Power Engineering and Engineering Thermophysics
https://www.acadlore.com/journals/PEET

Photovoltaic Solar Energy for Street Lighting: A Case Study at Kuwaiti Roundabout, Gaza Strip, Palestine

Hala J. El-Khozondar[1,2*], Ahmed A. Asfour[1], Yasser F. Nassar[3], Saleh W. Shaheen[1], Mahmoud F. El-Zaety[1], Rifa J. El-Khozondar[4], Mohamed M. Khaleel[5], Abdussalm A. Ahmed[6], Abdulgader H. Alsharif[7]

[1] Electrical Engineering and Smart Sysytems Department, Engineering Faculty, Islamic University of Gaza, 0970 Gaza, Palestine
[2] Department of Materials and London Centre for Nanotechnology, Imperial College, SW7 2AZ London, UK
[3] Research Center for Renewable Energy and Sustainable Development, Wadi Alshatti University, 721 Barck, Libya
[4] Physics Department, Al-Aqsa University, 0970 Gaza, Palestine
[5] Faculty of Engineering, Karabuk University, 78000 Karabuk, Turkey
[6] Engineering Faculty, Bani Waleed University, 322 Bani Walid, Libya
[7] Electrical and Electronic Engineering Department, High Institute of Technical Sciences, 21 Sebha, Libya

[*] Correspondence: Hala J. El-Khozondar (hkhozondar@iugaza.edu)

Received: 04-05-2024 **Revised:** 06-01-2024 **Accepted:** 06-07-2024

Citation: H. J. El-Khozondar, A. A. Asfour, Y. F. Nassar, S. W. Shaheen, M. F. El-Zaety, R. J. El-Khozondar, M. M. Khaleel, A. A. Ahmed, and A. H. Alsharif, "Photovoltaic solar energy for street lighting: A case study at Kuwaiti Roundabout, Gaza Strip, Palestine," *Power Eng. Eng. Thermophys.*, vol. 3, no. 2, pp. 77–91, 2024. https://doi.org/10.56578/peet030201.

Abstract: As populations expand and cities grow, the horizontal development of sustainable initiatives, coupled with the preservation of natural resources and the shift towards agricultural ventures, has led to an increased necessity for road lighting to mitigate traffic accidents. The burgeoning field of photovoltaic (PV) energy is significantly altering the energy paradigm, gaining prominence within regional energy mixes and power systems. This study presents an examination of various off-grid solar PV system designs for the illumination of the Kuwaiti roundabout, highlighting the distinct differences among these approaches. Through mathematical modeling and subsequent validation via PVsyst software, the focus is placed on sophisticated light emitting diode (LED) street lighting systems featuring automatic controls powered by solar energy. LEDs, acclaimed for their energy efficiency and longevity, are progressively supplanting traditional lighting technologies worldwide. This investigation explores multiple system configurations, transitioning from centralized systems employing sodium flashlights to autonomous systems with LED lamps. Key challenges such as power consumption, spatial limitations, and network load considerations are addressed. Innovative solutions including dual-voltage lamps and charge controllers are introduced, pinpointing optimal design strategies for roadway applications, which have implications for sustainable urban lighting paradigms. Additionally, the proposal of a solar-powered searchlight underscores potential cost-effectiveness, reflecting the continuous evolution of solar lighting technologies. Collectively, the findings underscore the crucial role of comprehensive design considerations in achieving efficient and sustainable lighting solutions within urban settings.

Keywords: Off-grid photovoltaic system; PVsyst software; Street lighting; Light-dependent resistor; Light emitting diode

1 Introduction

Increased population and economic growth resulted in the extension of cities and the consequent expansion of streets to assist in the transportation of people and commodities to and from these cities, leading to a rise in energy consumption for street lighting. Street lighting makes cities more appealing, offers a civilized outlook for communities, and emphasizes interesting landmarks at night. However, the most significant reason for street lighting is to increase traffic safety and save lives. Proper and well-designed lighting is crucial for safe roads, fewer automobile accidents, and better comfort for drivers and pedestrians. Studies have shown that good roadway illumination reduces pedestrian accidents by around 50% [1].

https://doi.org/10.56578/peet030201

The Gaza Strip's energy sources are allocated as follows: 120 MW from the Israeli Electricity Company, 65 megawatts from the Strip's lone producing station, and roughly 2 megawatts from solar energy, even though the Gaza Strip requires approximately 450 megawatts, with a 55% shortage. As a result of this shortage, the Gaza Electricity Distribution Company operates on a contingency schedule that includes eight hours (or more) of on-and-off electricity [2]. In Palestine, the household sector consumes the most energy (60%), followed by the service and commercial sectors (26% for each), and the industrial sector (13%). While the agriculture sector utilizes less than 1% [3].

