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Feasibility Assessment of Solar Panel Implementation for Energy Generation in the Desert Regions of Western Iraq

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Abstract: The feasibility of utilizing solar panels for electricity generation in desert environments has been critically assessed, with a particular focus on Rutba, a city located in Anbar Governorate, western Iraq. Rutba presents a promising opportunity for solar energy investment due to its desert location and the substantial amount of solar radiation it receives, estimated at approximately 3000 hours of sunshine annually. The average daily solar radiation in Rutba is approximately 9.3 hours. The city also faces a significant deficit in electrical power, with an annual demand of 209.5 GWh, while current diesel generators provide only 52.56 GWh annually, resulting in a shortfall of approximately 156.94 GWh. In light of these challenges, the implementation of solar panels is proposed as a viable solution to mitigate the electricity shortage. The potential for solar energy to meet the city's growing energy demands has been demonstrated, positioning Rutba as an ideal candidate for solar energy development. The study concludes that, based on the area's solar irradiance, energy needs, and geographical conditions, Rutba is a highly suitable site for large-scale solar energy projects, offering both economic and environmental benefits.

Keywords: Solar energy; Desert energy solutions; Renewable energy; Electrical energy deficit; Renewable energy in desert

1 Introduction

Cities provide fertile ground for scientific and geographical research, serving as multi-use environments encompassing residential, commercial, and industrial areas. These urban spaces experience continuous development both in the short and long term, leading to their expansion and population growth. The need for sustainable energy solutions in such urban areas has become increasingly critical. The importance of renewable energy, particularly solar power, has grown in recent years, as it provides a promising alternative to traditional energy sources. The role of solar energy in achieving sustainable development is pivotal, especially in regions where conventional energy infrastructure is lacking or unreliable. Rutba, a city located in Anbar Governorate, western Iraq, represents one such region. With a population of approximately 29,925 distributed across 12 neighborhoods, Rutba plays a vital role as a border city, serving as a crucial land crossing for the movement of goods and passengers between the Hashemite Kingdom of Jordan and other countries. However, the city faces a chronic shortage of electricity supply, compounded by the sabotage of its diesel-powered generating stations during the period when it was under the control of terrorist groups. This study evaluates the potential of solar energy in Rutba, specifically through the use of solar panels for electricity generation. The results indicate that Rutba is highly suitable for solar energy production, with solar panels capable of covering approximately 70% of the city's electricity needs. The adoption of solar energy can therefore play a significant role in the promotion of sustainable development and the advancement of renewable energy in the region.

1.1 Study Problems

• What are the available capabilities in Rutba city for the implementation of solar panels for electricity generation?

• Has the instability of the electricity supply in Rutba caused problems that negatively impact the daily lives of its residents, hinder economic growth, and contribute to environmental degradation?

1.2 Study Justification

• Rutba city possesses the necessary resources for the establishment of solar farms for electricity generation, making it an ideal location for solar energy projects.

• The use of solar panels to generate electricity in Rutba provides an effective solution to the ongoing electricity shortages, contributing to both environmental improvement and economic development in the city.

1.3 Study Objectives

• To assess the suitability of Rutba's geographical and climatic conditions for the installation of solar panels for electricity generation.

• To investigate the average solar radiation received by Rutba throughout the year and its implications for solar energy production.

• To estimate the potential electricity output from solar panels installed in Rutba.

• To evaluate the environmental benefits of solar panel adoption, particularly in comparison to the use of diesel fuel for power generation.

• To assess the technical feasibility and efficiency of different types of solar panels for use in Rutba.

1.4 Study Area Boundaries

Rutba city is located geographically between longitudes 38.56°E and 42.09°E, and latitudes 30.15°N and 33.75°N. Situated in the western part of Iraq, Rutba's geographical location has contributed to the demarcation of both international and administrative boundaries. The city shares borders with several Arab countries, including the Syrian Arab Republic to the north, the Kingdom of Saudi Arabia to the southwest, and the Hashemite Kingdom of Jordan to the west. Administratively, Rutba is bordered by the Karbala and Najaf governorates to the east and southeast, the Ain and Hit districts to the northeast, the Qaim district to the north, and the Ramadi district to the east along the 90° east longitude border [1–3].

