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ORIGINAL RESEARCH

Design and feasibility study of an on-grid photovoltaic system for green electrification of hotels: a case study of Cedars hotel in Jordan

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Abstract
This paper presents a feasibility study of utilizing an on-grid photovoltaic (PV) system for electrification of Cedars hotel located in Amman in Jordan as a case study. The PV system has been designed, keeping in view the required electrical load and energy available from the sun in Jordan. The actual energy consumption of the hotel is estimated (444 MWh/year) for the design and simulation of the on-grid PV system using Photovoltaic Geographical Information System software (PVGIS) and photovoltaic software (PVsyst). The results showed that PV system required 912 panels distributed over 12 inverters, with a required area of 1757.3 m^2. In addition, the on-grid PV system produced a total yearly energy of 541 MWh, with an average performance ratio of 0.828. The economic study for the proposed PV system showed that the system's payback period was 4.1 year. Moreover, life cycle savings (LCS) and levelized cost of energy (LCOE) analysis have been carried out. The LCS and LCOE of the system were found to be $51,493 and $0.0199 /kWh, respectively. Therefore, installing a proposed on-grid PV system on the Cedars hotel will save $38,718/year. It is concluded that an on-grid PV system is a technically and economically viable technology for the electrification of residential hotel applications.

Keywords Renewable energy · Solar energy · Photovoltaic · PVGIS · PVsyst

Introduction

Most of the consumed energy in Jordan is generated by fossil fuels, while the future government plans to make Jordan more independent and green. Moreover, solar energy is well accepted in Jordan as a good energy source and an outstanding for the generation of electricity by private individuals. The dramatically increased fossil fuel prices lead to a higher utility tariff cost and conventional electricity production cost. This encourages the trend toward a need for using sustainable energy as a good alternative [1–3]. Moreover, the benefit of alternative energy is not only for compensating the shortage and expense of fossil fuel sources, but other important reasons become behind using clean, renewable energy and its effect on the environment. Scientists have imputed climate change mainly due to the increasing concentration of greenhouse gas (GHG) emissions resulting from fossil fuels' combustion [4]. Therefore, improving renewable energy technologies and regulations has been taken great attention around the world [5, 6]. As a result, several efforts have been executed to increase energy efficiency and integrate renewable energy sources to accomplish zero or near-zero yearly consumption of energy buildings [7–9]. These efforts have been shown in various prosperous projects in buildings worldwide, such as the Mongkok hotel in Hong Kong [10], Nusa Lembongan hotel [11], a residential building in Cyprus [12] and a small-sized industrial enterprise in Algeria [13].

The 39% of whole energy used and 33% of GHG in the world correspond to buildings [14]. One of the most

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energy-consuming buildings is tourist hotels, where its energy demands range from 250 to 350 kWh/m^2 [5, 15, 16]. The tourism sector has a substantial contribution to the country's gross domestic product (GDP) and presents an important source of income. In fact, the income of tourism worldwide reaches 1400 billion dollars, representing 9% of the world's GDP [17]. In Jordan, tourism represents 11.4% of GDP and generates fifty five thousand jobs [18]. Tourist hotel buildings have a vital impact on the tourism industry, making it one of the critical fields to manage their energy consumption and reduce GHGs emissions [19]. Jordan, as a non-oil-producing country, imports around 96% of its energy demand. In 2019, primary energy demand imports acquired 8.5% of the country's GDP, with an energy bill of 3.4 billion dollars. Electricity generation consumed 39% of total fuel consumption. Energy demand is a significant burden on the country's economy and a considerable impediment to achieve socioeconomic growth along with long-term sustainable development that Jordan targets [20, 21]. The high population growth rate and urbanization and influx of refugees, especially in recent years, have led to a rise in electricity demand [22]. This will put more pressure on a country's economy and infrastructure.

Besides that, Jordan has a great potential for solar energy sources; it enjoys more than 300 sunny days and high Global Horizontal Irradiation (GHI) range from 4 to 6.5 kWh/(m^2 day). It distributed with the highest level at the southern [6 to 6.5 kWh/(m^2 day)] then decline gradually with moving up to the north [5 to 5.5 kWh/(m^2.day)] while the lower level was shown in Western [4 to 4.5 kWh/(m^2 day)] [23]. This high solar radiation level urges reliance on solar energy in a country target and increased its local energy dependency as a priority.

The on-grid PV system is defined as a solar system that converts solar into electricity. It has no moving parts during the converting process. It has three main parts: PV array, the balance of system and AC loads. A PV array is produced from a combination of PV modules to boost up electrical power [24]. The balance of the system converts the DC current into AC current. There are three types of PV systems: off-grid, on-grid or hybrid. Off-grid systems fully self-contained with no reliance on the electrical grid. A hybrid system uses both backup batteries and an on-grid PV system. In an on-grid PV system, the generated power goes directly into the electrical grid. The only elements that are common to all PV systems are the inverters and the solar panels themselves [25]. Some researchers [26–28] investigated the design and modification of the PV system for some power applications such as office appliances, refrigeration and water pumping. Other researchers have studied the techno-economic feasibility of utilizing PV systems in Jordan; they have not covered the case of a large-scale hotel yet; few investigations dealt with the PV are found in the literature. Al-salaymeh et al. [29] studied the feasibility of utilizing the off-grid PV solar cells in an apartment in Amman city and perform the system's economic analysis. The payback period of the on-grid PV system was about 30 year. It was concluded that implementing an off-grid PV system to supply the residential flat in Jordan is not cost-effective due to the high cost of installing the system in that time in 2010. Additionally, the authors found that a feed-in tariff law of solar electricity would reduce the payback period. Another research concentrates on a vital sector, which is street lighting [30]. This essential sector represents 2% of annual electricity consumption in Jordan. The work has introduced a feasibility study for the installation of solar-powered light-emitting diode (LEDs) for street lighting. The results showed that the payback period equal to 3.2 year for solar-powered LED. In another study, a PV system was used to cover the University of Jordan's energy demand [31]. This study investigated different technical solutions of the on-grid solar PV system with an estimated area of 150 thousand square meters, with a capacity of 15 MW. The results demonstrated that the suggested PV system provided a 32% internal rate of return (IRR) with three years payback period. The use of solar energy was successfully used to cover the energy consumption of water pumping in different areas in Jordan [32].

Various software has been established for computation and simulating the energy application, especially in the renewable energy industry. The PV Geographical Information System (PVGIS) and PVsyst have widely used to simulate and design the PV system's energy production [33–37]. Haydaroglu and Gumus [38] evaluated the energy production performance of PVGIS software by comparing its simulated results with actual results of Dicle University (Turkey) Solar Power Plant. They indicated that the PVGIS simulation foretold 5% less energy generation than the exact production amount. Another study assessed the potential of PV to produce energy in Odisha, India. The PVGIS software was used to create rasterized maps of the solar energy potential, helping the PV projects designer and policy-making for the state [39]. Barua, Prasath and Boruah [40] used PVsyst software to simulate the rooftop PV system's energy performance for an academic campus. The output results showed that PV system produces 590 MWh annually and reduces 42 tons of carbon dioxide emission. The load required in engineering college Bikaner in India has been designed and simulated used PVsyst software. Also, the PVsyst has been used to analyze the performance ratio (PR) and loss of the system [41]. Belmahdi and Bouardi [42] investigated the best location in north Morocco to install 1 MWh PV system. The comparison between sites was conducted based on the PR, losses and energy production of the system using PVsyst software. In another study, Kumar et al. [43] adopted PVsyst software to analyze the performance and feasibility of installing a 100 kWp PV system in an educational institute. The simulation results indicated that the PV system generates 166 MWh per year, with an annual PR of 80%.

In this paper, an on-grid PV system for an under-construction hotel in Amman, Jordan, is designed using simulation software of PVGIS and PVsyst. The expected hotel's energy profile was determined by identifying its application and determining the consumption rate. The PR and the potential losses of the system are determined. Also, the economic viability of the project has been investigated, including payback period, life cycle savings (LCS) and levelized cost of energy (LCOE). In this study, all PV arrays were drawn using AutoCAD software. The overall purpose is to enhance understanding of PV systems' usage in electrification of residential hotel applications by addressing a case study highlighting the potential and the advantages of using solar energy in this sector.

PVGIS software

Photovoltaic Geographical Information System (PVGIS) is open-source online software for energy calculation of photovoltaic for both on-grid and off-grid PV systems and plants. It is supported in Europe, Africa, America and Asia. It is the proper tool to measure the solar electricity generation of a PV system, and it gives the annual output power of solar PV panels. Also, it uses the Google Maps application to assign the geographical information that makes it easy to use [44]. This software has ability to calculate the energy yield monthly or yearly. Furthermore, it provides the user with free maps of radiation for various areas worldwide. The data processing approach relies on the solar radiation model and the interpolation executed within the open-access GIS software Geographical Resources Analysis Support System (GRASS). PVGIS is a simple and straightforward web-based computation tool that uses an extensive database and maps with many forms. The maps include recent data on annual solar irradiation for flat and sloping surfaces based on the location and country, latitude and longitude. Also, PVGIS has a large and detailed database over a period of time and provides the parameters and information applied for the calculations [45]. The web-based tool includes a data interface where the user provides the required information about the project to measure the energy generation of a PV installation. The output results can be exported as a pdf or web page. Also, the PVGIS enables the user to upload hourly consumption information to forecast daily and monthly radiation, helping determine the yield of the photovoltaic installations system. Although PVGIS produces a full year (12 months) solar irradiance and electricity generation graphs, it does not provide any economic projections of PV system's energy yield [46, 47].