Using solar energy for street lighting is an effective and sustainable technique for reducing energy consumption and greenhouse gas emissions. LED streetlights may run efficiently by harnessing sunlight and converting it into electrical power via solar panels. These lights use light-dependent resistors (LDRs) that automatically adapt based on ambient light levels [4, 5]. Furthermore, sophisticated technologies are used for these lights. For example, piezoelectric sensors enable the creation of extra electrical energy from the pressure applied by cars on the road, increasing the system's energy efficiency [6].

Adoption of solar-energy-based street lighting systems improves the performance and durability of existing infrastructure while also lowering costs [7]. Economic analysis has shown that deploying PV systems for street lighting results in a quick return on investment as well as significant environmental benefits from reduced carbon dioxide (CO_2) emissions [8]. As a result, solar-powered street lighting systems are not only environmentally beneficial but also financially profitable when compared to traditional lighting techniques.

The development of smart cities and a reduction in the prices of solar street lighting solutions will increase the value of the solar street lighting market from $5.7 billion in 2019 to $14.6 billion by 2030, at a 9.4% compound annual growth rate (CAGR) during 2020-2030 (forecast period) [9]. The global deployment of solar-powered street lighting has increased in recent years, indicating a substantial move toward sustainable energy options. One innovative option is the installation of off-grid solar energy systems, in which solar panels gather sunlight during the day. This captured solar energy is then stored in batteries and released to power street lighting at night [10]. Another novel approach connects PV systems to the grid, allowing excess energy generated during daylight hours to be sent to the grid and used to illuminate streets after dark [11]. In Libya, Khalil et al. [12] studied the effects of switching Libya's street lighting from fossil fuels to solar energy, concentrating on a 4-kilometer stretch of road equipped with four different kinds of lamps: stand-alone solar-powered LED lamps, conventional high pressure sodium (HPS) lamps, conventional LED lamps, and grid-connected solar-powered LED lamps. According to their research, switching from HPS lamps to LED lighting can cut CO_2 emissions and electricity use by 75%. Ibrahim et al. [13] suggested using solar energy in Egypt to power an intelligent smart street light system in Giza. Using a 15 W LED Philips lamp, a 45 W monocrystalline panel, a 12 V 37.5 AH lithium-ion battery, and a 10 A 12 V charge controller, they assessed the viability of solar street lighting and found considerable promise. Several nations in the Middle East and North Africa (MENA) have conducted solar cell experiments, with notable results in terms of industry, development, and utilization [12–17].

Advanced solar street lighting systems use LEDs with automated intensity adjustments and are powered by solar energy. This guarantees ideal brightness levels during peak usage periods and allows for smooth switching on and off during the night [4]. Despite these advances, standalone solar streetlights (SASSL) suffer issues such as early battery failure owing to undercharging and low energy output from PV modules [11]. To address these challenges, a highly innovative and cost-effective smart solar streetlight was created. This next-generation design includes defect detection technologies as well as continuous monitoring of solar and battery voltage to handle possible difficulties ahead of time [18]. By effectively tackling technical concerns and leveraging advancements in monitoring and fault detection, the smart solar streetlight offers enhanced reliability and performance. This not only reinforces the viability of solar energy as a sustainable and efficient solution for street lighting but also contributes to the global transition towards cleaner and greener urban infrastructure.

The use of solar powered LED street lights has arisen as an intriguing topic for both research and practical applications in the commercial sphere. Currently, there is a significant transition away from conventional high intensity discharge (HID) lamps, notably HPS lamps, and toward more energy-efficient LED lights [19]. In modern installations, the essential components of a solar-powered LED street light system include a solar panel, an LED light fixture, a rechargeable battery, a controller, and a pole.