2 Study Area Characteristics

2.1 Population in Al-Rutba City

Population growth is a significant topic of interest in geography due to its complex relationship with various challenges faced by urban populations, including the demand for food, services, and housing. High population growth exerts considerable pressure on public services, escalating the need for essential resources such as drinking water and electricity. The population of Rutba city is approximately 29,925, distributed across 12 neighborhoods: Al-Intisaar, Gharib Al-Wadi, Al-Harah Al-Qadimah, Al-Methaq Al-Qadim, Al-Matar Al-Qadim, Al-Wadi, Al-Matar Al-Jadid, Al-Askari, Al-Harah, Al-Jadidah Athari, Al-Mowadhafin Al-Ola, and Al-Mowadhafin Al-Thaniyah. Rutba is a strategically located border city in Anbar Governorate, Iraq, covering an area of 5.5959 hectares. This land area is divided into various urban uses, which support its status as a vital hub for cross-border trade and movement. As one of the key border cities of Iraq, Rutba faces unique challenges and opportunities related to its growing population and urban development [4–7].

2.2 Electrical Energy Demand Per Capita

Electricity consumption serves as a critical indicator of living standards and economic activity. According to the Iraqi Ministry of Electricity (2024), the estimated annual per capita electricity demand is 7,000 kilowatt-hours, which accounts for domestic use, services, and infrastructure needs. Based on this per capita demand, and with a population of 29,925 in Rutba, the total annual electricity demand for the city can be calculated as follows:

$$29,925 \times 7000 = 209,475,000 \text{ kWh per year}$$

This value represents the total electricity demand required to meet the needs of the city's population, highlighting the significant energy requirements of Rutba.

2.3 Statistical Tools and Methods Used in Analyzing Solar Radia Data

Various statistical tools and techniques are essential for understanding the patterns and variations within data, as well as for exploring the relationships between variables. The following methods are commonly employed in the analysis of solar radiation data:

• Linear Regression Analysis: This technique is used to assess the correlation between solar radiation and other variables, such as time or weather conditions. It enables the evaluation of how specific factors influence the level of radiation.

• Logistic Regression Analysis: Typically applied to binary data (e.g., present/absent), this method is used to examine the relationship between independent variables and the probability of solar radiation occurring in a given location or condition.

• Correlation and Variance Analysis: These methods are used to explore relationships between two or more variables. The correlation coefficient is calculated to quantify the strength of the relationship, while variance analysis estimates the degree of variability between the variables.

• Factor Analysis: This technique is employed to identify the underlying factors that influence solar radiation levels. It is also useful for determining the interrelationships between these factors.

• Spatio-Temporal Analysis: This method is used to examine the spatial distribution of solar radiation and its variation over time. It provides insights into the geographic spread and temporal changes in radiation levels across the study area.

2.4 Fuel Consumption Analysis of Diesel Generators in Rutba City

Al-Rutba is supplied with electricity from a set of six diesel generators, each with a processing capacity of 12 MW. However, each generator operates at 2 MW capacity, supplying electricity for 12 hours a day in alternating cycles. The total annual electricity generation from these generators is calculated as follows:

$$12MW \times 12\frac{h}{day} \times 365 \text{ day } = 52,560 \text{ Mwh per year}$$

This electricity supply, while significant, falls short of the total annual electricity demand of 209.5 GWh, resulting in a deficit of approximately 156.94 GWh per year.

Each diesel generator consumes between 160 and 240 liters of diesel per hour, with the price of diesel set at $0.31 per liter. The operating cost of one generator is approximately $75 per hour. This fuel consumption tends to increase during the hotter months due to the higher temperatures in the desert climate of Rutba.

The fuel consumption analysis of the diesel generators can be broken down into the following components:

• Daily Consumption: To calculate the daily fuel consumption for the six generators, each with a total supply capacity of 12 megawatts, it is important to note that each generator operates at 2 megawatts for 12 hours each day. The cost of operating one generator for 12 hours is $900, since it costs $75 per hour to run one generator. The total daily cost for operating all six generators is therefore $5,400.

• Annual Consumption: To estimate the total amount of fuel required for the entire year, the daily consumption cost is multiplied by the number of days in a year (365 days). As a result, the annual operating cost for all six generators is approximately $1,971,000.

• Seasonal Consumption: Fuel consumption varies with the seasons, especially as diesel consumption increases during the hotter months when the temperatures rise in the desert. Seasonal consumption estimates take into account these fluctuations, reflecting how higher temperatures in Rutba lead to increased fuel consumption by the generators.

2.5 Solar Radiation

Solar radiation refers to the radiant energy emitted by the sun in all directions. It consists of two main types: ultraviolet radiation and infrared radiation. The intensity of solar radiation is influenced by several factors, most notably the angle of the sun's elevation during the day. The closer the sun's rays are to being perpendicular to the Earth's surface, the more intense and concentrated the radiation becomes [8, 9]. Al-Rutba city, due to its geographical location, receives high levels of solar radiation. This is primarily attributed to the city's extended hours of sunshine, which total approximately 3,000 hours annually, along with its generally clear skies. Analysis of the data shows that the average daily solar radiation in the city is 9.3 hours. This value fluctuates across the months, with the highest recorded in July at 635.2 watts per square centimeter per day, and the lowest in January at 232.1 watts per square centimeter per day, as shown in Table 1 and Figure 1.