PVsyst software

PVsyst is PC software for PV frameworks produced by the University of Geneva. It combines practicality, accounting and support for whole PV frameworks. PVsyst is among the most used solar simulation software for energy yield estimation and the optimal solar power plant design. PVsyst uses the comprehensive knowledge of PV technology, meteorological irradiation resources data and PV system components. PVsyst is a product set that allows the users to appropriate a comprehensive examination and analysis of a PV venture. PVsyst includes a reenactment of a PV framework with an evaluation of its achievability, estimating and feasibility, regardless of whether it is an on-grid, standalone (off-grid) or DC matrix framework. This software is considered the most important among the software that was used in the PV system simulation process. It can calculate all the required values on both standard test conditions (STC) and normal operating cell temperature (NOCT), giving very accurate numbers that can determine whether to develop the project. PVsyst requests the peak power of the system, location, the panels and inverters types. Also, several types of loss parameters related to the PV system should be identified according to system specification, like wiring loss, shading loss, temperature loss, module quality, inverter behavior and module array loss. The primary simulation outcomes are the total energy production (MWh), specific energy in kilowatt-hours per kilowatts peak (kWh/kWp), PR and the loss diagram that describes the energy balance and features of whole losses in the system [35, 48].

Studied area overview

The Cedars hotel is an under-construction hotel near the Queen Alia International Air- port (QAIA) Amman, Jordan (31.7631° N, 35.9399° E). Figure 1 illustrates the exact location of the Cedars hotel.

The hotel complex will be split across three buildings, one of which will primarily be used for rooms and the others for suites. The first building (I) will have a reception hall and 12 suites, three of which will have one bathroom, and nine will have two bathrooms. The second building (II) will have a celebration hall and 60 rooms, including double and single rooms. Furthermore, there will be two ballrooms on separate floors, which will be available for events. The last building (III) provides a luxurious restaurant. Figure 2 presents the layout drawing of the three buildings using AutoCAD software.

The geographical location and the weather conditions provide Jordan with a massive potential for renewable energies. Jordan's government has taken measures and defined the first suitable legal conditions to support the expansion

Fig. 1 Cedars hotel location near QAIA in Amman

and development of such energies. There is an excellent potential for solar energy in Jordan through global solar irradiation of a total annual value of 1600–2300 kWh/m^2 year [49]. PV is an optimal way for a private person or company, such as the Cedars hotel, to generate their electricity. In addition to the net metering, a service enables surplus electricity to be added to the transmission network. Figure 3 shows the average number of sun hours per month in Jordan [51]. The total sun hours will be 1088.5 per year month in Jordan.

A change in the stagnation intensity can be seen over the year, but the level of radiation is sufficient for PV applications. Figure 4 resembles the temperature throughout the year around the hotel area. The ambient temperature does not get below 0 °C. However, the hotel still needs significant heating in the winter months since 20 °C to 21 °C is the optimum temperature for more than 90% of people during that time. Figure 5 shows the solar irradiation distributed across Jordan for a year. The global solar irradiation in the middle region (30.5–32.0°N, 35.50–36.50°E) is 4.5 kWh/m^2 per day. This makes Amman city with a latitude of 31.96°N and longitude of 35.93°E to a perfect location, and the perfect orientation would be with a tilt angle of 32° facing south [49].

For the Cedars hotel, PV system is an optimal energy source due to geography. The hotel complex has high energy consumption, especially in the summer months, due to a high number of tourists and the associated use of air conditioning (AC). In summer, the AC requirements and the output of PV system coincide peak during the day. Additionally, the feed-in tariff system in Jordan supports the PV system and is an essential factor from an economic point of view for a hotel. The feed-in tariff system encourages private individuals or small- to medium-sized companies to reduce

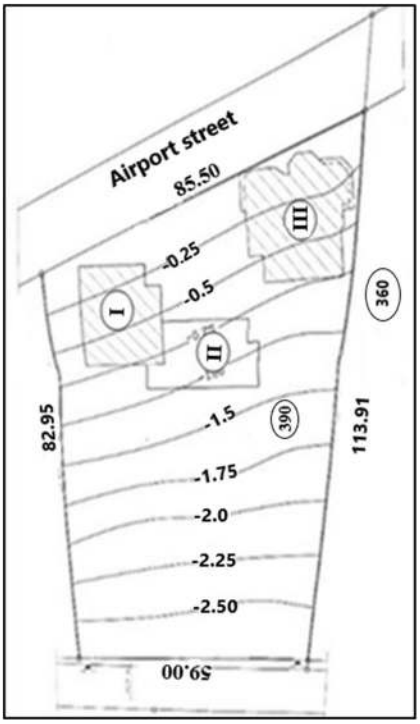


Fig. 2 Cedars hotel buildings

their monthly electricity costs by 32% to 70%. According to an Electricity Regulatory Commission (ERC) study, individuals with a PV system producing between 300 and 500 kWh electricity per month can reduce monthly electricity costs by more than 70%. With a consumption of 750 kWh and 1000 kWh, a monthly savings of 32% can be achieved [29]. For the reasons mentioned above, a PV is a suitable and long-term energy source for Cedars hotel.

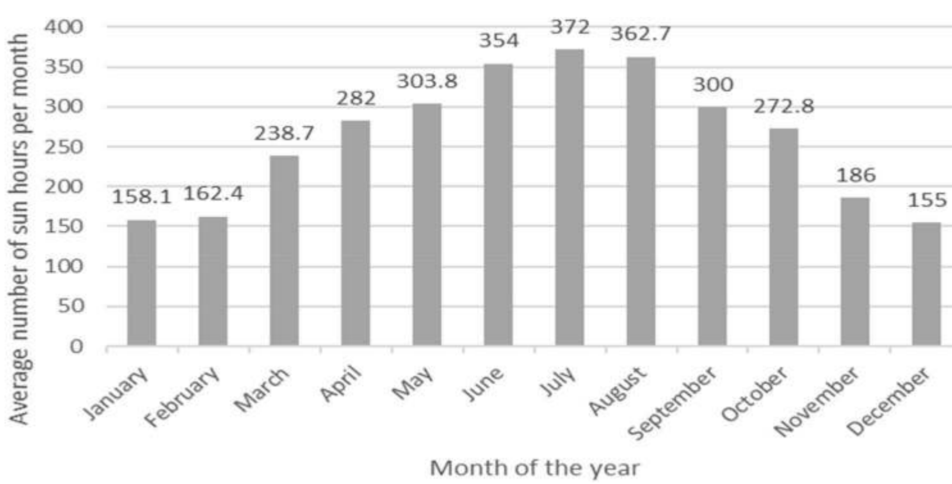
Electrical load estimation of the hotel

The electrical load for the individual units in the hotel can be estimated by determining the consumption of each hotel unites based on its plug load (appliances and its electrical specification) and occupancy density. The hotel units consist of a single/double bedroom, one-bedroom suite, two-bedroom suite, restaurant, reception, corridors and other consumptions, including the staff lounges, the washrooms and water pumps alien and parking areas.

For example, the load can be estimated in detail for single and double bedrooms. The hotel has 60 single and double rooms. The rooms are equal and differ from each other by the size of the beds. The sleeping area is 16 m^2 and the bathroom is 4 m^2, which gives a total area of 20 m^2. The single room is equipped with a refrigerator, television, hair dryer, electric kettle, iron, microwave oven and water heater. The lighting was divided into large area lighting, which used ten spotlights, one lamp at the mirror and four standing lamps with shades. The energy consumption for each equipment located in the room was calculated according to its manufacturer's data sheets. The power is multiplied with the estimated working hours to get a daily consumption in kWh. The results are presented in Table 1.

It is clear that the consumption per day is 8.115 kWh, and for 60 rooms, the consumption will be 487 kWh per day. Based on one month (30 days), the total consumption is equal to 14,607 kWh. With similar calculations, the total monthly load consumptions for three single bedroom suites' and nine two-bedroom suites are 781.2 kWh and 2398 kWh, respectively. Moreover, the monthly load in restaurants and reception was estimated to be 2069.4 and 2166.6 kWh, respectively. Other load consumptions include the staff lounges, washrooms, washing machines and dries, and parking areas were also estimated to be 4620.6 kWh per month. The total AC consumptions for room areas, floors,

Fig. 3 Average number of sun hours per month in Jordan [50]



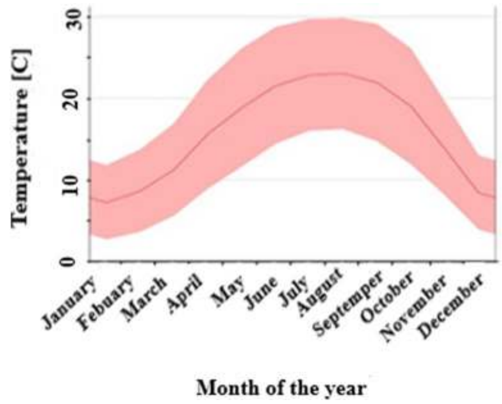


Fig. 4 Average temperature distribution around the hotel area

celebration hall, corridors, restaurant and reception were estimated to be 50,457 kWh per month. Table 2 presents the total estimated monthly load of the hotel (77,099 kWh).