During daylight hours, the solar panel converts sunlight into power, charging the battery for later usage. A charge controller regulates the charging process to guarantee that the battery is healthy and long-lasting. A control circuit monitors the performance of the LED bulb and, in many cases, incorporates sensors such as LDRs to alter brightness based on ambient light conditions. These components are usually attached to a pole for easy installation. The solar panel is strategically positioned atop the pole to reduce shadowing, optimizing solar energy absorption and system efficiency [19]. This arrangement allows for continuous charging cycles and excellent performance from the LED street light system.

The purpose of this study is to solve the issue of inadequate illumination at the Kuwaiti roundabout in the Gaza

Strip, Palestine. Persistent power outages have left the roundabout inadequately lighted, resulting in several automobile accidents. This roundabout is significant since it is located on the main route that connects Gaza's eastern and western districts. This study aims to present realistic alternatives for lighting the roundabout using solar energy via the placement of solar cells. In addition, this study discusses numerous possibilities for adopting solar-powered lighting systems and provides recommendations based on a thorough investigation.

2 Methodology and Results

This section presents the concerns of system design and the selection of the optimal design. The study methodology can be divided into two parts:

a) Use of mathematical modeling to design solar PV systems step by step.

b) Validation of the simulation result using PVsyst v7.3.

2.1 Study Site

The Kuwaiti roundabout (Figure 1) is located on Salah El-Deen Street in the middle of the Gaza Strip. Salah El-Deen Street connects Gaza's east and west. At the Kuwaiti roundabout, four streets converge, each with two directions and a width of 12 meters. A Kuwaiti roundabout is surrounded by four 12-meter-tall electrical poles spaced 30 meters apart. Each pole is equipped with three 150-watt illumination lights.

Figure 1. The Kuwaiti roundabout

Source: Google map.

2.2 Site Analysis

Research on the solar radiation was conducted at the study site of the Kuwaiti roundabout (31.4799 N, 34.4423 E). Using Meteonorm 8.1 (https://meteonorm.com/en/meteonorm-version-8), the average irradiation is $5.4\mathrm{kWh}/\mathrm{m}^2$/day.

2.3 Proposed Scenarios

The goal of each scenario is to illuminate the roundabout in times of power outages with solar energy, while the lighting lamps work with electricity in times of availability.

In this study, six scenarios were proposed to light a Kuwaiti roundabout, which are the most proposed ones in the literature. In addition, the chosen components were taken from local markets.

Scenario 1: Centralized systems with a 400 W sodium lamp and a 220 volt alternating current (VAC) input voltage.

Scenario 2: Centralized systems using a 150 W LED lamp with a 220 VAC input voltage.

Scenario 3: Decentralized independent systems (each lighting pole contains all the components of the complete system), using a 150 W LED lamp with a 220 VAC input voltage.

Scenario 4: Decentralized independent systems equipped with a 150 W LED lamp and a 24 direct current voltage (VDC) input voltage.

Scenario 5: Decentralized independent systems, using a 150 W LED lamp and an input voltage of 24 VDC or 220 VAC.

Scenario 6: All-in-one LED solar street lighting solution.

2.4 Assumptions and Limitations of This Study and Uncertainties of the Results

To make the analysis easier, the following assumptions were considered:

a) There is no shading or partial shading on the panel.
b) Neglect of the degradation in energy production with time.
c) There are no faults occurring in controllers.

This study has several limitations. Harsh weather factors were not taken into consideration, such as storms during the operation and/or the safety of the panels. The impact of dust accumulation and cleaning work was also not taken into account in energy and economic calculations [20]. The study did not consider other schemes of street lighting, such as the scheme proposed by Nader [1]. In addition, as for the impact of the technical characteristics on the performance of the entire system, a sensitivity analysis was not made.

The availability of climatic and load data, the choice of system modeling, and parameter estimations are the main sources of uncertainty. The cost of renewable energy facilities also results in uncertainty. According to Fathi et al. [21], the prices of solar instrumentation varied by 360%. However, the uncertainty of PV systems is considered the lowest among all renewable energy systems, not exceeding 4% [22].

2.5 Calculation Procedure

The following steps were taken for each situation:

a) Determining the demand for power consumption.
b) Determining the suitable size for PV modules.
c) Choosing appropriate inverters and charge controllers.
d) Calculating the battery capacity.
e) Choosing proper cables and wiring.
f) Selecting circuit breaker and fuse safety.
g) Determining the angle of inclination for the panels using computation.
h) Determining the cost of energy (COE) and payback period.