The direct impact of solar radiation is a key factor in determining the prevailing climate of the study area. This is particularly evident in Al-Rutba's location within the semi-tropical latitudes, characterized by a high solar radiation angle, clear skies, and low cloud cover, all of which contribute to high solar radiation levels. The daily rates of solar radiation reaching the central region of Iraq, and specifically the study area, provide an energy equivalent to between 5.6 and 6 kilowatt-hours per square meter per day [9, 10].

Table 1. Average solar radiation amount (watts/cm^2/day) for Al-Rutba station from 1990 to 2024

Month	Solar Radiation
Jan.	232.1
Feb.	312.6
March	406.3
April	491.7
May	582.6
June	633.1
July	635.2
Aug.	593.3
Sep.	507.3
Oct.	393.1
Nov.	286.9
Dec.	216.4
Annual Average	440.9

Source: Ministry of Transport and Communications, Iraqi Meteorological Organization and Seismic Monitoring, Climate Department.

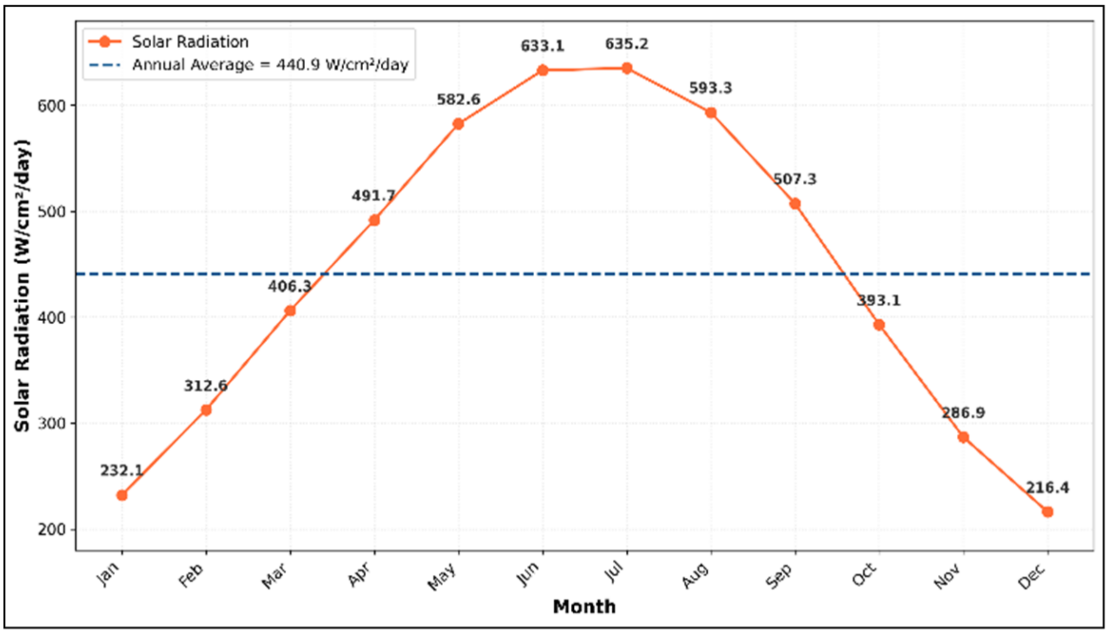

Figure 1. Average solar radiation for AI-Rutba station (1990-2024)
Based on Table 1

The most significant climatic factors influencing solar energy utilization in the study area are as follows:

(1) Sunlight Incidence: During the summer months, sunlight strikes the Earth's surface almost perpendicularly, increasing the amount of radiation received. In Al-Rutba, the solar radiation intensity reaches 635.2 milliwatts per square centimeter in July, whereas it decreases to 232.1 milliwatts per square centimeter in January.

(2) Length of Daylight Hours: The number of daylight hours in summer contributes to an increase in the total hours of sunshine. In Al-Rutba, the city experiences 12.9 hours of sunlight per day in July, which reduces to 6.6 hours per day in January.