The total load consumption was 77,099 kWh monthly (925 MWh yearly). This estimation is considered a maximum consumption, which was calculated based on using the hotel's full capacity. All rooms are fully occupied for 30 days, while the celebration hall is used for events and all suites are rented for the whole month. This situation is unlikely. Therefore, the maximum consumption of the hotel is not suitable for a simulation process and would falsify the further results. For this reason, the average of real consumption should be determined based on the maximum consumption, which will be used later in the simulation process, according to Eq. 1:

$$\text{Consumption ratio} = \frac{\text{Avg. consumption}}{\text{Max. consumption}} \tag{1}$$

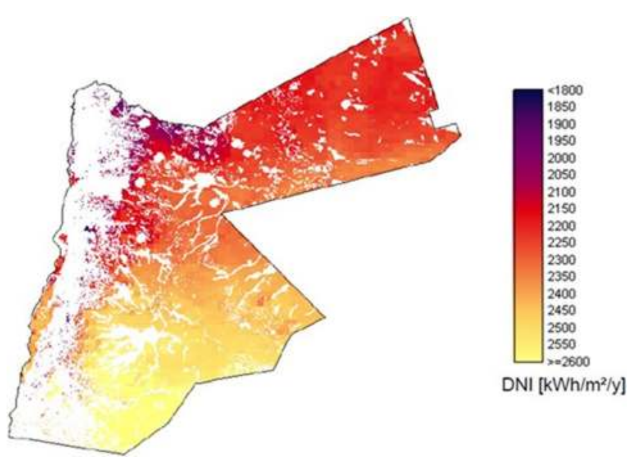


Fig. 5 Solar map of Jordan

In this case, the consumption ratio should be calculated based on other operating hotels similar in size and condition to Cedars hotel.

Okonkwo, Okwose and Abbasoglu [51] found that the real annual electrical load is 34.4 MWh for a typical hotel in Jordan. Therefore, the consumption ratio is around 0.43 based on the maximum electrical load (77.1 MWh) for Cedars hotels. In addition, Harir Palace Hotel, located in Amman, has similarities in capacity and load compared with Cedars hotel. According to the website of Harir Palace Hotel, the average used electrical load during the period of April 2017 to April 2018 was 55.0 MWh per month, with a consumption ratio of 0.54 [52]. In another longer estimation of the consumption ratio, the Jordan Ministry of Tourism and Antiquities reported occupancy of hotels in Jordan per year from 2010 to 2019, as shown in Table 3 [53]. The occupancy of hotels in 2020 was not considered for the reason of the Covid 19 pandemic.

The average occupancy rate of hotels in Amman 47.7% can be used for the case of Cedars hotel. Based on that, only 47.7% of the maximum electrical consumption is used. If the ratio is applied to the expected maximum consumption of Cedars hotel, the average real electrical consumption will be 36.8 MWh per month. Based on the above three consumption ratios, the average ratio 0.48 will be considered for the calculation of the electrical load of the Cedars hotel. In this case, the electrical consumption will be 37 MWh monthly (444 MWh yearly), which makes the electricity bill reach around JOD 3330 ($4690) per month and JOD 39,960 ($56,281) per year.

Design of the on-grid PV system

The PV system design, in terms of its elements, safety, calculations and orientation, will be covered in this section. This step comes after the calculation of the real electrical load step. This means that the PV system should produce an average of 37 MWh per month. The flow diagram of the on-grid solar PV system used in this work is shown in Fig. 6. It consists of three parts; PV arrays, balance of system and the load. The next step is to find the suitable types of the main components to continue designing the system. After detailed research in different manufacturers available in Jordan about the best brands of the main components PV panels and inverters, the following types were chosen. The used PV module is Jinko solar Panel Monocrystalline (JKM330M-60H) with 330 W peak power, while the inverter type is ABB Solar Inverter (TRIO-20.0-TL-OUTD) with 20 kW power. The AC Disconnect model is ABB 40 A with manual switch disconnect (ABB OT40F3). However, two types of DC Disconnects are used: The first one is ABB 16 A switch disconnect (OTDC16F2), and the second one is the Siemens 60 A switch disconnect (hnf362pv).

Table 1 Load consumption of a single bedroom

Singel bedroom	60 rooms			
Appliances	Type	Power (kW)	Working hours (h)	Energy consumption (kWh)
Refrigerator	lg(gr-051ssf)	0.075	10	0.75
TV	LG(435700PTC)	0.045	6	0.27
Hair dryer	Conair wall mount	1.6	0.15	0.24
Water kettle	Hamilton Beach (40,880)	0.4	0.1	0.04
Iron machine	Panasonic (NI-E660SR)	1.2	0.5	0.6
Microwave oven	LG (MS2336GIB)	1	0.15	0.15
Water heater	Ariston	2	3	6
Lights:				
Lamb shades*4	Osram LED (827E14)	0.0057	5	0.0285
Spot lights*10	Osram (830gGU10)	0.0043	5	0.0215
Mirror light*1	Osram (827S14 s)	0.015	1	0.015
Total				8.115

Table 2 Electrical load results

Loads	kWh (monthly)
Single/double rooms	14,607
One-bedroom suites	781.2
Two-bedroom suites	2398
Restaurants	2069.4
Reception	2166.6
Total AC in the hotel	50,457
Others	4620.6
Total	77,099

Table 3 Occupancy rate of hotels in Amman (Ministry of Tourism)

Year	Occupancy rate (%)
2010	49.5
2011	44.6
2012	57.9
2013	47.0
2014	48.2
2015	43.8
2016	43.1
2017	48.8
2018	44.2
2019	42.4
Average	47.7

After choosing the system element specifications, the required numbers of all PV system elements were determined using simulation software such as PVGIS and PVsyst.

Simulation process

The simulation process is one of the critical phases in this work; it applies the design implemented on the actual field of the project, using PVGIS and PVsyst. In order to start the simulation software, several data are required, such as the energy consumption of the system, coordinates of the project, types of the PV panels and inverters.

PVGIS results

The running of PVGIS software required some data such as the system's peak power, the project location, the technology used in the PV panels and inverters. Figure 7 shows the provided inputs and the simulation outputs of the software. The output results show that the system's total yearly energy production will be 474,214 kWh (average 39,518 kWh monthly) with a slope angle (tilt angle) of 7° and azimuth angle of 0° of the PV collectors (see Fig. 8) [54].

In addition, the yearly in-plane irradiation is 2197 kWh/m^2, while the total loss of the system will reach 24.3%. The outline of the horizon at the chosen location is shown on the right side of Fig. 7.

On the other hand, the PVGIS software output gives the monthly electricity production and the global solar irradiation per square meter received by the panels of the PV system as shown in Table 4. The maximum electricity generation is obtained in July with a value of 53,116.3 kWh, while the minimum electricity generation is obtained in January with a value of 24,856.1 kWh. During summer, the system will produce more energy than needed, which will be credited to the hotel's balance at the national electricity company. However, this energy balance will be used in winter due to the system's low energy production compared to consumption. The last

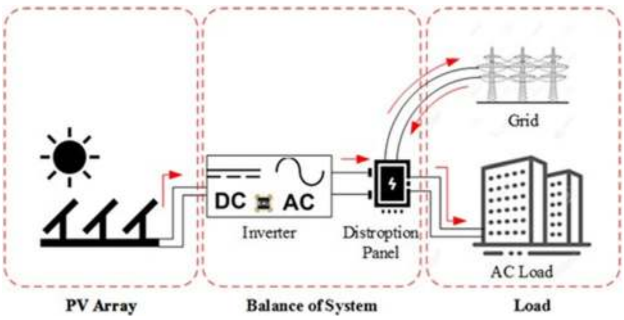


Fig. 6 Flow diagram of the on-grid PV system

column in Table 4 shows the standard deviations of monthly electricity production, which their values are acceptable.

PVsyst results

Figure 9 shows all data about the used panels and inverters in the PV system. It shows that the peak power at the maximum power of the panel, when tested under STC, is 301 kWp, while on NOCT the peak power is 277 kWp with a model area of 1539 m^2.

Figure 10 illustrates the total energy production per installed on nominal power 301 kWp on STC. It also shows the product's useful energy in red color, and the collection and system losses are shown in the color of purple and green, respectively. The maximum useful energy production (6.9 kWh/kWp/day) was obtained in June, while the minimum value (2.8 kWh/kWp/day) was obtained in January and December. The average useful energy of the 12 months was 4.93 kWh/kWp/day. Moreover, the average total losses of energy production through the PV array, wiring and the inverters, were around 1.0 kWh/kWp/day.

