

## Investigation into the Feasibility of Using Solar-Powered Household Air Conditioner in the Kurdistan Region of Iraq

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### ABSTRACT

The extensive use of fossil fuels contributes to global warming and the release of toxic metals into the environment, resulting in climate change in some regions. It has been estimated that cooling buildings accounts for about 20% of global electricity consumption and this figure continues to grow. The purpose of the current study is to evaluate the feasibility of using an air conditioning unit for cooling a residential building, powered by solar energy in the conditions of Iraqi Kurdistan. Such an assessment is required for the sustainable development of the region. The study location is Erbil city in Iraq (latitude: 36.1911 °N, longitude: 44.00917 °E). The PVsyst software tool was used for modeling because it is characterized by great versatility in the field of modeling solar energy systems. The specified solar panel power (kW) was a constant parameter. Variable parameters were height of solar panels, albedo reflector, tracker system. In the current study, three simulations were performed in which the variable parameter was height and four simulations in which the variable parameter was the solar panel angle. An average of 3.5 kWh was produced throughout the day, and an average of 3.3 kWh was produced during working hours. Only 0.2 kWh was produced outside of working hours, meaning that almost all of the electricity produced is available during working hours. This is useful in countries without high feed-in tariffs where only a small feed into the grid is needed. Also with the lowest calculated values (of all the options under study) the energy produced is 2264 kW/h/year or 2.264 MW/h/year (month – January, panel installation height – 0.5 m, inclination – 20°, azimuth – 0°), greenhouse gas emissions of at least 604.3 kg CO<sub>2</sub> per year are eliminated. At the same time, an additional measure to increase the efficiency of using a solar panel to power an air conditioner is to place reflective material in which the reflection rate or reflection coefficient is different under the solar panels. However, as mentioned earlier, this is an expensive solution. In the future, it will be beneficial to develop smart control technologies to improve performance and evaluate the impact of a solar air conditioning.

**Keywords:** circular economy, alternative energy, residential air conditioning, energy efficiency.

### INTRODUCTION

Due to the accelerated processes of industrialization, the environment is experiencing serious stress, which in turn is reflected in the form of cataclysms and disasters with significant human and financial losses (Dolchinkov, 2024). The extensive use of fossil fuels contributes to global warming (Al-Yasiri et al., 2022) and the release of toxic metals into the environment, resulting in climate change in some regions, decreased yields and the use of chemical fertilizers and plant protection products, which is harmful to public

health (Grinzovskyy et al., 2017; Zahorodniuk et al., 2019; Hulai et al., 2022). This chain of events forces us to use green technologies (Omoyajowo et al., 2024) and to search for alternative energy sources (Al-Yasiri et al., 2022; Ahmad and Samara, 2023; Khan et al., 2022).

In hot regions, air conditioning and cooling is essential, making the indoor environment more comfortable by removing heat from enclosed spaces. The main role in this process belongs to heat pumps. These devices effectively transfer heat from one place to another, depending on where it is needed. Unlike the spontaneous

transfer of heat, which always occurs from a hot body to a cold one, a heat pump transfers heat in the opposite direction (Olmuş et al., 2023). Heat pumps are significantly more efficient than other systems such as air conditioners and furnaces. For an air source heat pump, the efficiency ranges from 175–300%, while for a geothermal heat pump it ranges from 300–600% (Olmuş et al., 2023). To operate, the heat pump requires an external source of energy. With energy prices continually rising and the urgent need to reduce dependence on fossil fuels, improving building efficiency is high on the list of priorities to achieve reduced energy consumption worldwide.

In light of the growing challenges facing the air conditioning and cooling sector, current research is aimed at to improve the energy efficiency of air cooling systems through the solar energy use. This approach is a sustainable and efficient solution as it helps reduce fossil resources consumption and harmful greenhouse gases emissions. Reducing global greenhouse gas emissions in 2050 will increase the likelihood of keeping warming below 1.5 °C (Sulaiman et al., 2023). Global decarbonization is a process that depends on various actions, including decarbonization of the electricity sector. It has been estimated that cooling buildings accounts for about 20% of global electricity consumption and this figure continues to grow. By 2050, energy costs for cooling buildings could already be three times higher (IEA, 2018).

Simulation and Optimization of Photovoltaic-Powered Air Conditioning Systems for Commercial Buildings by Chen et al. (2017). The study found that using photovoltaic panels to power residential air cooling unit in commercial buildings can reduce electricity consumption by up to 30% and significantly improve energy efficiency. The study recommends the necessity of choosing highly efficient photovoltaic panels and improving energy management to achieve the maximum benefit from the system. Performance Analysis of a Photovoltaic-Powered Air Conditioning System Using Dynamic Simulation” by Li et al. (2018). The study found that dynamic control technology and continuous optimization of PV panel-based air conditioning system settings can improve energy efficiency by up to 25% and reduce dependence on the external electrical grid. The study also recommends employing smart control technologies to achieve a better balance between energy consumption and user comfort.

Simulation and Optimization of Photovoltaic-Powered Air Conditioning Systems for Off-Grid Applications by Zhang et al. (2019). The study finds that using standalone PV systems to power air conditioning systems could be a sustainable and cost-effective alternative in areas lacking an electrical grid. The study recommends improving the system design, selecting photovoltaic panels, and using smart management techniques to achieve the best performance and sustainability of the system.

Optimal Design and Performance Analysis of Photovoltaic-Powered Air Conditioning Systems” by Zhao et al. (2019). The study finds that optimal sizing, configuration and control of an air conditioning system based on photovoltaic panels can improve energy efficiency and reduce costs. The study recommends the need to improve the system design, select highly efficient components, and apply intelligent control to achieve the best performance and economy of the system. Study by Wu et al. (2020) Performance of solar assisted air conditioning system with adsorption cooling. The study analyzed the energy consumption and thermal comfort level of the system under different operating conditions. Conducted by Zhao et al. (2021) An energy and entropy analysis of a heat absorption-based solar air conditioning system. The study evaluated the system’s performance and efficiency using energy and entropy methods.