2.6 Average Temperature

The surrounding climatic conditions, particularly the influence of Mediterranean Sea hurricanes, play a significant role in the temperature fluctuations observed in Al-Rutba city. The city's temperatures are characterized by a large thermal range, with an average annual temperature of 6.33℃. The temperature variation is notable, with the highest recorded temperature occurring in July at 31.8℃, while the lowest temperature is observed in January at 6.9℃. This temperature variation highlights the significant thermal difference between day and night, typical of a continental climate. Such large temperature fluctuations may lead to increased energy costs, as residents may require additional heating during the colder months and extra cooling during the hotter months. These climatic conditions can therefore impact the overall energy demand in the city [5, 11], as shown in Table 2 and Figure 2.

Table 2. Average temperature for Al-Rutba station for the period (1990-2024) in °C

Month	Degree °C
Jan.	6.9
Feb.	9.4
March	13.2
April	20.8
May	23.4
June	28.7
July	31.8
Aug.	31.4
Sep.	27.7
Oct.	20.8
Nov.	14.9
Dec.	9.3
Annual Average	19.8

Source: Ministry of Transport and Communications, Iraqi Meteorological Organization and Seismic Monitoring, Climate Department.

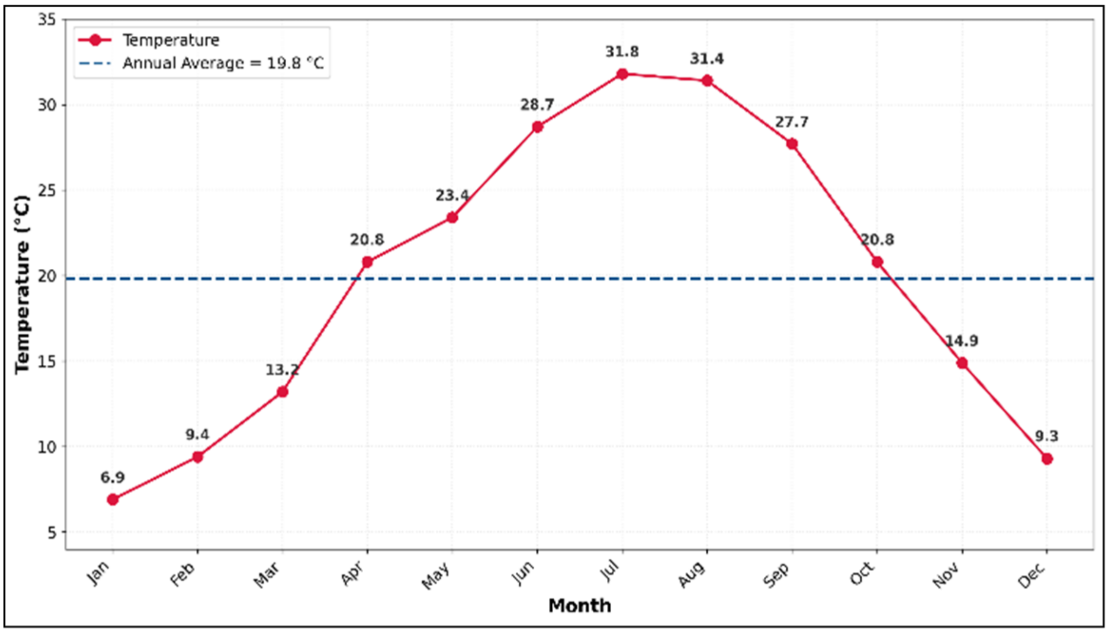

Figure 2. Average temperature for Al-Rutba station for the period

Based on Table 2

2.7 Solar Brightness

Climate data from the Rutba station covering the period from 1990 to 2024 indicate that the region experiences high levels of solar irradiance throughout the year, with an annual average of 9.3 hours of sunshine per day. The distribution of solar irradiance exhibits a clear seasonal variation. During the winter months (December and January), the lowest values are recorded, with an average of 6.5 to 6.6 hours per day. As spring arrives, solar irradiance gradually increases, reaching 8.7 hours per day in April. In the summer months, irradiance peaks, with the highest values of the year recorded in June (12.3 hours per day) and July (12.9 hours per day). Following this peak, irradiance declines again as autumn approaches, as shown in Table 3 and Figure 3.

According to this study and the climate data for Anbar province, the annual average solar energy quantity in the region is approximately 5.5 kilowatt-hours per square meter per day. This equates to 1,825 kilowatt-hours per square meter per year. It is important to note that this moderate level of energy is associated with the region's moderate total solar radiation, which averages 440.9 watts/cm^2/day, as shown in Table 4.

From Table 4, it can be observed that the annual rates of solar energy vary between 5.1 and 5.3 kilowatt-hours per square meter per day. This indicates that Anbar province, where Al-Rutba is located, receives moderate levels of solar radiation throughout the year. Most of the stations in the region report similar rates, ranging between 5.1 and 5.3 kilowatt-hours per square meter per day, suggesting a relatively stable solar radiation pattern over time.