2.6 Load Sizing

Table 1 shows the number of streetlights and their capacities, as well as the expected monthly and yearly total consumption. It is worth noting that streetlight usage changes throughout the year, with an increase in the winter and a decrease in the summer. As a result, streetlights were designed to operate for an average of twelve hours every day [10].

Table 1. Load sizing

Number of LED street lights	12
Rating of each light	150 W
Total load	1.8 kW
Operating duration	12 hrs/day
Energy consumption/day	21.6 kWh
Yearly consumption	78.8 MWh

2.7 Stand-Alone System (Off-Grid System)

Off-grid systems (Figure 2) rely only on solar power. They may consist merely of PV modules and a load, or include batteries for energy storage. When batteries are used, charge regulators are incorporated. These regulators deactivate the PV modules upon full battery charge and may also disable the load to prevent battery drain below a certain threshold, as shown in the figure below.

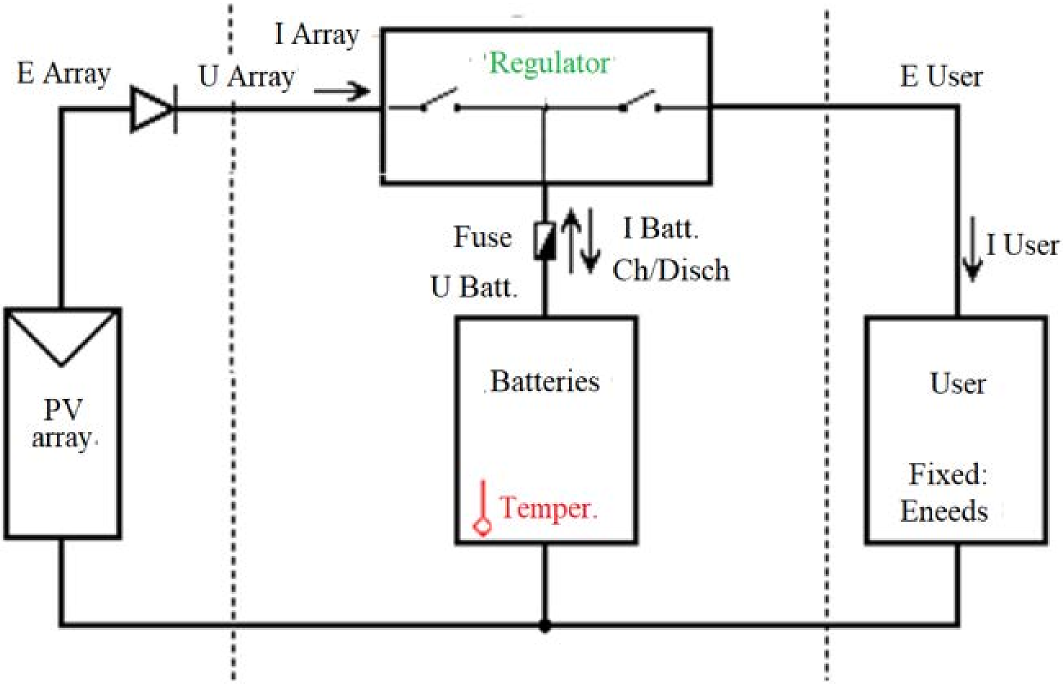


Figure 2. Stand-alone system schema

As an illustration, Scenario 2 was employed to elucidate detailed calculations and simulations for the proposed system, as outlined in Sections 2.8 and 2.9, respectively. Then Scenario 6 was explained.

2.8 Case Study 1: Design of the PV System Using Mathematical Equations

When designing the PV system using mathematical equations, Scenario 2 was chosen as an example to demonstrate the calculations.