In another study, Zhu et al. (2022). An optimal control strategy for a solar assisted ground heat pump system used in building air conditioning. The study aimed to maximize system efficiency and reduce dependence on grid electricity. He et al. (2023) compared the performance of solar air cooling systems using different types of solar arrays. The study evaluated the energy efficiency and cooling capacity of the systems under various operating conditions. Kapsalis and Founti (2019) conducted a review of solar air conditioning systems. The study showed that these systems provide an opportunity to reduce energy consumption and carbon emissions, enhance environmental sustainability and improve user comfort. Wang and Dai (2017) conducted a review of the latest technologies in solar air conditioning and cooling systems. The study showed significant progress in solar cooling technologies, indicating that they can be widely used in various applications. Chaichan and Kazem (2018) conducted a review of improving the performance of solar air cooling

unit. The results show that improving component efficiency and system control strategies can increase the performance of solar air cooling unit and achieve additional energy savings. Mohanraj et al. (2010) conducted a review of solar energy-assisted absorption cooling systems. The study showed that these systems are a sustainable and effective alternative to meet cooling demand in areas with abundant solar energy. Hasan and Mujahid (2020) conducted a review of recent developments in solar-assisted heat absorption cooling systems. The study showed that using these systems could improve cooling efficiency and reduce energy consumption and carbon emissions.

Li et al. (2024) stated that, under baseline conditions, Photovoltaic driven air conditioner (PVAC) systems showed promising cost savings. However, the cost of PV systems and batteries has greatly impacted the potential of PV systems in general. Thus, recent scientific research tends to demonstrate the positive aspects and serious prospects of using solar energy for cooling purposes in buildings in various countries. At the same time, there are few studies that are devoted to the energy efficiency of residential air cooling units powered by solar energy in Iraqi Kurdistan, although the solar radiation potential is adequate.

Kurdistan is a mountainous region with natural borders, located between latitudes 34° and 39° and longitudes 37° and 46°. The Taurus Mountains, the upper Mesopotamian plateau, the island, and the lower Martin Mountains border it to the west. As for its east, the Kurdistan mountain range is located in an area confined between Lake Uremia and Lake Van. In the southeast are the Zagros Mountains. Monthly solar energy potential of the Kurdistan region. The annual average total sunshine duration is 2979.5 hours (8.16 hours/day), and the average annual solar radiation is 1803 kWh/m<sup>2</sup>/year (4.94 kWh/m<sup>2</sup>/day). Radiation values were obtained using simulation software. The values for May 7, as shown in Figure 2, appear to be very typical for this region, with radiation reaching 992 W/m<sup>2</sup>. Some cloud cover between 12:00 and 1:00 reduces irradiance to approximately 500 W/m<sup>2</sup>, but it rises again, and there is some light cloud cover for the rest of the day. On May 9, it looks sunny and cloudless all day, except for a small cloud at 7:00 AM. A radiation of 1,000 W/m<sup>2</sup> can be expected for this type of day, but it most effectively reaches 692 W/m<sup>2</sup>. These low values are very likely due to the presence of an overcast cloud or, more likely, smog.

Taking into account the solar energy potential of Kurdistan and based on the results of recent scientific research on the application of solar energy for building cooling purposes, the objective of the current study was developed. The goal is to evaluate the feasibility of using an air conditioning unit for cooling a residential building, powered by solar energy in the conditions of Iraqi Kurdistan. Such an assessment is required for the sustainable development of the region through the implementation and wider dissemination of these environmentally friendly systems. The decision on feasibility will follow from an analysis of such a system performance, possibilities to improve its operational characteristics in terms of energy consumption, as well as the cost of the environmental effect.

## METHODOLOGY

The simulation was carried out for a photovoltaic system to provide power to one air conditioner. The study location is Erbil city in Iraq (latitude: 36.1911 °N, longitude: 44.00917 °E). The home area of 28 m<sup>2</sup> is powered. The monthly climatic data were imported from the Meteorism software, which aggregates data from various sources including satellites and weather stations to generate accurate and comprehensive climatic information for any location worldwide.

### Overall system design

The study presents an example of a practical justification for the feasibility of using a photovoltaic system with a power input 940 (190–1270) W for power supply to a residential air conditioner. The main components are shown in Figure 1.

### Technical characteristics of PV

The photovoltaic system consists of three panels 144-cell Bifacial HJT Mono Half Cell PV Modules, specifically the HS-B144 DS455 model, with a power output of 440W each. These panels have an efficiency of 21.7%, operating at voltages up to 45.53V, with currents at maximum power around 10.15 A. The modules are designed to function optimally in temperature extremes ranging from -40 to + 85 °C and maintain a Nominal Operating Cell Temperature (NOCT) of 44 °C (± 2 °C). The system is robust, capable of withstanding system voltages of DC1500V

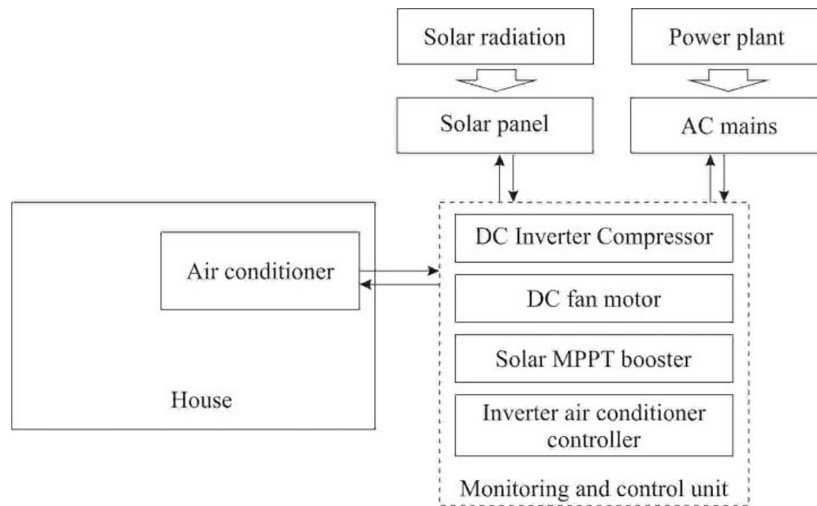


Figure 1. System schematic diagram

(IEC) and enduring mechanical loads like snow of 5400 Pa and wind of 2400 Pa. Certified with IEC61515, IEC61730 standards, the panels carry a 10-year product warranty and a 30 – year linear power output warranty, promising less than 12% degradation over three decades. The autonomous system includes a T1/T3 Hybrid ACDC Solar Air Conditioner with a 12000BTU capacity, capable of being powered directly from the PV modules. The air conditioner can run on DC power within the range of 80–380 V with a current of  $\leq 12$  A, supporting the direct utilization of solar energy. The unit is designed to operate with solar panels configured in series (3 panels of 440 W), making it highly suitable for the advised power supply

of 3510 W. The air conditioning unit features a high-performance rotary inverter compressor, has an Energy Efficiency Ratio (EER) of 3.75, and a coefficient of performance (COP) of 3.51. It operates with a highly efficient BLDC fan motor, with an indoor noise level at 42.5 dB(A) in turbo mode. Using R410A refrigerant and capable of handling a maximum design pressure of 4.3/1.5 MPa, the system is geared for efficiency and reliability. The integration of the solar panels and the air conditioning unit exemplifies a synergistic system that leverages solar tracking from north to south to enhance energy absorption, situated within the Erbil Governorate, Northern Iraq at coordinates 36° 11' 28" N, 44° 00' 33" E.