Table 3. Solar brightness (hours/day) for Rutba station for the period (1990-2024)

Month	Solar Brightness
Jan.	6.6
Feb.	7.3
March	8.2
April	8.7
May	9.8
June	12.3
July	12.9
Aug.	11.8
Sep.	11.1
Oct.	9.3
Nov.	7.8
Dec.	6.5
Annual Average	9.3

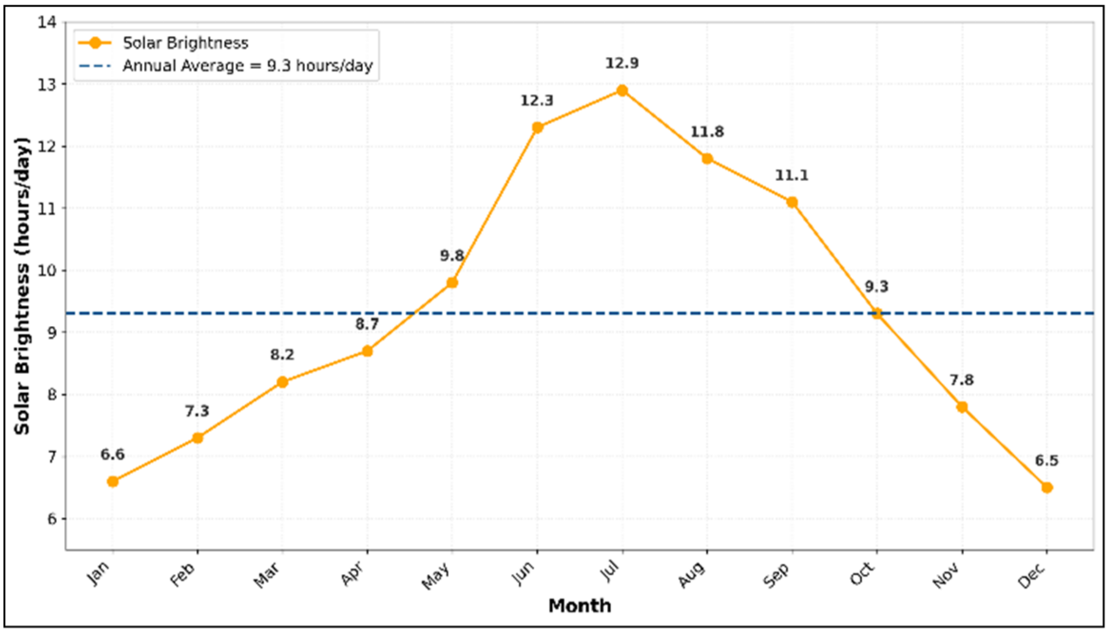

Figure 3. Solar brightness (hours/day) for Rutba station for the period
Based on Table 3

Table 4. Annual average solar energy quantity reaching the climate stations in Anbar governorate (kilowatt-hours/m^2/day) for the period 1990-2024

Station Name	Annual Average Solar Energy Quantity (kilowatt-hours/m^2/day)
Anah	5.2
Al-Qaim	5.1
Haditha	5.3
Eij Wan	5.3
Ramadi	5.3
Al-Rutba	5.3
Al-Nukhayb	5.2

Source: Ministry of Transport and Communications, Iraqi Meteorological Organization and Seismic Monitoring, Climate Department.

Based on the data in Table 4, Anbar province can be divided into distinct solar energy regions, as depicted in Figure 4.