Figure 11 shows the PR of the PV system in each month. The PR is defined as the ratio of the actual produced useful energy (Yf, kWh/kWp/day) with respect to the energy which would be produced if the PV system was continuously working without any losses (Yr, kWh/kWp/day) as given by Eq. 2. The average value of the PR was calculated using PVsyst Software, and it was found to be 0.828.

$$\mathrm{PR} = \frac{\mathrm{Yf}}{\mathrm{Yr}} \tag{2}$$

Figure 12 illustrates all the PV system losses that could happen during the year that were obtained from PVsyst Software. The total amount of effective energy received on the collector plane was 3232 MWh, but the effectiveness plane receives the irradiances only at 2100 kWh/m^2. This amount of energy was converted down to 634 MWh at an array nominal energy with a STC efficiency of 19.62%. The largest losses happened in PV array production energy, affected by several factors such as ambient temperature, solar incidence, manufacture mismatch and ohmic wiring. The total losses through array nominal energy are 13.7%, which drop the energy down from 634 to 551 MWh, representing the array virtual energy at maximum power point (MPP). Finally, the total losses through the inverters are 1.7%, so the net amount of energy injected into the AC grid was 541 MWh. On the other hand, based on PVsyst Software, the panels alone will need a minimum area of 1539 m^2.

The output of PVsyst software shows that the system will need 912 Panels distributed over 12 inverters. In addition, the required area to install the PV system includes the steel structure and will be 1757.3 m^2. The system's total yearly energy production will reach around 541 MWh, and the average PR will be 0.828.

PV model arrangements using AutoCAD

AutoCAD drawings are used in this study in order to distribute the calculated PV panels in the available areas of the hotel rooftops and parking area. Two scenarios were

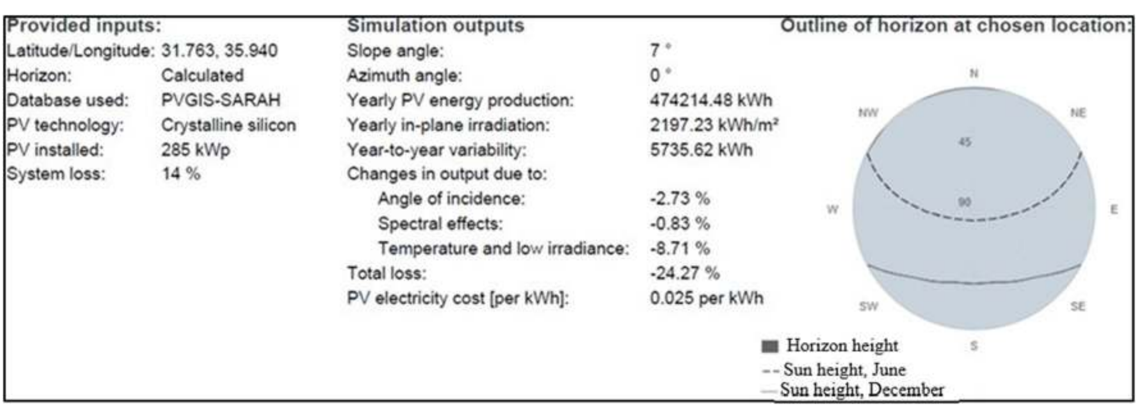


Fig. 7 PVGIS estimation of electricity generation

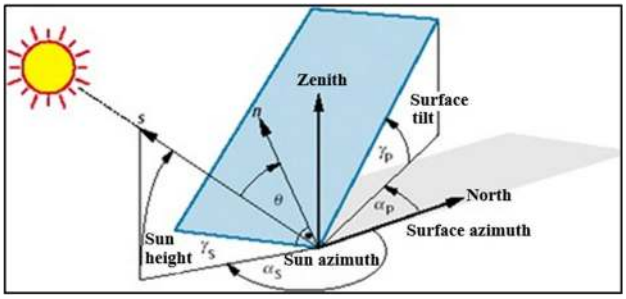


Fig. 8 Solar panel instillation angles [54]

Table 4 Monthly PV energy and solar irradiation

Month	E-M (kWh)	H-M (kWh/m^2)	SD-M (kWh)
January	24,856.1	107.2	2131.6
February	27,703.0	120.9	1678.8
March	39,059.6	175.6	1649.8
April	44,329.4	204.5	2105.9
May	50,263.7	237.3	1835.1
June	51,972.2	250.6	632.9
July	53,116.3	257.1	443.3
August	50,410.4	240.3	777.4
September	43,299.1	203.8	1009.3
October	36,411.7	168.1	1640.3
November	27,934.2	124.0	1814.5
December	24,859.0	107.8	2369.9
Total	474,214.0	–	–

E-M: Average monthly electricity production from the given system (kWh)

H-M: Average monthly sum of global irradiation per square meter received by the panels of the given system (kWh/m^2)

SD-M: Standard deviation of the monthly electricity production due to year-to-year variation (kWh)

suggested for that reason: mount the PV panels on either the building's rooftops or the parking area which will be discussed in the following two sections.

Mount the PV panels on the building's rooftops

The total areas of the rooftops for the three building were calculated in order to check whether their areas are enough to mount the panels on them, and the areas found are as follows (see Fig. 13):

- 336.0 m^2 available on building number I,
- 295.5 m^2 available on building number II and
- 406.4 m^2 available on building number III.

So, the total available roof areas on all buildings were 1037.85 m^2, which is not enough to mount the needed number of PV panels compared to the required area of 1757.3 m^2.

Mount the PV panels in the parking area

The parking area was better than the rooftops area to install all required PV panels as its area (3480 m^2) is higher than the required area (1757.3 m^2). However, when it comes to the orientation of the PV panels, there is initially a problem in hotel parking design as the PV panels, in this case, will face the east direction (see Fig. 14). In Jordan, the panels should face south to get the maximum irradiation with minimum collection loss.

Therefore, PV panels should be installed in a horizontal way to face south. In this item, more spaces should be left between PV arrays; then, there will not be enough space for all panels if the panels were rotated alone. To solve this problem, different options were studied to find a suitable arrangement. It is suggested to rotate all the parking design by 90°, including the PV panels, the cars' spots and the steel structure to face the south. The new suggested orientation was drawn using AutoCAD software, as shown in Fig. 15. Based on the new modification of the parking area, the following observations were noticed:

1. The parking capacity was slightly decreased from 132 to 130 cars, which is not a big difference compared to the problem that was improved by the modification.

PV module	Si-mono	Model	**JKM 330M-60H**		
		Manufacturer	Jinko		
Number of PV modules		In series	19 modules	In parallel	48 strings
Total number of PV modules		Nb. modules	912	Unit Nom. Power	330 Wp
Array global power		Nominal (STC)	**301 kWp**	At operating cond.	277 kWp (50°C)
Array operating characteristics (50°C)		U mpp	599 V	I mpp	462 A
Total area		Module area	**1539 m²**		
Inverter		Model	**TRIO 20.0 TL OUTD**		
		Manufacturer	ABB		
Characteristics		Operating Voltage	440-800 V	Unit Nom. Power	20.0 kW AC
Inverter pack		Number of Inverter	12 units	Total Power	240.0 kW AC