2.8.1 Size of PV modules

The governing equation of the electrical characteristics (ζ_{PV}) of the PV panel under real operation and climatic conditions is given by the following equation [23]:

$$\zeta_{PV} = \zeta_{STC}\left[1 + \beta_{\zeta}\left(T_{cell} - T_{STC}\right)\right]\frac{H_t}{H_{STC}} \tag{1}$$

where, ζ_{PV} and ζ_{STC} denote the real and standard test conditions (STC) of any electrical characteristic, such as current, voltage, power, and efficiency; H_t and H_{STC} are the states for global solar radiation incident on the PV panel and the STC solar radiation; T_{STC} and T_{cell} are the cell's surface temperatures at STC and under real conditions; β_{ζ} is the temperature coefficient of the characteristic. It is challenging to estimate T_{cell}. The following empirical equation has been used to determine the cell surface temperature T_{cell} as a function of ambient air temperature T_{∞} and the global solar radiation H_t by many researchers [24–27]:

$$T_{\text{cell}} = T_{\infty} + 7.8 \times 10^{-2} H_t \tag{2}$$

The following equations were used to determine the PV size:

$$PV\ Sizing(kWp) = \frac{Loads(kWh)}{D.F \times Sunny\ Hours(hours)} \tag{3}$$

$$PV\ Sizing(kWp) = \frac{21.6(kWh)}{0.8 \times 5.4(hours)} = 5000Wp \tag{4}$$

$$Number\,of\ PV\ Panels = ceil\left(\frac{PV\ Sizing(kWp)}{Power\ Panel(kWp)}\right) \tag{5}$$

$$Number\,of\ PV\ Panels = ceil\left(\frac{5000Wp}{650Wp}\right) = 8panels \tag{6}$$

Therefore, eight panels were needed to cover the load. RSM132-8-650BMDG PV panel type was chosen according to the recommendation of Nassar et al. [28], which is consistent with the specifications in Table 2.

Table 2. Specifications of the solar panel [29]

Electrical Data	RSM132-8-650BMDG
Technology Type	Monocrystalline
Nominal Maximum Power (Pmax)	650 W
Optimum Operating Voltage (Vmp)	37.87 V
Optimum Operating Current (Imp)	17.17 A
Open Circuit Voltage (VOC)	45.49 V
Short Circuit Current (ISC)	18.18 A
Power Temperature Coefficient (β_p)	-0.377 (%/°C)
Voltage Temperature Coefficient (β_V)	-0.290 (%/°C)
Current Temperature Coefficient (β_I)	0.49 (%/°C)

2.8.2 Tilt and azimuth angles of the PV module

It is critical to realize that the tilt angle of the PV module is the angle between the module and the ground. As a result, it is critical to select the appropriate tilt angle for maximum solar energy absorption. The PV module keeps a steady tilt throughout the year, aiming to find the tilt angle that allows for the most solar radiation intake. The solar panels were fixed south-facing at an angle of 30° based on the recommendation of local researchers [30, 31]. At this position, the maximum yearly insolation value is 5.4 $\mathrm{kWh/m^2/day}$.

2.8.3 Rated inverter

The inverter is required to operate at 1.25 times the peak power. Therefore, the rated power of the inverter equals:

$$Rated\,inverter\,apperant\,power(kVA) = \frac{1.25 \times peak\,power(kW)}{pf\ (\frac{kW}{kVA})} \tag{7}$$

$$Rated\,inverter\,apperant\,power(kVA) = \frac{1.25 \times 1.8}{0.8} = 3\text{kVA} \tag{8}$$

Selected according to the research by Nassar et al. [32], the inverter (MPS-3500H) can satisfy this condition and is available in the local market. Table 3 presents its specifications.

Table 3. Specification of the inverter [33]

Electrical Data	MPS-3500H
Maximum PV Array Power	5000 W
Maximum PV Array VOC	500 VDC
Maximum Solar Charge Current	110 A
Maximum AC Charge Current	80 A
Maximum Efficiency	97%

2.8.4 Panel connection

Two arrays of panels, each with four panels connected in series, were used to provide the necessary voltage and current [34]. The following are the VOC and ISC that result from this configuration:

$$(panel) = 4 \times 45.49 = 181.96 \text{ V} < VOC(PV \text{ Array }) \tag{9}$$

$$ISC = 18.18VA \tag{10}$$

$$IMax\, PV\, Array = ISC\,(2parallel\, Arrays) = 2 \times (panel) = 36.36 \tag{11}$$

The current from the PV array is 36.36A, which is lower than the maximum solar charge current of 110A.