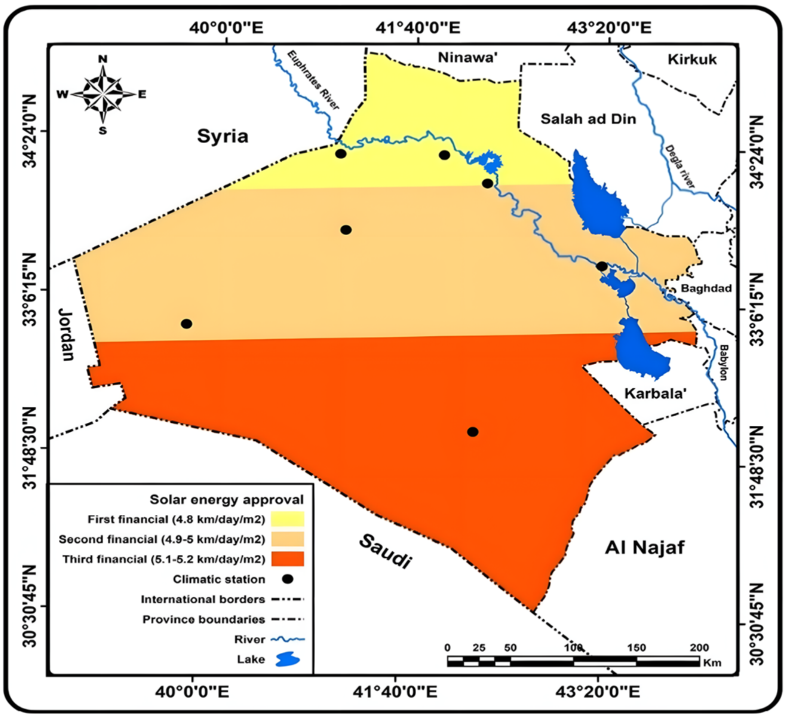

Figure 4. Annual average solar energy quantity reaching the climate stations in Anbar governorate

3 Methodology and Work Procedures

3.1 Methodologies of Study

The description of the methods used to gather and analyze data is a critical component of the research process, as it enhances the credibility of the study and facilitates the replication and generalization of its findings. The following methodologies were employed to gain insights into the research process and the phenomena under investigation:

• Field Study Methodology for Identifying Solar Panel Phenomena and Variables: This approach involves the use of surveying and field observation techniques to collect images and detailed data related to solar panels. It includes the assessment of solar panel performance under various environmental conditions and the evaluation of how these factors impact their efficiency.

• Approaches for Examining Data on Panels from Diverse Sources: This methodology is essential for understanding and interpreting data related to solar panel performance. It involves employing analytical tools to identify patterns and correlations between variables, as well as key factors influencing the efficiency of solar panels.

3.2 Work Steps

• Collection of Geographical and Climatic Data: Gather data on the geography and climate of Al-Rutba city to measure the extent of solar radiation throughout the year.

• Analysis of Climatic and Geographical Data: Analyze the collected data to assess the suitability of the region for the installation and operation of solar panels.

• Study of Solar Panel Types: Evaluate different types of solar panels in terms of efficiency, cost, and compatibility with local conditions.

• Financial Cost Calculation: Calculate the financial costs associated with implementing the solar panel project, including installation, maintenance, and operation.

• Environmental Impact Assessment: Assess the expected environmental impact of utilizing solar panels, considering factors such as reduced emissions and energy savings.

• Presentation of Results and Recommendations: Present the findings of the study, along with any necessary recommendations, to the relevant authorities for further consideration and action.

4 Results and Discussion

4.1 Appropriate Solar Panels

The selection of an appropriate type of solar panel for a particular location requires a thorough evaluation of various factors. These considerations are essential for determining the most effective solar panel for the specific environmental conditions of the area. Key factors to consider include [12–14]:

• Climate: The choice of solar panel is significantly influenced by factors such as temperature, rainfall levels, the amount of sunlight, and variations in weather conditions.

• Solar Panel Efficiency: The efficiency of the solar panels in converting available sunlight into electrical energy is crucial. Higher efficiency allows for greater electricity generation using a smaller surface area of panels.

• Solar Cell Technology: Different solar cell technologies, including polycrystalline, thin-film, and perovskite, should be considered based on their compatibility with local conditions and their expected performance.

• Investment Costs and Return on Investment: Calculating both the initial purchasing and installation costs, as well as the expected long-term return on investment from the generated solar energy, is essential for determining the economic feasibility of the project.

• Local Experiments and Field Tests: Conducting field tests on various types of solar panels within the area is one of the most effective ways to assess their actual performance under local conditions.

Based on the criteria outlined above, two types of solar panels have been identified as suitable for the study area. These panels will be discussed in detail, including their manufacturers, specifications, and electrical capacities:

A. SOLARWORLD, German-made, Model (SW 230 Poly) characterized by the following features:

-Maximum electrical capacity per panel: 230W

-Stable voltage without load: 36.9V

-Voltage under load: 31V

-Maximum current: 8.25A

-Minimum current: 7.72A

-International standard: Provides 1000W per square meter at an ideal temperature of 25 degrees Celsius.

B. MAXMA, a most sensitive type, Model (MX-280 Mono), affected by natural factors more than other types, such as high temperatures and dust. It has the following features:

-Class A quality

-Maximum electrical capacity: 280W

-Maximum current: 9.10A

-Minimum current: 8.81A

-Stable voltage: 31.8V

-Voltage without load: 36.50V

-Ability to withstand temperatures ranging from -40 to 65 degrees Celsius.

-The solar panels are designed to withstand temperatures ranging from -40 degrees Celsius to 65 degrees Celsius without experiencing any significant changes. However, sudden or extreme temperature fluctuations can result in malfunctioning of the panel or individual solar cells.