Fig. 9 PV array characteristics

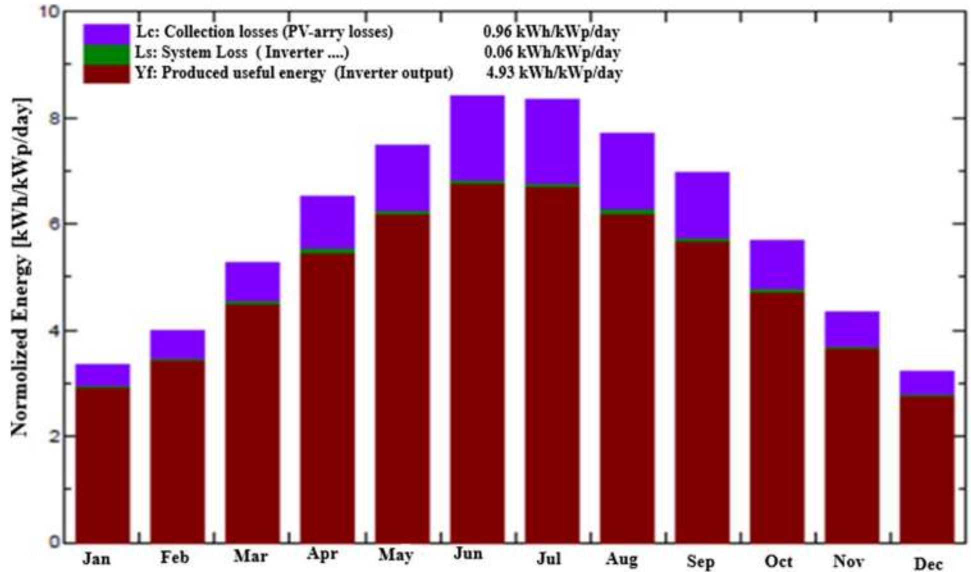


Fig. 10 Monthly normalized energy productions, inverter loss and PV array losses

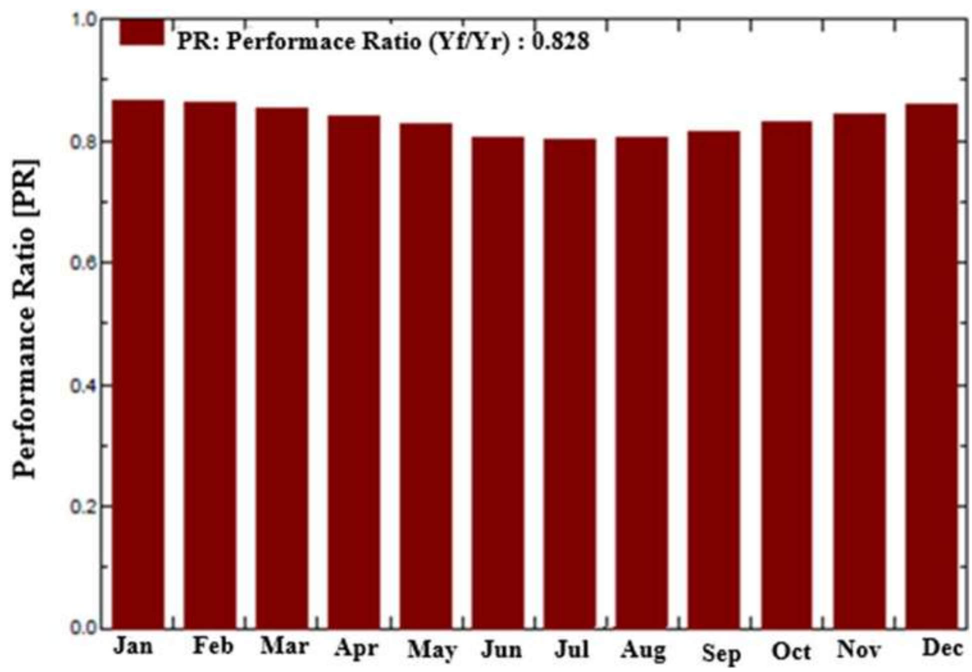


Fig. 11 Performance ratio (PR) for each month

2. The panels are now facing directly in the south direction.
3. The panel's Azimuth angle is 0°, and the tilt angle is 7°.

Economic estimation of the PV system

Cost of the PV system

The cost of the PV system will include the PV panels, inverters and AC and DC circuit breakers. In addition, the cost will include civil works, steel structure and labor costs. After referring to many renewable energy companies in Jordan (such as Philadelphia Solar company, Kawar Energy company and the Contractor for Energy company) to check the PV system cost, most of their prices for the PV system was in the range of JOD 450–600/kWp ($ 634–845)/kWp. As the PV system will require 301 kWp and by taking the highest prices in Jordan of JOD 600/ kWp ($845/ kWp), the cost of the project will be accounted as shown in Eq. 3:

$$\text{Total project cost} = 301 * 600 = JOD\ 180600\ \left(\$254366\right) \quad (3)$$

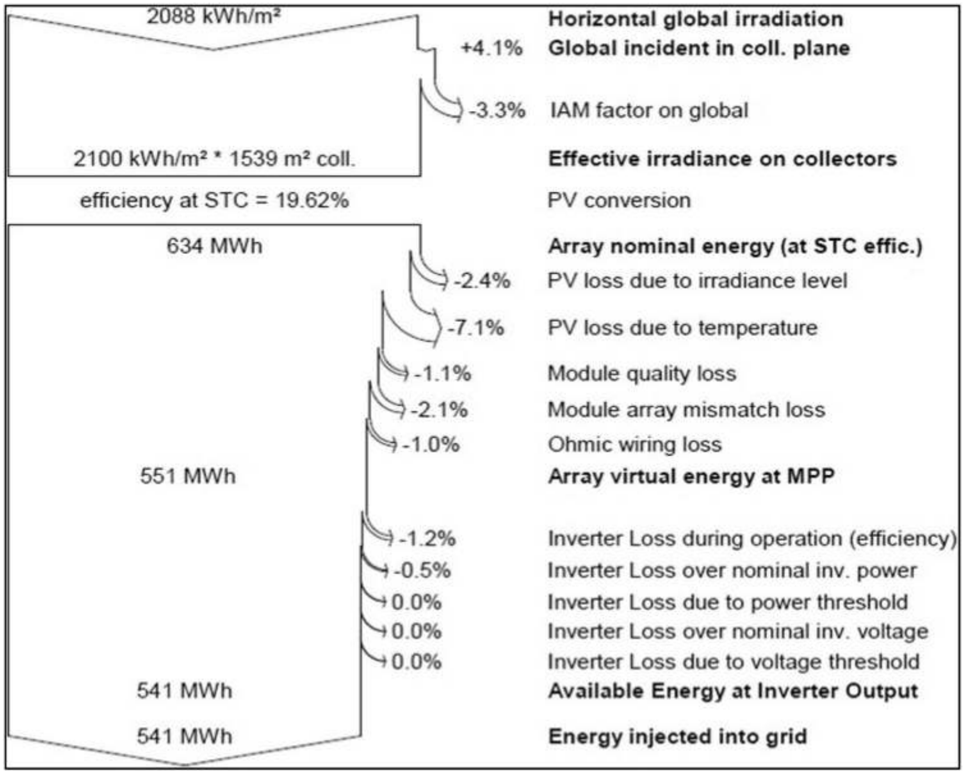


Fig. 12 Overall system loss diagram over the whole year

Degradation rate and system lifetime

The operation efficiency of PV panel will decrease over time, resulting in some energy yield reduction. This reduction is identified as a degradation rate. The annual degradation rate is considered as a significant parameter in the economic viability analysis. As the annual degradation rate is known, it is easy to estimate the PV system's production energy over the lifetime. When a higher degradation rate is used, it will lead to a lower estimate of generated power and reduced cash flow in the future [55]. In this study, an annual degradation rate for PV cells is considered 0.7% per year, according to the manufacturing company. Another critical parameter is the system lifetime. This parameter has an inverse relation with the degradation time and a direct link with the system's reliability. Consequently, it was found that a lower degradation rate and longer system lifetime will increase the reliability of the system [56].

Related to the literature, it can be revealed that the utilized lifetime for PV system is in the ranged of 20 to 30 years [57]. In this work, 25 years will be considered as a lifetime for the proposed PV system. Figure 16 shows the produced energy over the lifetime of the system.

Payback period

The PV system payback period (estimated in years) indicates the number of years when the project return backs all expenses. The payback period for PV system is calculated as the ratio of the capital cost to the yearly electricity bill [29]; as shown in Eq. 3, the life cycle cost of the PV system is estimated for 25 years.

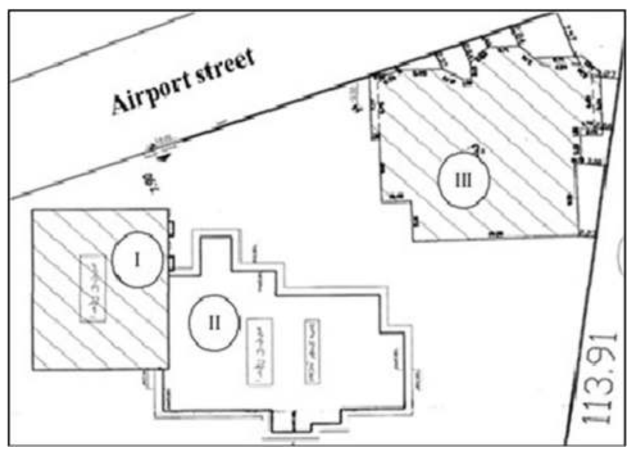


Fig. 13 AutoCAD drawing of the buildings (I, II and III)

$$\text{Payback period} = \frac{\text{Capital cost}}{\text{Average yearly electricity bill}} \tag{4}$$

where the capital cost can be found using Eq. 5.