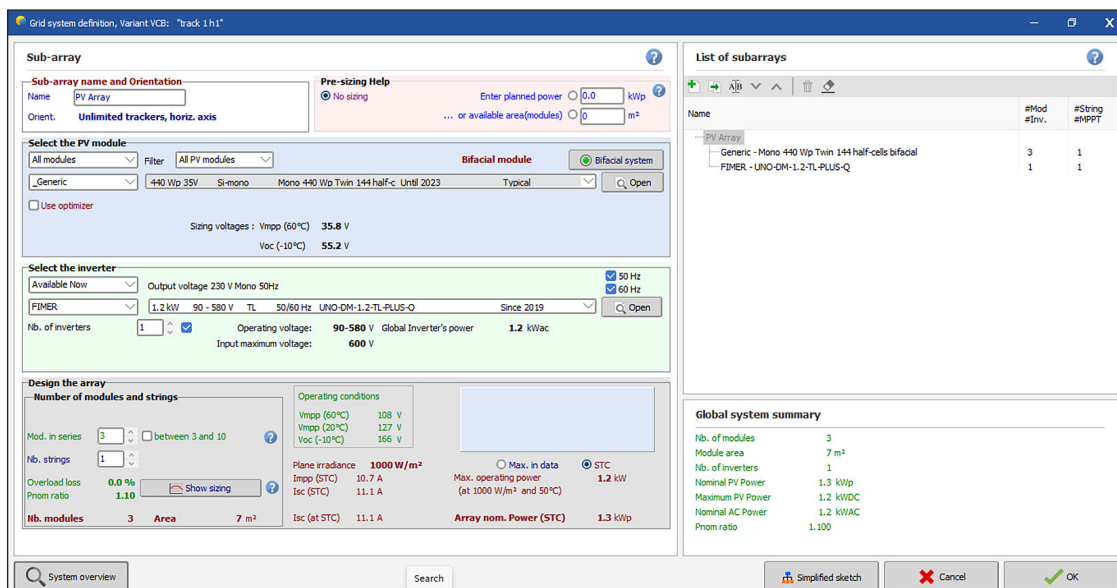


Figure 2. Interface PVsyst version 7.2. for data entry

## Simulation

The PVsyst software tool was used for modeling because it is characterized by great versatility in the field of modeling solar energy systems, high accuracy and flexibility in solving problems (González-Peña et al., 2021; Salmi et al., 2022; Milosavljević et al., 2022). PVsyst allows you to enter data on solar systems, photovoltaic modules and inverters under study into the software database, as well as import weather data, which makes this tool convenient for research in different time periods. The current study used a free trial version, namely PVsyst version 7.2. Data entry into the programmer is shown in Figure 2. The specified solar panel power (kW) was a constant parameter. Variable parameters were height of solar panels, albedo reflector, tracker system. In the current study, three simulations were performed in which the variable parameter was height and four simulations in which the variable parameter was the solar panel' angle. The height varied from 0.5 m to 2 m; the reflection rate for the simulation was assumed to be 0.4, 0.6, 0.8 and 0.95; a two-axis and one-axis tracker system was used. The height of solar panels above the ground can affect energy production due to changes in ambient conditions. For example, increasing height may improve airflow around solar modules, which helps cool the modules and increase their efficiency. Height may lead to a change in the distribution of solar radiation on the Earth's surface. There may be a decrease in radiation as elevation increases, which can negatively affect the productivity of solar modules. Reflection rate control is possible via changing the solar panel' angle. The importance of the solar PV system's tilt angle is to absorb maximum solar radiation (Ramanan et al., 2024). Using a tracker system allows solar modules to track the movement of the sun throughout the day. This means that the solar modules will benefit from the sun's radiation better and over a longer period. Depending on the orientation of the solar panels, a 20% to 40% increase in energy productivity can be achieved compared to a fixed system that does not track the sun (Lu, Ajay, 2024; Jahangiri et al., 2024). The choice of all variation intervals is justified by the cumulative experience of previous studies.

## RESULTS

The simulation results show that the system has a total PV generator power of 1320 W to power one device (air conditioner) with the power of 1170 W of electrical power.

Accordingly, the total annual energy production of the system will be equal to 2264 kWh. This number is calculated based on the solar radiation available in the Safin region of Iraq.

The term “specific throughput” is used to measure the performance of a system. According to the report, the system's power density is 1,715 kWh for every kilowatt-hour of solar installed on the system per year

This is an important figure for assessing the effectiveness of the system. Rated performance (PR) indicates the system's efficiency in converting solar radiation into electrical energy. According to calculated indicators, the system's coefficient of performance (COP) is 85.89%. A high efficiency value indicates that the system operates very efficiently. Figure 3 shows the loss graph in the system.