-The weight of each solar panel is approximately 18.60 kg. The dimensions or measurements of the panel from Maxima are 992mm × 1640mm × 40mm, which is equivalent to approximately 99 cm in width, 164 cm in length, and 4 cm in thickness.

The Maxima solar panel system has a maximum voltage limit of 1000V when connected within the system. The global standard for Maxima solar panels indicates that they can generate 1000W per square meter when the temperature is at the ideal range of 25 degrees Celsius. The prices of these two types in the Iraqi market range between \$250 and \$450 per panel. Each panel produces between 9 and 12 amps.

4.2 Factors Affecting Solar Panels Efficiency

Similar to thermal machines, several factors can influence the efficiency of electricity generation in solar cells. In thermal machines, the temperature of evaporation and condensation is a critical determinant of the theoretical efficiency of electricity production, alongside the efficiency of intermediate devices used in the system. In solar cells, efficiency is defined as the maximum value of the product of current and voltage, divided by the surface area and multiplied by the intensity of solar radiation.

• Quality of internal materials: The efficiency is influenced by the materials used in manufacturing the solar cell and their effectiveness.

• Pollution and manufacturing defects in the materials can reduce the efficiency of the cell.

• The relationship between the energy of sunlight photons and the binding energy of electrons in atoms.

• Leakage of a portion of the electric current at contact points.

• Other sources of loss, such as reflection of a portion of the radiation by the cell.

4.3 Problems and Obstacles Facing Solar Panel Investment in the Study Area

There are several natural and human-related problems and obstacles facing solar panels, including [15–17]:

A. Solar Energy Density

One of the biggest challenges for solar energy is the variations in solar energy density. According to multiple reports, the sun emits its rays differently from one place to another. Since the production of solar panels usually relies on the amount of solar energy they receive, this means that solar energy will only be an ideal source of energy in areas where sunlight is abundant. While solar panels can provide at least some free electricity anywhere in the world, the investment will take longer to pay off in areas with lower solar coverage.

B. Photovoltaic Efficiency

The efficiency of solar panels determines the amount of usable energy they can generate. Most commercial solar panels on the market have efficiencies lower than 25%. The higher the efficiency of a panel, the higher its production cost. For example, if we live in a desert, one square meter of solar panels can receive the equivalent of more than 6 kilowatts/hour of energy in one day. However, solar panels cannot convert this entire quantity of energy into electricity.

C. Lack of Sufficient Awareness for Solar Panel Usage in the Study Area

The residents of the area lack adequate awareness in using such technology, and solar panels require regular maintenance and cleaning to receive the strongest possible sunlight. This lack of usage awareness negatively affects the panels themselves by decreasing their electrical capacity due to scratches caused by improper cleaning and the use of incorrect cleaning tools that scratch the surface of the cells. This creates a film that reduces the cells' efficiency and subsequently shortens their lifespan due to the continuation of this incorrect cleaning process.

4.4 Scenario and Future Outlook for Solar Energy Usage in Al-Rutba City

Al-Rutba city has a high level of solar radiation, estimated at an average of 5.5 kilowatt-hours/square meter/day. This means that Al-Rutba city receives more solar energy than many other parts of the world, including Germany, which is a leading country in solar energy production. In addition to the high level of solar radiation, the wet city possesses several other factors that make it an ideal location for solar energy production. These factors include:

• Availability of Land: Al-Rutba has a large area of open land suitable for solar farms.

• Low Labor Costs: The cost of labor in Al-Rutba city is relatively low, making it a cost-effective location for building solar farms.

• Government Support: The Iraqi government is supportive of solar energy development and has set ambitious goals for renewable energy usage in the country.

The usage of solar energy in Al-Rutba city is still limited due to its high cost at present. The future outlook for solar energy usage in Al-Rutba city is based on successful projects implemented in many Arab countries and Iraq. The following are some applications that can be initiated in the study area [18–20]:

A. Solar Water Heating

Solar water heating is one of the most successful and economical applications of solar energy. It consists of a solar heater typically installed on building rooftops to collect solar radiation. Most of these heaters are simple in design and work to increase the temperature of water (up to 100 degrees Celsius). This type of heater is used for household purposes.

B. Building Heating (Solar Heating)

Solar heating continues to be of interest to engineers, and the residents of Iraq in general, and Anbar province in particular, are known for their high fuel consumption for heating purposes. This is achieved through the use of solar energy equipment, such as photovoltaic cells, solar collectors, energy storage tanks, pumps, compressors, and auxiliary components like connections and pipes.