2.8.5 Battery sizing and connection

The capacity of the required batteries can be estimated as follows [35, 36]:

$$Battery\, Bank\, Capacity(Ah) = \frac{Daily\, Energy\,(wh/day) \times Days\, of\, autonomy(day)}{\eta \times DoD \times System\, Voltage(V)} \tag{12}$$

The depth of discharge (DoD) was taken at 50%.

$$Battery\, Bank\, Capacity(Ah) = \frac{21600\left(\frac{wh}{day}\right) \times 1(day)}{0.85 \times 0.5 \times 24(V)} = 2118AH \tag{13}$$

$$Number\, of\, Series\, Batteries = \frac{System\, Voltage(V)}{Battery\, Voltage(V)} \tag{14}$$

$$Number\, of\, Series\, Batteries = \frac{24}{12} = 2 \tag{15}$$

$$Total\, Number\, of\, Batteries = \frac{Number\, of\, Series\, Battery \times Battey\, Bank\, Capacity(Ah)}{Capacity\, of\, One\, Battery(Ah)} \tag{16}$$

$$Total\, Number\, of\, Batteries = \frac{2 \times 2118(Ah)}{200(Ah)} = 22 \tag{17}$$

The 200AH type FUSION model was chosen for the batteries, as it is available on the market.

As for the connection of batteries, 11 branches were used to fulfill the above condition, with each branch having a two-battery connection in series.

2.8.6 The cost of the system

Table 4. The cost of the system

Component	Number	Cost of One Unit ($)	Total Cost ($)
Solar panel type Risen 650 wp	8	250	2000
MPS-3500H inverter	1	360	360
Battery 200 AH - FUSION	22	290	6380
LED street light 150 W	12	50	600
Total cost			**9340**

Table 4 displays the total cost of the system. However, the cost depends on the DoD for the batteries. Table 5 displays the number of batteries which change as the DoD changes, which in turn affects the total cost of the system.

Table 5. Number of batteries and total cost with DoD as a function

DoD	Number of Batteries	Total Cost
50%	22	9340
60%	18	8180
70%	16	7600
80%	14	7020
90%	12	6440

Each component in the above computation was carefully chosen based on its accessibility in the regional market. This guarantees that the parts utilized for the project not only fit the standards and specifications needed but are also easily accessible. The goal of sourcing components locally is to make procurement simpler, shorten lead times, and assist regional vendors. The close proximity of suppliers enables quicker maintenance and replacements, guaranteeing the project's seamless completion. The Levelized cost of energy (LCOE) is an economic measure to estimate the project profit and a reference for comparison with other production choices. The cost of environmental damage produced by CO_2 may be used to compute LCOE using the following equation [37]:

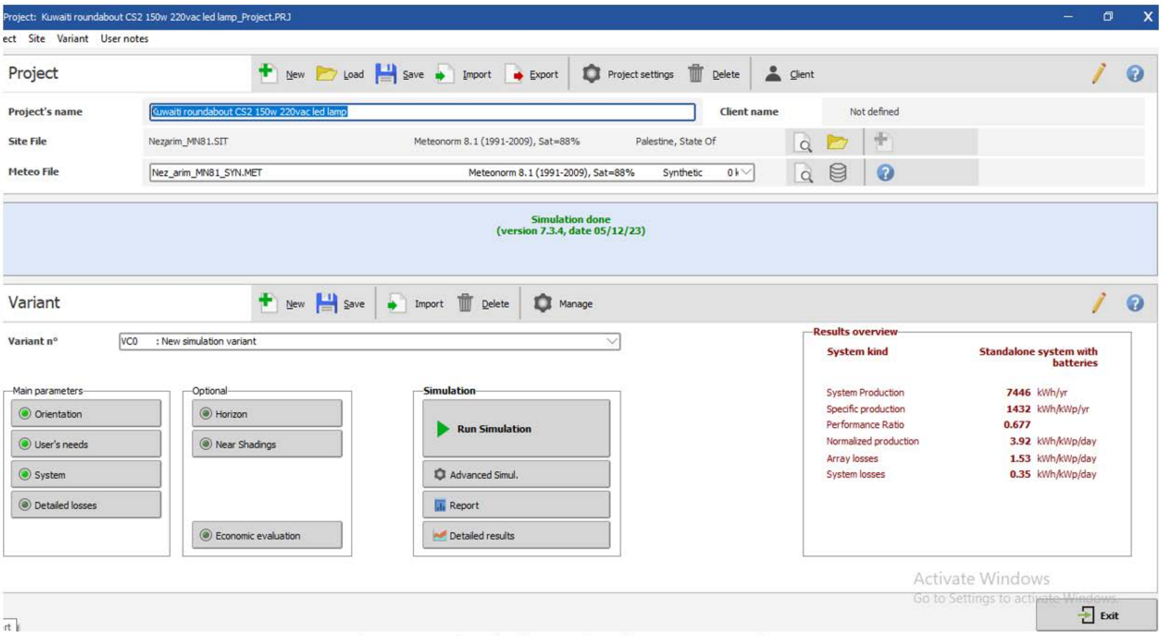
$$LCOE = \frac{\left(\frac{r(1+r)^n}{(1+r)^n-1}\right) \times C + C_{\mathrm{O\&M}},}{E_t} \tag{18}$$