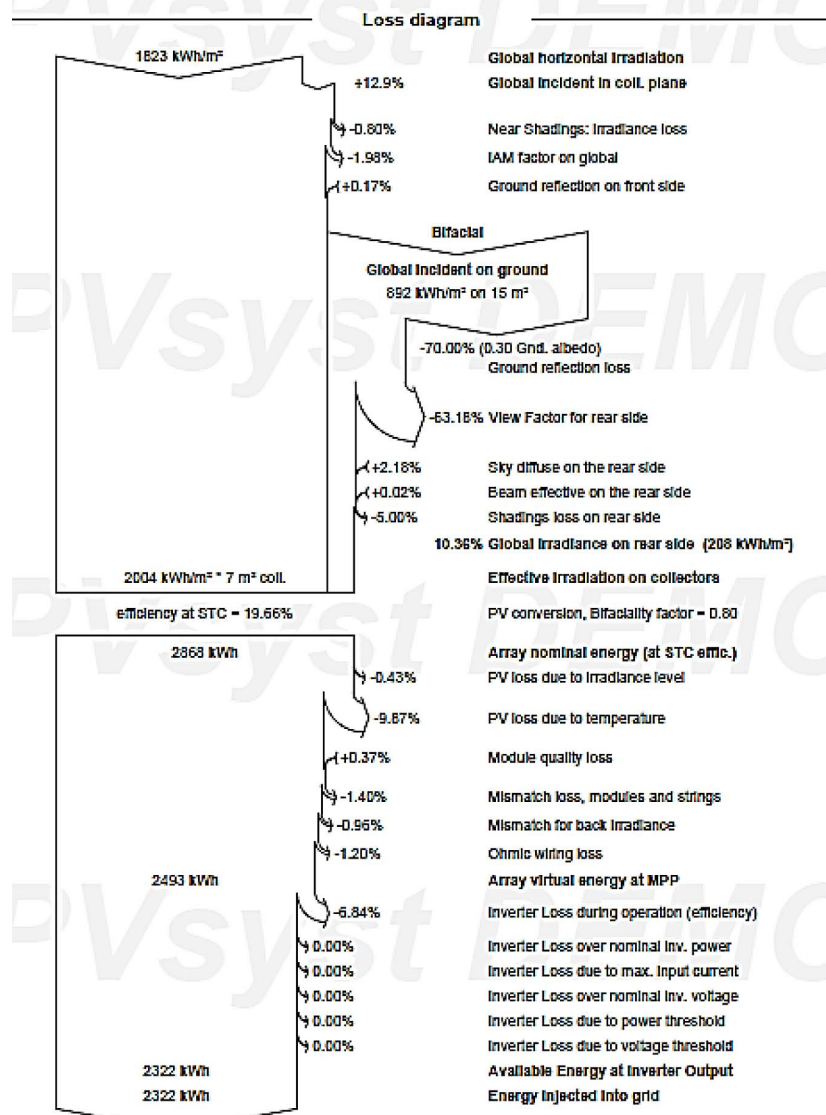
Losses are introduced in various parts of the system such as solar panels, wires and transformers. The most common losses are temperature losses from 5% to 15%, angular and spectral losses 0.5–7%, dirty and twilight 0.5–4.5%, mismatch 2–4% and others, which is consistent with the results of similar studies (Almonacid, et al., 2011; Adekanbi et al., 2023). The air conditioning system can be analyzed as presented in Table 1.

The peak radiation power is 1000 W/m<sup>2</sup> and the radiation height is 700 W/m<sup>2</sup>, but the best photovoltaic plant production is ready for 480 W for every day. Figure 4 shows the monthly output of PV panels taking into account solar radiation.

### Effect of height and location of the solar panels

Simulation results show that with increasing height, the amount of energy produced increases proportionately. Therefore, when the height of the units is 0.5 m, the system is able to produce 2264 kWh/y of energy, while the produced capacity increases to 2301 kWh/y when the height is 1.5 meters and reaches 2332 kWh/y when the height is 2 m. As shown in Figure 5, qualitatively, slight changes in the specific energy produced can be observed with increasing altitude. Therefore, the specific energy produced is 1715 kWh/y when the height is 0.5 m, increases to 1793 kWh/y when the height is 1.5 m, and then decreases slightly to 1767 kWh/y when the height is 2 m.

Similar observations have been reported in other scientific studies. Nnamchi et al. (2023) reported that solar panels are more likely to be



**Figure 3.** Solar panel power losses with installation at 1m height, 20° inclination, and 0° azimuth

Losses are introduced in various parts of the system such as solar panels, wires and transformers. The most common losses are temperature losses from 5% to 15%, angular and spectral losses 0.5–7%, dirty and twilight 0.5–4.5%, mismatch 2–4% and others, which is consistent with the results of similar studies (Almonacid, et al., 2011; Adekanbi et al., 2023). The air conditioning system can be analyzed as presented in Table 1.

effective at higher altitudes because solar radiation increases with altitude in the atmosphere and atmospheric temperature decreases with increasing wind speed, causing solar panels to cool rapidly. Similarly, it was stated by Ramanan et al. (2024), which with increasing height of the PV system is provided by the additional cooling effect of the solar panel along with the wind flow.

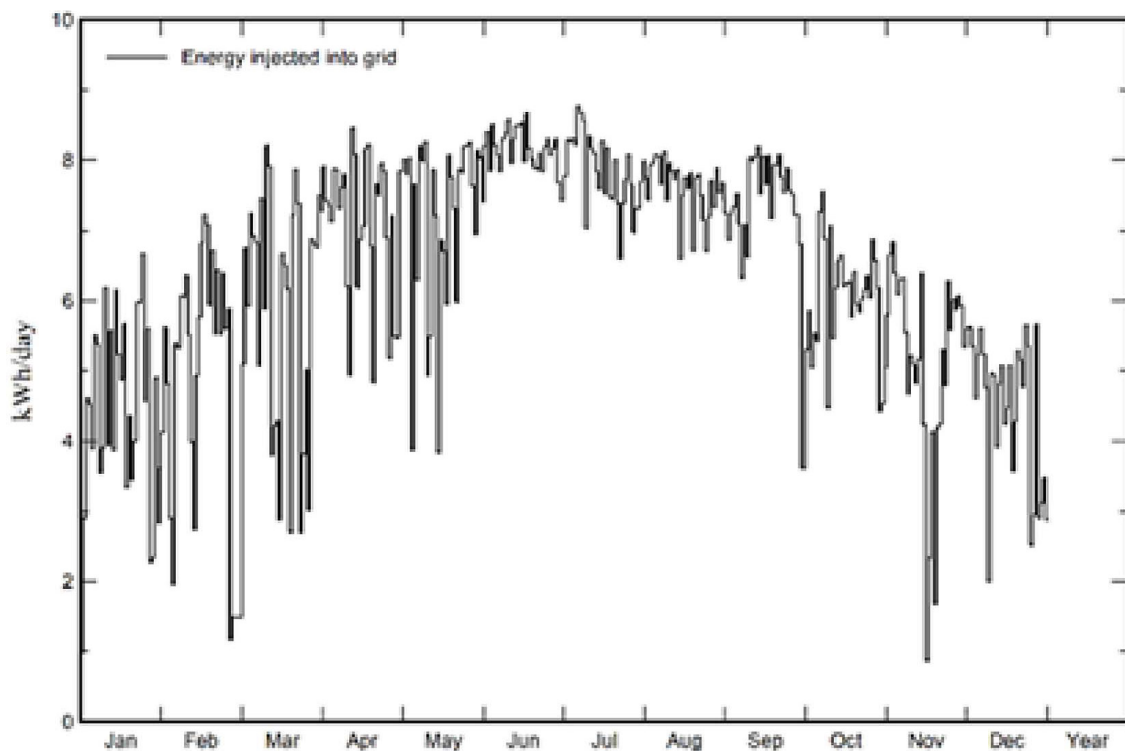
However, the final choice of height for installing solar panels should be justified by technical and technological research, taking into account the meteorological characteristics of the region, since the wind load can be quite powerful and contribute to regular system breakdowns.