$$\text{Capital cost} = \text{Intial cost of PV system} + \text{OM} \tag{5}$$

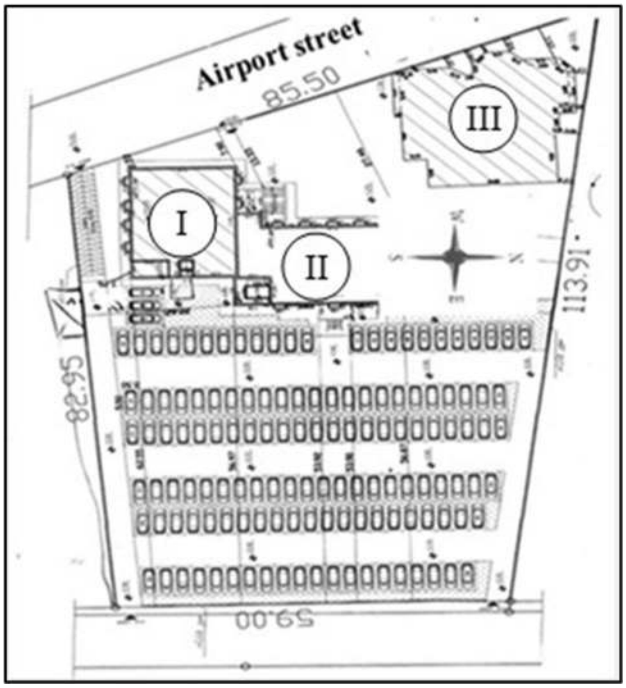


Fig. 14 Original parking plan with cars spots facing to the east direction

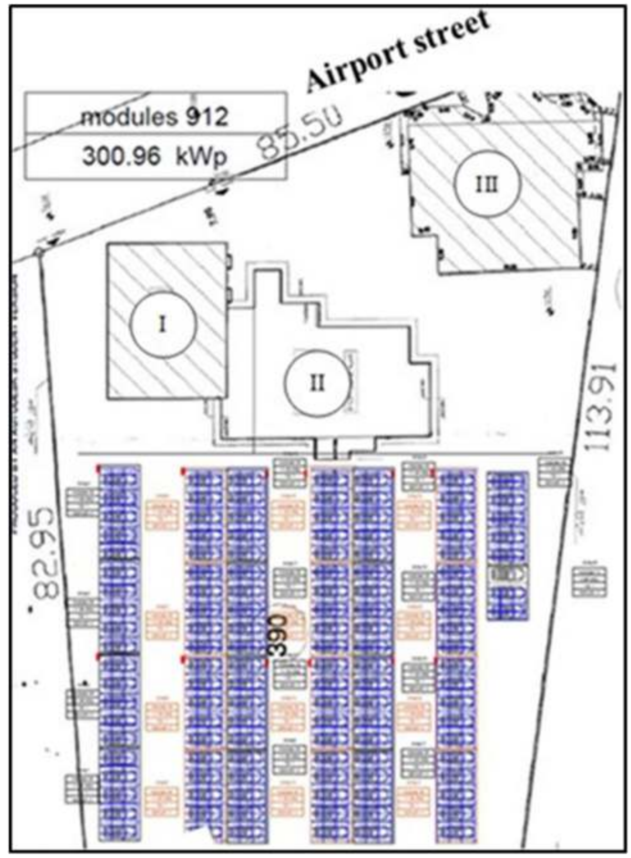


Fig. 15 Modified parking plan with PV panels

where OM is the cost of operation and maintenance over the lifetime of the system. The average annual cost of operation and maintenance AAOM is estimated using Eq. 6 [58].

$$AAOM = OM * (1 + f/N) \tag{6}$$

where f is the annual inflation rate expected equal to the interest rate to 4.63% (trading economics) and N is the system lifetime (25 years), OM is estimated at 6% of the initial cost; it is calculated using Eq. 7 [59].

$$OM = P * 0.06 \tag{7}$$

where P is the initial cost of PV system that equal to JOD 180,600 ($254,366) and AAOM equal to JOD 434 ($620). Therefore, the total capital cost is calculated using (Eq. 5) to be JOD 191,436 ($273,480). The average yearly electricity bill will be

$$\text{Annual electricity cost} = 541000\frac{\text{kWh}}{\text{y}} * \text{JOD } 0.091/\text{kWh} = \text{JOD } 49231/\text{y} \left(\$69339/\text{y}\right) \tag{8}$$

The expected payback period for the PV system is equal to 4.1 year, assuming that the interest rate is similar to electricity inflation rate of 4.63%. Figure 17 shows the cash flow for the PV system over 25 years.

Net present value

Net present value (NPV) is a critical parameter in determining an investment economic feasibility as it is considered as a method that used to analyze the profitability of the project. If the NPV is positive, the project will be accepted, while if the NPV is negative, it should be rejected. NPV can be determined for project lifetime (25 years) using Eq. 9 [60, 61].

$$NPV = \sum_{n=1}^{25} \frac{\text{Revenue}}{(1+i)^n} - \frac{\text{Decommesioning cost}}{(1+i)^{25}} - \text{Capital cost} \tag{9}$$

where n is the year and i is the interest rate equal to 4.5% according to the Central Bank of Jordan, and the decommissioning cost includes dismantling the equipment, managing the resulting waste streams and restoring the site. For PV system, the decommissioning cost is estimates as $57/MW of capacity [62]. Therefore, the estimated decommissioning cost is calculated according to Eq. 10.

$$\text{Decommesioning cost} = \frac{\$57}{\text{MW}} \times 541 \text{ MW} = \$30,837 \tag{10}$$

The annual revenue can be calculated by multiplying the produced annual energy by the PV system with the energy price (Eq. 11) [62]:

$$\text{Revenue (year)} = \text{Energy Produced} * \text{Energy Price} \quad (11)$$

The per unit energy price was considered as constant over the system lifetime and equal to JOD 0.09 per kWh. Therefore, NPV value for the PV system over 25 years will be JOD 542,118 ($763,547). The accuracy of the calculated revenue is in the range of ±3%.

Life cycle cost (LCC) and life cycle savings (LCS)

Another two of the most widely applied economic analysis methods for the implementation of PV systems are life cycle cost (LCC) and life cycle savings (LCS). The LCC method is the sum of every cost associated with the PV installation over the system lifetime. All costs are discounted to their present values. The LCS method is defined as the difference between the LCC cost of conventional fossil fuel-fired energy source alone and the LCC cost of the PV installation that will replace it or assist it [63]. The annual life cycle savings (ALCS) is calculated using Eq. 12 [63]:

$$\text{ALCS} = \frac{NPV}{\frac{1}{i}\left(1 - \frac{1}{(1+i)^N}\right)} \quad (12)$$

where i is the interest rate equal to 4.63% [64] and N is the estimated lifetime of the PV system. The ALCS is calculated for this project, and its value is JOD 36,560 ($51,493). The positive value indicates more cost savings by using the PV system as an energy supplier rather than conventional fossil fuel fired sources.

Levelized cost of energy (LCOE)

LCOE is used to compare different methods of electricity generation on a comparable basis. It is an economic assessment of the average total cost to build and operate a power-generating asset over its lifetime divided by its total energy output over that lifetime [65]. The LCOE in kWh represents the discounted price that PV electricity must be sold to recoup discounted project costs over the system [66]. Equation 13 calculates LCOE [60].

$$\text{LCOE} = \frac{\text{Annual cost} + \text{AAOM}}{\text{Total energy produced by the system}} \quad (13)$$

To calculate the system annual cost, a capital recovery factor (CRF) should be used to convert the present value of the system installation cost into an equal yearly cost throughout the system lifetime ($N = 25$). So, Eq. 13 can be presented as:

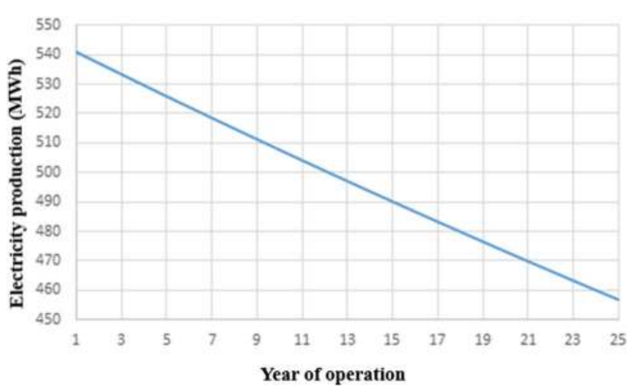


Fig. 16 Annual energy yield over the system lifetime

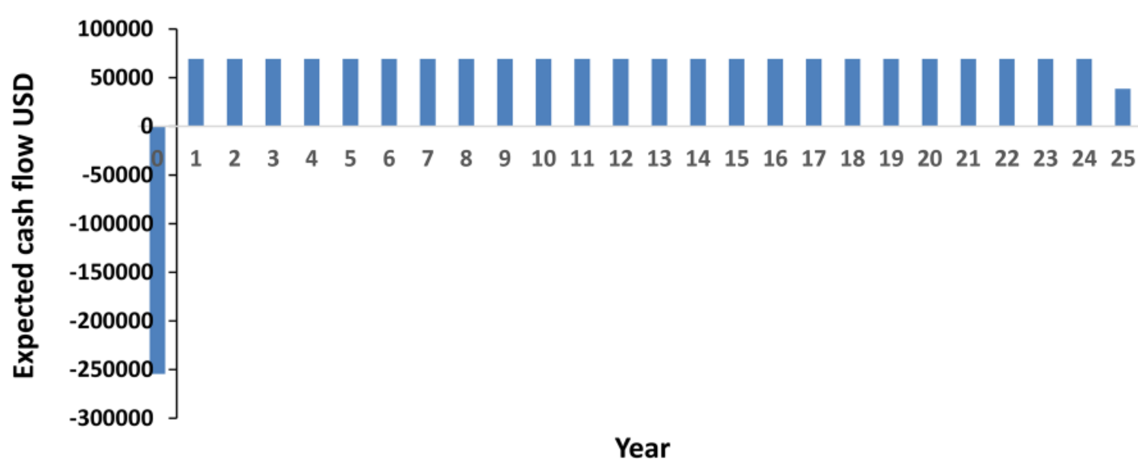


Fig. 17 Cash flow for PV system over the lifetime

$$\text{LCOE} = \frac{\text{Installation cost} * \text{CRF} + \text{AAOM}}{\text{Average energy produced by the system}} \tag{14}$$

where CRF is given by Eq. 15 [67].

$$\text{CRF} = \frac{i \times (1+i)^n}{\left[(1+i)^n - 1\right]} \tag{15}$$

where i is the interest rate and n the lifetime of the system. The calculated value for LCOE is equal to JOD 0.0141/kWh ($0.0199/kWh), which is cheaper compared with the electricity price given by Jordan Electricity Company JOD 0.090/kWh ($0.1285/kWh). Based on the actual electrical load of the Cedars hotel (37 MWh), using the PV system will save JOD 27,528 ($38,718) per year.

It is worthwhile to mention that uncertainty is the quantitative estimation of error present in the simulations data; all results data contain some uncertainty generated through systematic error and/or random error. Acknowledging the uncertainty of data is an important component of reporting the results of scientific investigation. In this research, the uncertainty in the investigated models is already covered through the simulation process and its value is expected to be very small (negligible) [68].

