 2019," 2021. Accessed: Sep. 20, 2023. [Online]. Available: https://iraqenergy.org/2020/02/20/overview-of-iraqs-renewable-energy-progress-in-2019/
10. J. Twidell and T. Weir, *Renewable Energy Resources*, Fourth edition. Taylor & Francis, 2021.
11. B. P. Singh, S. K. Goyal, and P. Kumar, "Solar PV cell materials and technologies: Analyzing the recent developments," *Mater Today Proc*, vol. 43, pp. 2843–2849, 2021, doi: https://doi.org/10.1016/j.matpr.2021.01.003.
12. C. F. Raouf and A. R. Majeed, "Investigation of Voltage Profiles and Power Losses in Radial Distribution Feeders Based on Smart Meter Data (Raparin Substation as a Case Study)," *Passer Journal of Basic and Applied Sciences*, vol. 5, no. 1, pp. 85–93, Apr. 2023, doi: 10.24271/PSR.2023.382269.1235.
13. R. Andréanne and S. Anjali, "Net metering and PV self-consumption in emerging countries," 2018. Accessed: Sep. 20, 2023. [Online]. Available: https://ieapvps.org/wpcontent/uploads/2020/01/T9_NetMeteringAndPVDevelopmentInEmergingCountries_EN_Report.pdf
14. IEA, "Renewables 2022," Paris, 2022. Accessed: Sep. 20, 2023. [Online]. Available: https://www.iea.org/reports/renewables-2022
15. M. S. Husami, "Energy crisis in Kurdistan and the impact of renewable energy," 2017.
16. A. Ivanova, "Iraq's Kurdistan awards 300 MW of solar projects," *Renewables Now*, 2021. Accessed: Sep. 20, 2023. [Online]. Available: https://renewablesnow.com/news/iraqs-kurdistan-awards-300-mw-of-solar-projects-report-767622/
17. D. H. Morad, "The Potential and Social Acceptability of Renewable Energy sources in North Iraq: Kurdistan Region," *Academic Journal of Nawroz University*, vol. 7, no. 4, p. 93, Dec. 2018, doi: 10.25007/ajnu.v7n4a276.
18. K Arulkumar, K Palanisamy, and D Vijayakumar, "Recent Advances and Control Techniques in Grid Connected Pv System-A Review," 2016.
19. "LONGI." Accessed: Nov. 10, 2023. [Online]. Available: https://static.longi.com/Hi_MO_6_Explorer_LR_5_72_HTH_560_575_M_V03_DG_a74dacd587.pdf
20. M. Victoria *et al.*, "Solar photovoltaics is ready to power a sustainable future," *Joule*, vol. 5, no. 5, pp. 1041–1056, May 2021, doi: 10.1016/J.JOULE.2021.03.005.

21. A. N. Mizard, D. R. Aryani, A. Verdianto, and C. Hudaya, "Design and Implementation Study of 3.12 kWp On – Grid Rooftop Solar PV System," in *2019 International Conference on Electrical Engineering and Informatics (ICEEI)*, 2019, pp. 465–470. doi: 10.1109/ICEEI47359.2019.8988862.

22. Big Power co, "Solar Energy," 2023. Accessed: Sep. 20, 2023. [Online]. Available: https://bigpower.co/en/company/about-us/

23. S. K. Naqvi and Z. A. Nayyar, "Techno-Financial Viability of PV Solar Energy with Net Metering for Karachi City," 2021.

24. Mustafa Shilani, "Kurdistan Region promotes energy efficiency by installing smart electricity meters," 2019. Accessed: Sep. 20, 2023. [Online]. Available: https://www.kurdistan24.net/en/story/21091-Kurdistan-Region-promotes-energy-efficiency-by-installing-smart-electricity-meters

25. Google map, "Kalar city," Google Map. Accessed: Sep. 20, 2023. [Online]. Available: https://www.google.com/maps/place/34%C2%B037'60.0%22N+45%C2%B018'00.0%22E/@34.6333308,45.2999988,283455m/data=!3m1!1e3!4m4!3m3!8m2!3d34.6333308!4d45.2999988?hl=en&entry=ttu

26. H. M. Tawfeeq and S. A. K. Ali, "Molecular-based assay for genotyping Leishmania spp. from clinically suspected cutaneous leishmaniasis lesions in the Garmian area, Kurdistan Region of Iraq," *Parasite Epidemiol Control*, vol. 17, May 2022, doi: 10.1016/j.parepi.2022.e00240.

27. Climate data, "Data and graphs for weather & climate in Kalar," 2023, Accessed: Sep. 20, 2023. [Online]. Available: https://en.climate-data.org/asia/iraq/diyala/kalar-946945/

28. "Climate and monthly weather forecast Kalar, Iraq." Accessed: Aug. 07, 2023. [Online]. Available: https://www.weather-atlas.com/en/iraq/kalar-climate

29. "Energy supply and demand," Ministry of electricity Control Center, Kurdistan Regional Government-Iraq., 2023.

30. "Average energy supplied, demand," Directorate of electricity of Kalar, Ministry of electricity, Kurdistan Regional Government-Iraq., 2023.

31. A. Shrivastava, R. Sharma, M. Kumar Saxena, V. Shanmugasundaram, M. Lal Rinawa, and Ankit, "Solar energy capacity assessment and performance evaluation of a standalone PV system using PVSYST," *Mater Today Proc*, vol. 80, pp. 3385–3392, Jan. 2023, doi: 10.1016/j.matpr.2021.07.258.

32. Ashan Induranga D.K. and Viduruwan Geekiayange, "Reliability Comparison of Weather Data of PVGIS, NREL and Solcast for PV Solar Energy Generation Forecasting," 2021. doi: DOI: 10.13140/RG.2.2.14453.50400.

33. "Solcast V Solargis Comparison | Solcast™." Accessed: Nov. 10, 2023. [Online]. Available: https://solcast.com/historical-and-tmy/solargis/