The ground-level solar radiation falls on the solar modules. When you have a high reflectance value (0.95), it can increase the amount of radiation received from the solar modules, resulting in an increase in energy yield. However, when you have a low albedo value (0.4), the amount of radiation received by the solar modules will be less, and thus energy productivity decreases. The reported results for changing the reflectance rate show that increasing the reflectance ratio leads to an increase in the total power produced. Therefore, when the reflection rate is 0.4, the system produces 2375 kwh/y of energy, and the energy produced increases to 2479 kwh/y when the

**Table 1.** Accumulated energies for the measured year with panel installation at 1 m height, 20° inclination, and 0° azimuth

Month	GlobHor (kWh/m <sup>2</sup> )	T-Amb (°C)	GlobInc (kWh/m <sup>2</sup> )	GlobEff (kWh/m <sup>2</sup> )	EArray (kWh)	E_Grid (kWh)	PR ratio
January	80.2	7.34	112.7	109.4	146.8	136.7	0.919
February	92.6	8.9	118	114.9	154.1	143.3	0.921
March	133.1	13.13	154.3	150	196.5	182.7	0.897
April	170.6	17.28	183	178	228.6	213.2	0.882
May	195.9	24.13	197.4	191.9	239.6	222.6	0.855
June	229.9	30.76	225.4	219.9	263.2	244.9	0.823
July	229.9	34.94	228.6	222.8	261.1	243	0.805
August	210.6	34.07	222.1	216.7	252.4	235.5	0.803
September	178.2	28.72	204.9	199.9	237.2	221.2	0.818
October	130	22.74	163.6	159.6	199.1	186.2	0.862
November	93.2	14.08	131.1	127.5	165.3	154.1	0.891
December	78.5	9.2	115.9	112.9	149	139.1	0.909
Year	1822.6	20.51	2057	2003.6	2493	2323.2	0.855

**Note:** GlobHor – global horizontal irradiation; T\_Amb – ambient temperature; GlobInc – global incident in coll. plane; GlobEff – effective global, corr. for IAM and shadings; EArray – effective energy at the output of the array; E\_Grid – energy injected into grid; PR – performance ratio



**Figure 4.** Output power of photovoltaic modules with panel installation at 1 m height, 20° inclination, and 0° azimuth

reflection rate is 0.6, reaches 2582 kWh/y when the reflection rate is 0.8, and reaches 2659 kWh/y when the reflection rate is 0.95. As in Figure 6, qualitatively, a gradual increase in the specific energy produced can be observed with an increasing reflection ratio. For example, the specific

energy produced is 1799 kWh/y when the reflection rate is 0.4, increases to 1878 kWh/y when the reflection rate is 0.6, reaches 1956 kWh/y when the reflection rate is 0.8, and then reaches 2015 kWh/y when the reflection rate is 0.95. A gradual increase in efficiency can be seen as the reversal

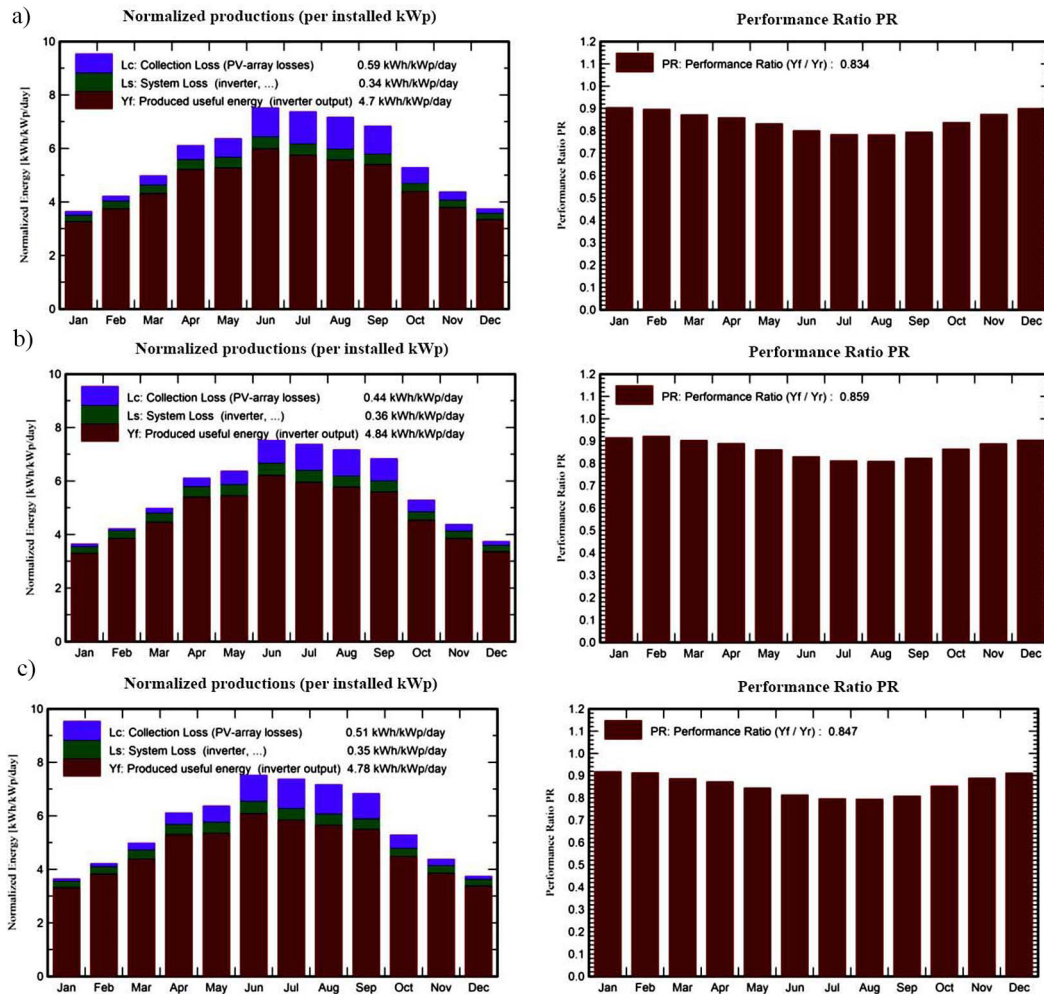


Figure 5. The influence of panel height on their performance: a – height 0.5 m; b – 1.5 m; c – 2 m

rate increases. For example, the performance efficiency is 87.46% when the reflection rate is 0.4, increases to 91.30% when the reflection rate is 0.6, reaches 95.11% when the reflection rate is 0.8, and reaches 97.95% when the reflection rate is 0.95.