Risk assessment

Before investing in the project of on-grid PV system for electrification of Cedars hotel, it is necessary conduct a risk analysis to evaluate the range of possible variations of outputs with response to the potential variation in the input parameters [69]. The input parameters that must be considered should relate directly affects the output of the project such as voltage fluctuations and the electricity tariff. If the power supply is greatly expanded through decentralized PV systems, there is a risk of imbalances that become noticeable through voltage fluctuations in the power grid [70]. There are various instruments available to network operators to limit these fluctuations to the permissible level such as their inverters which have considerable potential to reduce stability problems. In this direction, a research study was conducted to investigate the consequences for a strong expansion of decentralized power generation systems on the supply network in Dettighofen village, Germany [71]. The results showed that the decentralized feed-in of PV electricity places a heavy load on the grid. The grid voltage at the feed-in points was temporarily five to seven percent above the standard value of 230 V. Deviations of the mains voltage from the norm are not uncommon. The mains voltage is not exactly 230 V, but fluctuates around this value However, the voltage deviations must not become too large. Otherwise there is a risk that the connected IT systems and other electrical devices as well as the network itself may be damaged. For this reason, according to the standards of the International Electrotechnical Commission IEC 60,038: 1983 [72], maximum deviations of 10% are permitted, so the voltage must be between 207 and 253 V.

The second economic risk is including the electricity tariff increases by the local electricity suppliers, inverter replacement cost, operation and maintenance cost, inflation, interest rate and degradation coefficient [13]. Interest rates can directly affect inflation and the countries like Jordan is known to increase or decrease the interest rates according to inflation rate variations. They will achieve this by increasing interest rates, and therefore, hotel owner should be encouraged to save electricity rather than consumed. A risk study need to be conducted to present a methodology for calculating and determining the regulatory tariff of companies under risk conditions, which is designed to assist owner in regulating the electric power sector. Due to increasing exposure to market prices, the profitability of PVs depends on future electricity prices.

Conclusion

This paper presents a technical and economic feasibility study for covering an under-construction Jordanian Cedars hotel's energy demand using a PV system. The analysis was carried out by estimating the load of the Hotel. The load estimation was calculated by assuming a specific design for each room type in the hotel and calculating the total energy required over one-month duration. The PV system size and design were estimated using PVGIS and PVsyst software.

The simulation output shows that the PV system could produce around 37,000 kWh monthly on average. The required area to install the PV system was 1757.3 m^2, which could be facilitated at the hotel's parking yard. The optimal use of this area is presented visually and factually by using the AutoCAD software. The performance ratio analysis shows that the average PR for a year is 82%. The PV system's payback period was 4.1 year, and the net present value is JOD 542,118 ($763,547) over the estimated lifetime of the project (25 years). The annual life cycle savings and levelized cost of energy were JOD 36,560 ($51,493) and JOD 0.028/kWh ($0.0199/kWh), respectively. Based on that, the PV system will save JOD 27,528 ($38,718) per year in a comparison to using conventional gird electricity which confirms that the on-grid PV system is beneficial and suitable for the electrification of residential hotel applications.

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Author contributions All authors contributed equally to this work.

Data availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

1. Ebadian, M., Dyk, S.V., Mcmillan, J.D., Saddler, J.: Biofuels policies that have encouraged their production and use: an international perspective. Energy Policy **147**, 111906–111923 (2020)
2. Bryant, S.T., Straker, K., Wrigley, C.: Designing our sustainable energy future: a shock doctrine for energy. Energy Policy **147**, 111914–111929 (2020)
3. Albatayneh, A., Assaf, M.N., Alterman, D., Mustafa, J.: Comparison of the overall energy efficiency for internal combustion engine vehicles and electric. Vehicles. **24**, 669–680 (2020)
4. Gallina, V., et al.: Assessment of climate change impacts in the North Adriatic coastal area. Part II: consequences for coastal erosion impacts at the regional scale. Water **11**(6), 1300–1322 (2019)
5. Shao, M., Wang, X., Bu, Z., Chen, X., Wang, Y.: Prediction of energy consumption in hotel buildings via support vector machines. Sustain. Cities Soc. **57**, 102128 (2020)
6. Escribano, G., Paredes-gazquez, J., San-martín, E.: The European Union and the good governance of energy resources: practicing what it preaches? Energy Policy **147**, 111884 (2020)
7. Liu, Z., Zhou, Q., Tian, Z., He, B., Jin, G.A.: Comprehensive analysis on definitions, development, and policies of nearly zero energy buildings in China. Renew. Sustain. Energy Rev. **114**, 109314 (2020)
8. Stropnik, R., Ko, R., Zavrl, E., Stritih, U.: Improved thermal energy storage for nearly zero energy buildings with PCM integration. Sol. Energy **190**, 420–426 (2019)
9. Zhang, Y., Zhang, X., Huang, P., Sun, Y., Carlo, M.: Global sensitivity analysis for key parameters identification of net-zero energy buildings for grid interaction optimization. Appl. Energy **279**, 115820 (2021)
10. Cheung, M., Fan, J.: Carbon reduction in a high-density city: a case study of Langham Place Hotel Mongkok Hong Kong. Renew. Energy **50**, 433–440 (2013)
11. Giriantari, I.A.D.: Economic Cost Study of Photovoltaic Solar System for Hotel in Nusa Lembongan. International Conference on Smart Green Technology in Electrical and Information Systems (ICSGTEIS). Indonesia (2014)
12. Kamali, S.: Feasibility analysis of standalone photovoltaic electrification system in a residential building in Cyprus. Renew. Sustain. Energy Rev. **65**, 1279–1284 (2016)
13. Berkani, L., Hamidat, A., Fodhil, F., Nadjemi, O., Alliche, Z.: Feasibility study of grid-connected photovoltaic systems in small industrial enterprises. International Conference on Advanced Electrical Engineering (ICAEE), Algeria (2019)
14. Global Alliance for Buildings and Construction, International Energy Agency and the United Nations. Environment Programme (2019): 2019 global status
15. Palop, J.J., Mucke, L., Roberson, E.D.: Quantifying biomarkers of cognitive dysfunction and neuronal network hyperexcitability in mouse models of alzheimer's disease: depletion of calcium-dependent proteins and inhibitory hippocampal remodeling. Erik D. Roberson (Ed.), Alzheimer's Disease and Frontotemporal Dementia, Methods in Molecular Biology, pp 245–262. Springer Science+Business Media (2010)
16. Borowski, M., Mazur, P., Kleszcz, S., Zwolinska, K.: Energy monitoring in a heating and cooling system in a building based on the example of the Turówka Hotel. Energy **13**, 1968 (2020)
17. UNWTO World Tourism Barometer: International Tourism Highlights International tourism continues to outpace the global economy. UNWTO Publishing unwto.org, https://www.unwto.org/international-tourism-growth-continues-to-outpace-the-economy (2019). Accessed 12 May 2021
18. Alzboun, N.: Domestic tourism in Jordan: patterns, challenges and opportunities. J. Environ. Manag. Tour. **2**(34), 281–291 (2019)
19. Tourism, W., Unwto, O.: Tourism, key to development, prosperity and well-being (2014)
20. Albatayneh, A., Assaf, M.: Evaluation of potential biogas production from construction evaluation of potential biogas production from construction of anaerobic digestion from WWTP in Jordan. The 16th International Conference of Young Scientists on Energy, Kaunas, Lithuania (2019)
21. Al-Bajjali, S.K., Shamayleh, A.Y.: Estimating the determinants of electricity consumption in Jordan. Energy **147**, 1311–1320 (2018)
22. Hamed, T., Bressler, L.: Energy security in Israel and Jordan: the role of renewable energy sources. Renew. Energy **135**, 378–389 (2018)
23. Al-Omary, M., Kaltschmitt, M., Becker, C.: Electricity system in Jordan: status & prospects. Renew. Sustain. Energy Rev. **81**, 2398–2409 (2018)
24. Idris, N., Omar, A.M., Shaari, S.: Stand-alone photovoltaic power system applications in Malaysia. In: 2010, 4th International Power Engineering and Optimization Conference (PEOCO), Malaysia, pp. 474–479 (2010)
25. Twaha, S., Ramli, M.A.M.: A review of optimization approaches for hybrid distributed energy generation systems: off-grid and grid-connected systems. Sustain. Cities Soc. **41**, 320–331 (2018)
26. Adejuyigbe, S.B., Ekiti, O., Bolaji, B.O., Olanipekun, M.U., Adu, M.: Development of a solar photovoltaic power system to generate electricity for office appliances. Eng. J. **17**(1), 29–39 (2013)
27. Kattakayam, T.A., Srinivasan, K.: Photovoltaic panel—generator based autonomous power source for small refrigeration units. Sol. Energy **56**, 543–552 (1996)
28. Kou, Q., Klein, S.A., Beckman, W.A.: A method for estimating the long-term performance of direct-coupled pv pumping systems. Sol. Energy **64**, 33–40 (1998)
29. Al-salaymeh, A., Al-hamamre, Z., Sharaf, F., Abdelkader, M.R.: Technical and economical assessment of the utilization of photovoltaic systems in residential buildings: the case of Jordan. Energy Convers. Manag. **51**, 1719–1726 (2010)
30. Al-kurdi, L., Al-masri, R., Al-salaymeh, A.: Economical investigation of the feasibility of utilizing the PV solar lighting for Jordanian streets. Int. J. Therm. Environ. Eng. **10**, 79–85 (2015)
31. Ayadi, O., Al-Assad, R., Al Asfar, J.: Techno-economic assessment of a grid connected photovoltaic system for the University of Jordan. Sustain. Cities Soc. **39**, 93–98 (2018)
32. Hrayshat, E.S., Al-Soud, M.S.: Potential of solar energy development for water pumping in Jordan. Renew. Energy **29**, 1393–1399 (2004)
33. Pazcel, E., Wannaz, E., Pignata, M., Salazar, M.: *Tagetes minuta* L. variability in terms of lead phytoextraction from polluted soils: Is historical exposure a determining factor? Environ. Process. **5**, 1–17 (2018)
34. Siregar, Y., Hutahuruk, Y., Suherman, S.: Optimization design and simulating solar PV system using PVSyst software. The 4th International Conference on Electrical, Telecommunication and Computer Engineering (ELTICOM). Indonesia (2020)
35. Irwan, Y.M., et al.: Stand-Alone Photovoltaic (SAPV) System Assessment Using PVSYST Software. Energy Procedia, Vol. 79, Elsevier B.V. (2015)