where, $C_{O\&M}$ denotes the cost of operation and maintenance ($/year), C is the capital cost ($\$$), E_t is the power (kW) of the proposed system, n denotes the device lifetime (30 years), r is the annual inflation rate (8%), and the subscripts H and B denote the two power generation systems of hydropower turbine and biogas-based generator. In addition, the number 8760 refers to the number of working hours in a year.

2.9 Case Study 1: Design of the PV System Using PVsyst

When designing the PV system using PVsyst, Scenario 2 was chosen as an example to demonstrate the simulation using PVsyst system v7.3. Several steps were taken for the simulation.

2.9.1 Design of the solar PV system



Project: Kuwaiti roundabout CS2 150w 220vac led lamp_Project.PRJ

Project's name: Kuwaiti roundabout CS2 150w 220vac led lamp

Client name: Not defined

Site File: Nezarim_MN81.SIT — Meteonorm 8.1 (1991-2009), Sat=88% — Palestine, State Of

Meteo File: Nez_arim_MN81_SYN.MET — Meteonorm 8.1 (1991-2009), Sat=88% — Synthetic

Simulation done
(version 7.3.4, date 05/12/23)

Variant n°: VC0 : New simulation variant

Results overview

System kind	Standalone system with batteries	
System Production	7446	kWh/yr
Specific production	1432	kWh/kWp/yr
Performance Ratio	0.677	
Normalized production	3.92	kWh/kWp/day
Array losses	1.53	kWh/kWp/day
System losses	0.35	kWh/kWp/day

Figure 3. Simulation using the PVsyst software

The planning and simulation of a 5.2 kWp solar PV system were conducted using PVsyst software version 7.3. As a powerful software for PV systems, PVsyst is designed for architects, engineers, and researchers. It is also a very useful educational tool, including a detailed contextual "Help" menu that explains the procedures and models used and offers a user-friendly approach with a guide to developing a project. PVsyst is able to import meteo and personal data from many different sources and allows for both preliminary and post-analysis assessments of potential power generation [38]. The system is designed according to the specifications outlined in the methodology, which includes the selection and rating of PV modules, inverters, and array configurations tailored for a 5.2 kWp solar PV system, as shown in Figure 3. This comprehensive approach ensures accurate planning and optimization of the system's performance. The PVsys software has been validated and extensively used by local commercials, engineers and scientists in order to evaluate the feasibility of PV solar systems in the Gaza Strip [39–41].

2.9.2 Simulation results

a) Performance ratio

Figure 4 displays the performance ratio of this system, which is 67.6%, meaning that only 32.4% of the energy generated through the PV panels is lost in the system.