### Possible effects of the tracker system

A two-axis and one-axis tracker system was used. Using a tracker system allows solar modules to track the movement of the sun throughout the day. This means that the solar modules will benefit from the sun's radiation better and over a longer period. Depending on the orientation of the solar panels, a 20% to 40% increase in energy productivity can be achieved compared to a fixed system that does not track the sun. When the tracker is changed from one axis to another, an increase in the power produced appears. Therefore, when the tracker is shifted from one axis,

2383 units of energy are produced. When changing the tracker from two axes, 2978 kWh/y of energy are produced, as shown in Figure 7. The actual energy is achieved based on the efficiency of the system and the energy produced. The results show that the actual power is less than the power produced if the tracker is changed from one axis to two axis. Therefore, when changing the tracker from one axis, 1805 kWh/y of actual power are achieved, and when changing the tracker from two axis, 2256 kWh/y of actual power are achieved. Performance efficiency can be calculated based on the actual power and the power produced. The results show that the performance efficiency when changing the tracker from one axis to two axis is generally similar. If the tracker is changed from one axis, the performance efficiency is 80.44%, and if the tracker is changed from two axes, the performance efficiency is 80.39%. From the mentioned results, it can be concluded that changing the tracker from a single axis leads



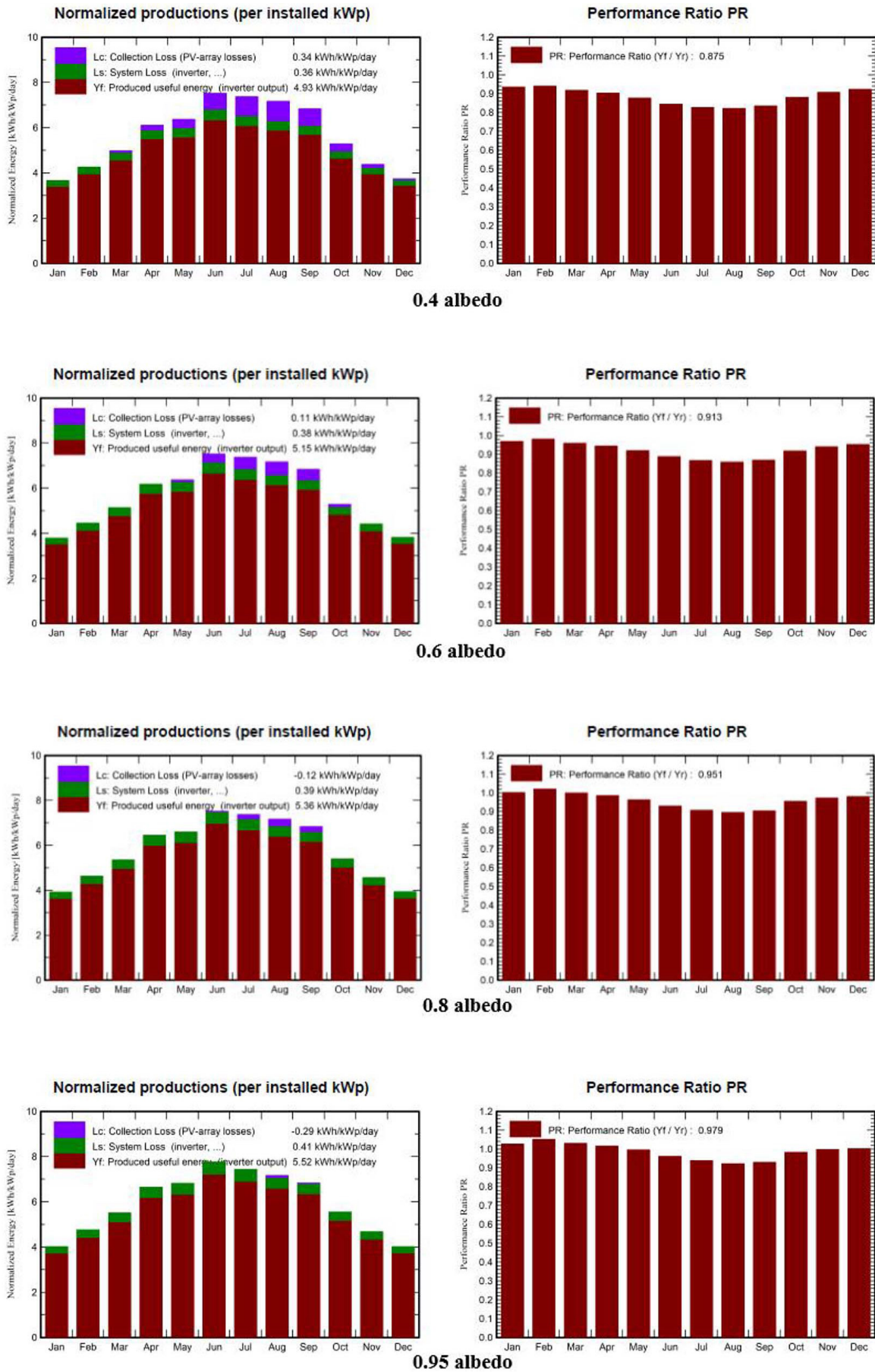


Figure 6. The specific energy produced depending of reflection ratio

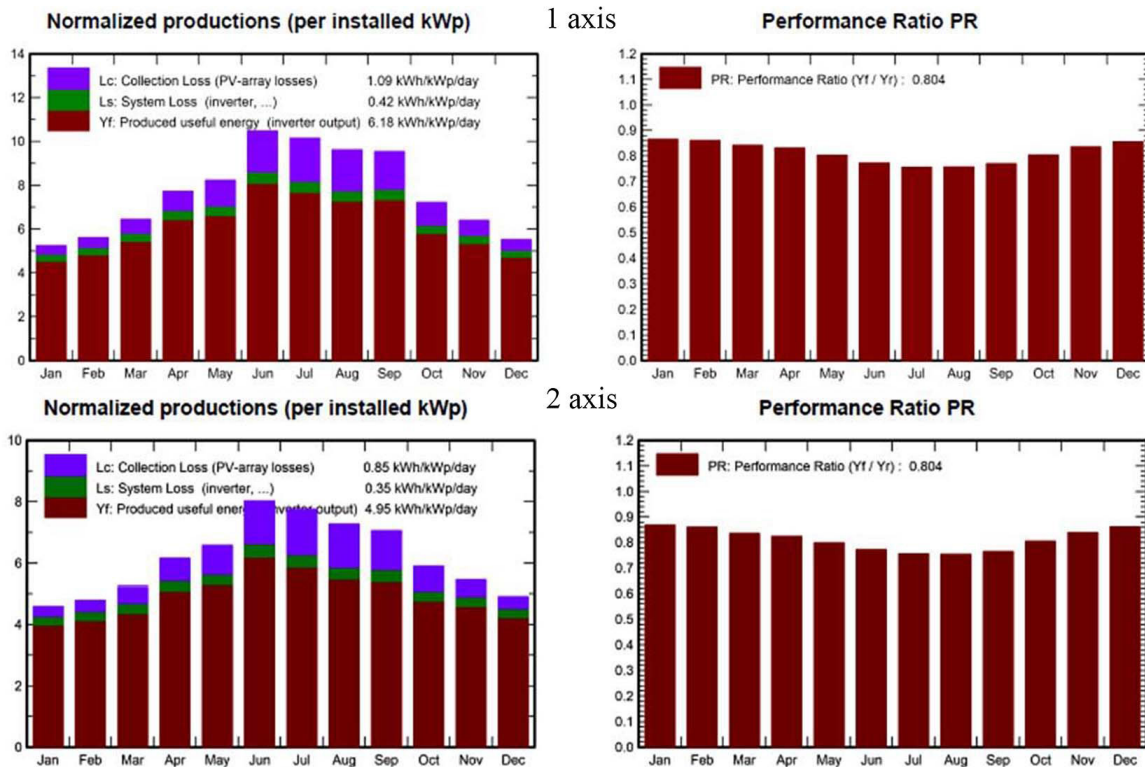


Figure 7. The effect of the tracker on the energy produced by 1, 2 axes

to a slight increase in the produced power and actual power, and the performance efficiency is stable. When changing the tracker from two axes, there is a greater increase in the produced power and the actual power, and the performance efficiency is stable. Figure 7 shows the solar energy data for a solar system. The data covers a period from January 1 to December 31. The horizontal axis shows the months of the year. The months start with January on the left and end with December on the right. The vertical axis shows three measurements: panel temperature, in red; effective radiation, in blue; and energy produced daily, in green. Panel temperatures range between 20 °C and 80 °C. Highest temperatures: July (80 °C) August (70 °C) June (60 °C), lowest temperatures December (20 °C) January (20 °C) February (30 °C), daily energy production ranges between 0 and 10 kWh. July (10 kWh per day) August (9 kWh per day) June (8 kWh per day) Lowest production December (2 kWh per day) January (2 kWh per day) February (3 kWh per day) From the results, we conclude that there is a relationship between panel temperatures and effective radiation. The data shows an inverse relationship between panel temperatures and effective radiation. At high temperatures with high radiation, the energy is low. A detailed study of research reports developed by