C. Using Solar Energy for Cooling

The summer in Anbar province, especially in the study area, is characterized by extremely high temperatures, resulting in a significant demand for electricity. Solar energy can replace conventional electricity in this case. Given the desert nature of the study area and the high temperatures, this advantage can be utilized to operate air conditioners and turn the city into an attractive area by using solar energy for air conditioning and cooling appliances such as refrigerators.

D. Using Solar Energy for Water Pumping

Solar water pumps utilize solar energy to provide the necessary power for operation. In the study area, which relies on well water in a desert region, experts believe that the operating costs of solar pumps are much lower than diesel pumps. Solar-powered pumps have the capacity to pump 470 m^3 of water per day from a depth of up to 10 meters or pump 53 m^3 per day from a depth of up to 80 meters.

E. Using Solar Energy for Water Desalination

Water desalination is the process of removing salts and impurities from water to make it suitable for drinking and other domestic uses. Solar energy can be used to produce clean and potable water. Solar distillation is a common method for water desalination. The desert location and the salinity of most of the wells in the Al-Rutba region, where the study was conducted, make it suitable for establishing water desalination plants.

F. Using Solar Energy in Agriculture

Solar energy can be used in various agricultural processes, including:

-Protected agriculture: This refers to farming in greenhouses and plastic or glass houses, where suitable conditions can be created for growing different plants with specific requirements. The use of plastic houses has gained popularity among farmers in Anbar province.

-Providing electricity for agricultural technologies: Solar energy can be used to power traditional irrigation systems or drip irrigation.

-Establishing sustainable agricultural systems that rely on solar energy in arid areas, such as cultivating drought-resistant plants and using solar-powered systems.

-Improving smart irrigation systems using solar energy: Smart irrigation systems that rely on data and control technologies can be developed and operated using solar energy to achieve balanced and efficient water distribution.

5 Conclusions and Recommendations

5.1 Conclusions

• Due to its geographical location, the city of Rutba is exposed to high amounts of solar radiation due to the increased hours of sunshine, which reach 3000 hours per year and the clear skies, and the average annual solar radiation is 9.3 hours per day. This average varies between months, with the highest rate recorded in July (635.2 watts/cm^2/day) and the lowest rate in January (232.1 watts/cm^2/day).

• The study showed that Al-Rutba city in Iraq is suitable for solar panel investment due to its high solar radiation. The average annual solar radiation reached 440.9 watts/cm^2/day, which is a suitable rate for establishing solar power plants.

• The population of Rutba is 29,925 people, and thus the city of Rutba consumes 209.5 GWh per year, recording a large deficit of 156.94 GWh per year.

• Al-Rutba is supplied with electricity from 6 diesel generators with a capacity of 12 megawatts. Each generator operates at a capacity of 2 megawatts. The city is supplied with electric power for 12 hours and operates alternately.

• The price of one liter of fuel (0.31 cents) is equivalent to ($75 the cost of running one generator per hour), and one generator consumes 160 to 240 liters of diesel per hour, and the amount of consumption increases according to the seasons of the year and the rise in temperature in the desert city of Rutba.

• The use of solar panels in Al-Rutba city can be an effective solution to the problem of electricity shortage. The study found that solar panels and solar energy are suitable steps to meet the city's electricity needs.

• The use of solar panels in Rutba is a feasible and cost-effective option, especially given the remote geographic conditions and logistical challenges associated with transporting conventional fuel. Highly efficient and low-cost solar panels have been adopted, commensurate with the city's budget and its status as a developing country, making the project realistic and practical at this stage.

5.2 Recommendations

• Encouraging local governments to support solar panel projects and provide the necessary facilities for their implementation.

• Raising awareness among local residents about the benefits of solar panels and how to use them.

• Directing investments towards high-efficiency solar panel technologies.

• Conducting similar studies to analyze the impact of solar panels on the local economy and the environment.

• Supporting research and development in solar panel technologies to increase their efficiency and reduce their cost.

• The study recommends keeping pace with future technological developments by introducing modern and more efficient solar cells, in addition to smart microgrid technologies, as these play a role in enhancing the system's flexibility and improving its long-term operational efficiency. This represents a strategic approach to ensure the project's sustainability and maximize the environmental, economic, and social benefits of renewable energy in the region.

Demographic shifts in the city of Rutba must be considered when planning future solar energy projects. Population growth is directly linked to increased electricity demand, necessitating the adoption of flexible models for the gradual expansion of solar energy systems, whether in terms of increasing the number of panels or enhancing storage capacities, to ensure the city's long-term needs are met without compromising the efficiency of the infrastructure or the stability of the grid.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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