36. Psiloglou, B.E., Kambezidis, H.D., Kaskaoutis, D.G., Karagiannis, D., Polo, J.M.: Comparison between MRM simulations, CAMS and PVGIS databases with measured solar radiation components at the Methoni station, Greece. Renew. Energy **146**, 1372–1391 (2020)
37. Spea, S.R., Khattab, H.A.: Design, sizing and performance analysis of stand-alone PV system using PVSyst software for a location in Egypt. 21st International Middle East Power Systems Conference (MEPCON), Egypt (2019)
38. Haydaroglu, C., Gumus, B.: Examination of PV_{gis} and Sunny DesignWeb photovoltaic system web-based simulation programs and evaluation of the reliability of results. International Engineering, Science and Education Conference, Turkey (2016)
39. Woodward, R.I., Kelleher, E.J.R.: Towards 'smart lasers': self-optimisation of an ultrafast pulse source using a genetic algorithm. Sci. Rep. **6**, 37616 (2016)
40. Barua, S., Prasath, R.A., Boruah, D.: Rooftop solar photovoltaic system design and assessment for the academic campus using PVsyst software. J. Electr. Electron. Eng. **5**(1), 76–83 (2017)
41. Kumar, R., Rajoria, C.S., Sharma, A., Suhag, S.: Design and simulation of standalone solar PV system using PVsyst software: a case study. Mater. Today Proc. (2020). https://doi.org/10.1016/j.matpr.2020.08.785
42. Belmahdi, B., Bouardi, A.E.: Solar potential assessment using PVsyst software in the Northern Zone of ScienceDirect Available ScienceDirect ScienceDirect Solar Potential Assessment using PVsyst Software in the Northern Solar Potential Assessment using PVsyst Software in the Northern. Procedia Manuf. **46**, 738–745 (2020)
43. Kumar, N.M., Kumar, M.R., Rejoice, P.R., Mathew, M.: Performance analysis of 100 kWp grid connected Si-poly and Cooling Performance analysis of grid Heating connected Si-poly photovoltaic system using PVsyst simulation tool photovoltaic system using PVsyst simulation tool Assessi. Energy Procedia **117**, 180–189 (2017)
44. Súri, M., Huld, T., Dunlop, E.D.: Geographic aspects of photovoltaics in Europe: contribution of the PVGIS website. IEEE J. Sel. Top. Appl. Earth Observations Remote Sens. **1**, 34–41 (2008)
45. The European Commission's science and knowledge service. Photovoltaic Geographical Information System (PVGIS). https://ec.europa.eu/jrc/en/pvgis https://ec.europa.eu/jrc/en/pvgis (2021). Accessed 02 March 2021
46. Psomopoulos, C.S., Ioannidis, G.C., Kaminaris, S.D., Mardikis, K.D., Katsikas, N.G.: A comparative evaluation of photovoltaic electricity production assessment software (PVGIS, PVWatts and RETScreen). Environ. Process. **2**, 175–189 (2015)
47. Huld, T., Müller, R., Gambardella, A.: A new solar radiation database for estimating PV performance in Europe and Africa. Sol. Energy **86**, 1803–1815 (2012)
48. Kandasamy, C.P., Prabu, P., Niruba, K.: Solar potential assessment using PVSYST software. In: 2013 International Conference on Green Computing, Communication and Conservation of Energy (ICGCE), India, pp. 667–672 (2013). https://doi.org/10.1109/ICGCE.2013.6823519
49. Al-Salaymeh, A.: Modelling of global daily solar radiation on horizontal surfaces for Amman City. Emirates J. Eng. Res. **11**, 49–56 (2006)
50. Qasaimeh, A., Qasaimeh, M., Abusalem, Z., Momani, M.: Solar energy sustainability in Jordan. Comput. Water Energy Environ. Eng. **3**, 41–47 (2014)
51. Okonkwo, E.C., Okwose, C.F., Abbasoglu, S.: Techno-economic analysis of the potential utilization of a hybrid PV-wind turbine system for commercial buildings in Jordan. Int. J. Renew. Energy Res **7**(2), 908–914 (2017)
52. Harir Palace Hotel Amman. https://harir-palace-amman-hotel.amman-hotels-jo.com/en/. (2021). Accessed 01 March 2021
53. Jordan Ministry of Tourism & Antiquities: https://www.mota.gov.jo/Default.aspx (2019). Accessed 02 March 2021
54. Quaschning, V.: Solar thermal power plants. Technology fundamentals. Renew. Energy World **6**, 109–113 (2003)
55. Jordan, D.C., Kurtz, S.R.: Photovoltaic degradation rates—an analytical review. Prog. Photovolt. Res. Appl. (2012). https://doi.org/10.1002/pip.1182
56. Pillai, G., Naser, H.: Techno-economic potential of largescale photovoltaics in Bahrain. Sustain. Energy Technol. Assess. **27**, 40–45 (2018)
57. Wohlgemuth, J., et al.: Using accelerated tests and field data to predict module reliability and lifetime. Presented at the 37th IEEE Photovoltaic Specialists Conference (PVSC 37), 19–24 June 2011, Seattle, Washington (2008)
58. Park, C.: Fundamentals of Engineering Economics. Pearson Education, US (2012)
59. Radhi, H.: On the value of decentralised PV systems for the GCC residential sector. Energy Policy **39**, 2020–2027 (2011)
60. Drury, E. et al.: The impact of different economic performance metrics on the perceived value of solar photovoltaics. BiblioGov (2011)
61. Brigham, E.F., Houston, J.F.: Fundamentals of Financial Management, Twelfth Edition, South-Western College Pubisher (2008)
62. Raimi, D.: Decommissioning US Power Plants: Decisions, Costs, and Key Issues. p. 53 (2017). https://www.rff.org/pblications/reports/decommissioning-us-power-plants-decisions-costs-and-key-issues. Accessed 05 May 2021
63. Audenaert, A., Boeck, L.D., Cleyn, S.D., Lizin, S., Adam, J.: An economic evaluation of photovoltaic grid connected systems (PVGCS) in Flanders for companies: a generic model. Renew. Energy **35**, 2674–2682 (2010)
64. Abuelyamen, A., Mohamed, M. H.: Techno-economic study of installing 10 MW PV power plant in Sudan. Proceed. paper 1–13 (2017). https://doi.org/10.1115/IMECE2016-66996
65. Central Electricity Generating Company. https://www.cegco.com.jo/Home_Page.aspx. (2021). Accessed 02 March 2021
66. Lai, C. S., Mcculloch, M. D. :Levelized Cost of Energy for PV and Grid Scale Energy. Storage Systems. arXiv preprint. arXiv:1609.06000 (2016).
67. Cucchiella, F., Adamo, I.D.: Residential photovoltaic plant : environmental and economical implications from renewable support policies. Clean Technol Environ. Policy **17**(7), 1929–1944 (2015). https://doi.org/10.1007/s10098-015-0913-1
68. Dorini, G., Kapelan, Z., Azapagic, A.: Managing uncertainty in multiple-criteria decision making related to sustainability assessment. Clean Technol. Environ. Policy **13**, 133–139 (2011)
69. Arango, L., Arango, H., Deccache, E., Bonatto, B., Pamplona, E.: Economic Evaluation of Regulatory Tariff Risk Planning for an Electric Power Company. J. Control. Autom. Electr. Syst. **30**, 292–300 (2019)
70. Egli, F. :Renewable energy investment risk: An investigation of changes over time and the underlying drivers. Energy Policy **140**, 111428 (2020).
71. ZHAW Institute of Energy Systems and Fluid Engineering (IEFE). How photovoltaic systems contribute to voltage regulation. https://www.zhaw.ch/en/about-us/news/news-releases/news-detail/event-news/how-photovoltaic-systems-contribute-to-voltage-regulation-1 (2020). Accessed 15 May 2021.
72. Commission, I. E. :IEC 60038-Standard Voltages. *Iec* **1997**, International Electrotechnical Commission, Edition 6.2, 2002–07, (2007).

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