PVsyst software shows the highest energy production and energy transferred to the grid from June to August. In other months, the energy received is significantly lower. These results are fully explained by climatic features, since according to statistics percentage of sunny (cloudy) daylight hours from June to September 80% (20%) – 86% (14%), while from December to February 62% (38%) – 67%(33%) (<https://www.climate.top/iraq/baghdad/sunlight/#:~:text=There%20is%20an%20average%20of,above%20the%20horizon%20at%20Baghdad>). As found in the study (Damm et al., 1995), with a decrease in illumination, power losses in photovoltaic arrays and photovoltaic chains increase, which are associated with changes in the current-voltage characteristics of photovoltaic modules. As was previously established, GHG emissions ranging from 266.9 to 586.2 kg CO<sub>2</sub> per 1 MWh of natural gas (Kazulis et al., 2018). Thus, with the lowest calculated values (of all the options under study) the energy produced is 2264 kW/h/year or 2.264 MW/h/year (month - January, panel installation height – 0.5 m, inclination – 20°, azimuth – 0°), greenhouse gas emissions of at least 604.3 kg CO<sub>2</sub> per year are eliminated. At the same time, an additional measure to increase the efficiency of using a solar panel to power an air conditioner

is to place reflective material in which the reflection rate or reflection coefficient is different under the solar panels.

### Economic evaluation

A cost analysis of the proposed grid-connected systems has calculated, including the total investment, payback period and levelized costs. Results for 10 kW PV systems are presented for both existing air conditioners with a COP of 3.5. Since it is not entirely clear whether feed will be paid into the tariff or not, this economic evaluation is calculated with and without feed in the tariff. The feed in the tariff not affected by inflation because it is a fixed rate. PV modules from HUASUN manufactured in China are used, and the feed-in tariff assumed 0.12 USD/kWh. The tariff converted to 156 IQD per kWh. The project is supposed to be 25 years old. To calculate the economic feasibility of the system you describe, you must determine the expected costs and returns over a 25 – year period. Here is the information you need:

- Initial costs:
  - o Cost of 3 solar panels:  $3 \times 180\$ = 540\$$
  - o The cost of the air conditioner: 675\$
  - o Cost of baseboards: 300\$
  - o Installation cost: 100\$
  - o Total initial cost:  $540 + 675 + 300 + 100 = 1615\$$
- Annual costs:
 

System maintenance and operation: can estimated at 2% of the initial total cost. Therefore,  $0.02 \times 1615 = 32.3\$$  per year. The daily consumption of the system is 300 watts. We can calculate the expected annual return as follows:

  - o Annual electricity consumption = capacity  $\times$  number of hours per day  $\times$  number of days per year
  - o Annual electricity consumption =  $300 \text{ watts} \times 24 \text{ hours} \times 365 \text{ days} = 2,628,000 \text{ Wh}$ .
  - o To calculate the annual financial savings, you must take the cost of electricity and multiply it by the amount of annual electricity consumed:
  - o Annual financial savings = annual electricity consumption  $\times$  electricity tariff
  - o Annual financial savings =  $2,628,000 \text{ watt-hours} \times 0.12 \text{ \$/Wh} = 315360 \text{ \$}$
  - o Now we can use the previously calculated values to calculate the net return and payback period for the initial investment cost. If the total initial cost of the system

is 1,615 \$ and the annual financial savings are 315,360 \$ (according to previous calculations), the annual net return can be calculated as follows:

- o Annual net return = annual financial savings – annual cost
- o Annual net revenue =  $315,360 \text{ \$} - 32.3 \text{ \$}$  (annual maintenance and operating costs)

Figure 8 The graph shows upfront costs of investment throughout the life of a project with a feed-in tariff against different financial performance without photovoltaic (PV) panels, an 8 kW system and a 10 kW system. The pay-back period for PVs can be determined from the intersections of these two lines with no PV system – where cumulative costs for PV systems become equal to those without it, showing when they start generating economic returns compared to non-PV setup. In case of an 8 kilowatt power rating this happens just before five years while in case of ten kilowatts it occurs slightly after five years.

### DISCUSSION

As mentioned previously, one of the main motivations for conducting this study was to examine the interaction between PV energy production and air conditioning use. When comparing PV energy production throughout the day with working hours (07:30–17:30), the values were found to be very similar. An average of 3.5 kWh was produced throughout the day, and an average of 3.3 kWh was produced during working hours. Only 0.2 kWh was produced outside of working hours, meaning that almost all of the electricity produced is available during working hours. This is useful in countries without high feed-in tariffs where only a small feed into the grid is needed. The backup network in this system has two main functions. The first function is to supply power to the air conditioner when the PV power output is low. The backup network uses an average of 20% of the air conditioner’s consumption, and most of it is used in the last two hours of the day when radiation is low. To reduce dependence on the grid, the PV panels need to be large, but from 15:00 onwards, the radiation on the panels is less than 300 W/m<sup>2</sup> and decreases rapidly. If the air conditioner is operated during this time using PV energy, it will greatly increase the size of the system unless batteries are used to store excess energy during

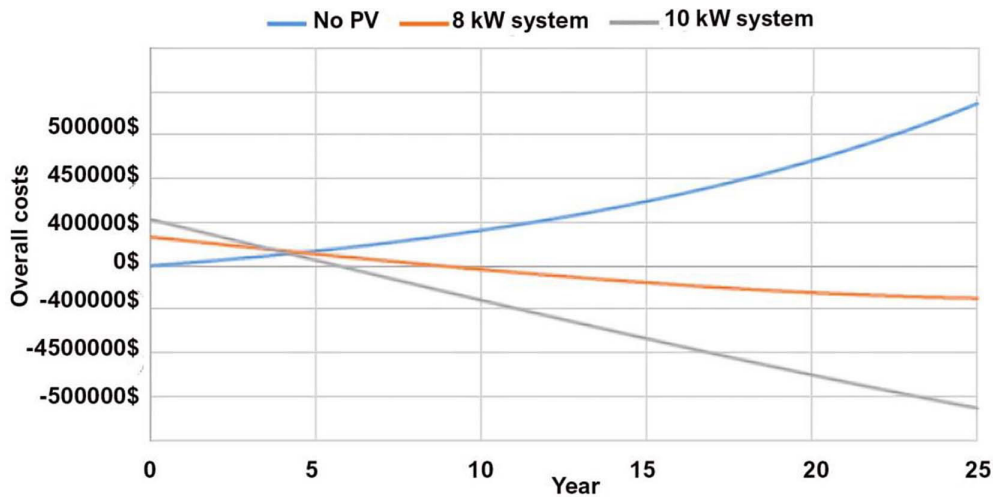


Figure 8. Overall costs of the project

the day. However, as mentioned earlier, this is an expensive solution. A second use for off-grid backup is to run the air conditioner during startup; this eliminates the need to upsize the inverter as would be required in an off-grid system. By using grid backup, you do not rely on the energy stored in the batteries while starting the air conditioner, which reduces the need for large batteries in the PV system. In general, it can be said that using PV energy to power air conditioners can be possible and effective in certain situations. However, there are several factors to consider, such as the size of the PV system, the amount of energy produced, the energy consumption requirements of the air conditioners, the cost of equipment and installation, the cost of maintenance, and the cost of battery storage if necessary.

As the results showed, this approach to cooling the air in domestic premises has a tangible environmental effect in the form of preventing the emission of greenhouse gases. So, in the future, it will be beneficial to develop smart control technologies to improve performance and evaluate the impact of a solar air conditioning system on environmental sustainability and emission reduction.

## CONCLUSIONS

Solar cooling technology is a sustainable and efficient air conditioning solution in the Kurdistan Region, providing tangible environmental and economic benefits. However, this technology faces challenges related to climatic, technological, and economic conditions, and its adoption requires good planning and appropriate guidance.

In this research, a solar-powered air conditioning system simulated using PVsyst, where the variable parameters were the height of the panel above the ground, the reflectance and the axis tracker was changed from one axis to two. All of these parameters significantly affected the efficiency of the system.

Based on the results obtained, discussions and conclusions, it should be noted that the solar panel provides approximately 80% of the air conditioner with electricity (that is, the backup network is used by 20%). Even at the lowest energy output, that is, under the most unfavorable conditions, using solar energy for one air conditioner can prevent approximately 604.3 kg of CO<sub>2</sub> emissions per year.

The use of the tracking system allows you to increase the efficiency of energy production. The tracking system allows solar modules to track the movement of the sun throughout the day, which means that the solar modules will benefit from the sun's radiation better and over a longer period. The results showed that using a tracking system leads to an increase in the energy produced by between 20% and 40% compared to a fixed system that does not track the movement of the sun. Also, when changing the tracking system from single axis to two axis, an increase in power output of up to about 10% is seen solar panel technology is constantly evolving, and new features are added to enhance their efficiency and increase their productivity. Many studies are being conducted to improve the performance of solar panels and use them more effectively in renewable energy production. Considering that the system is high-tech, its cost is correspondingly high, the payback period

in the case of a nominal power of 8 kW is shortly before five years, and in the case of 10 kW – after five years. Therefore, financial motivation of the population is an important component for its widespread use. All of the above indicates the feasibility of using such systems and their further development. Although at present, the promotion and implementation of solar energy to ensure the operation of air conditioners in warm countries should have significant support from government agencies in the form of financial motivation.

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