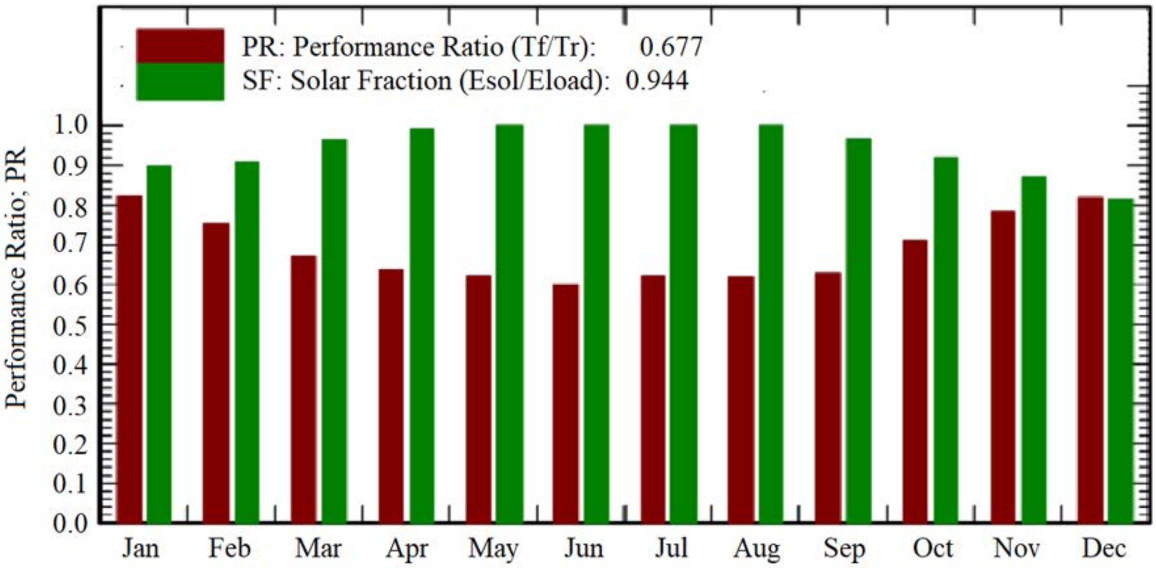


Figure 4. Performance ratio

As depicted in Figure 5, the normalized production per installed kWp demonstrates a nominal power of 5.2 kWp for each month in the year. The maximum occurs in June which is the hottest month of the year.

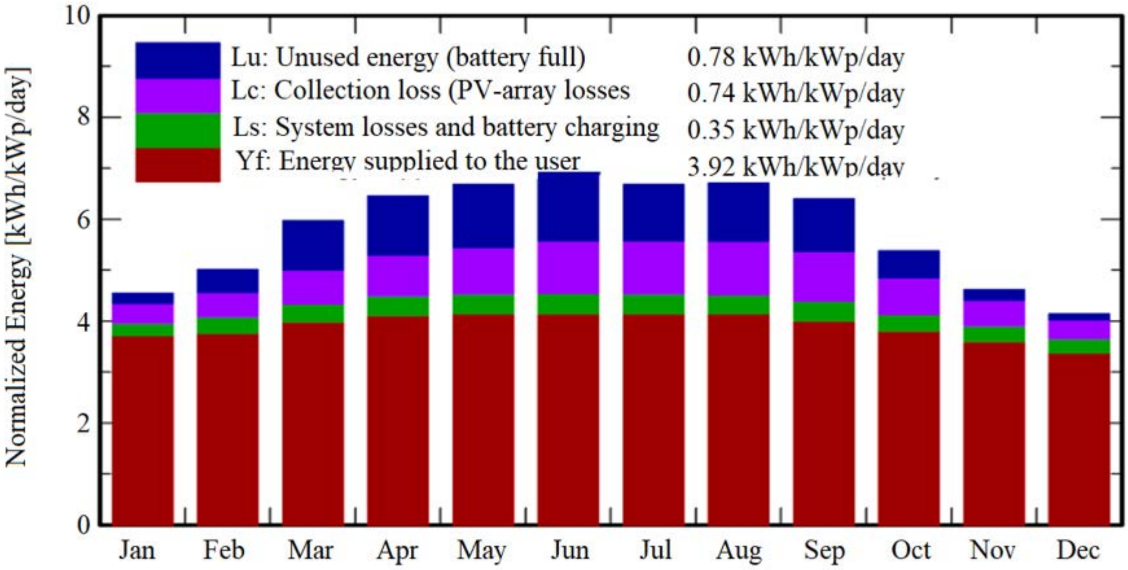


Figure 5. Normalized production (per installed kWp) with a nominal power of 5.2 kWp

b) Daily input/output diagram

Figure 6 shows the connection between the worldwide incidents of solar irradiation on the collector plane (measured in $\mathrm{kWh/m^2/day}$) and the effective energy production (measured in kWh/day) at the array's output. The amount of solar irradiation a PV module obtains directly affects its production. The technology produces more electricity when the PV panel's sun irradiation rises. Put another way, a PV system produces more energy when there is more sunshine.

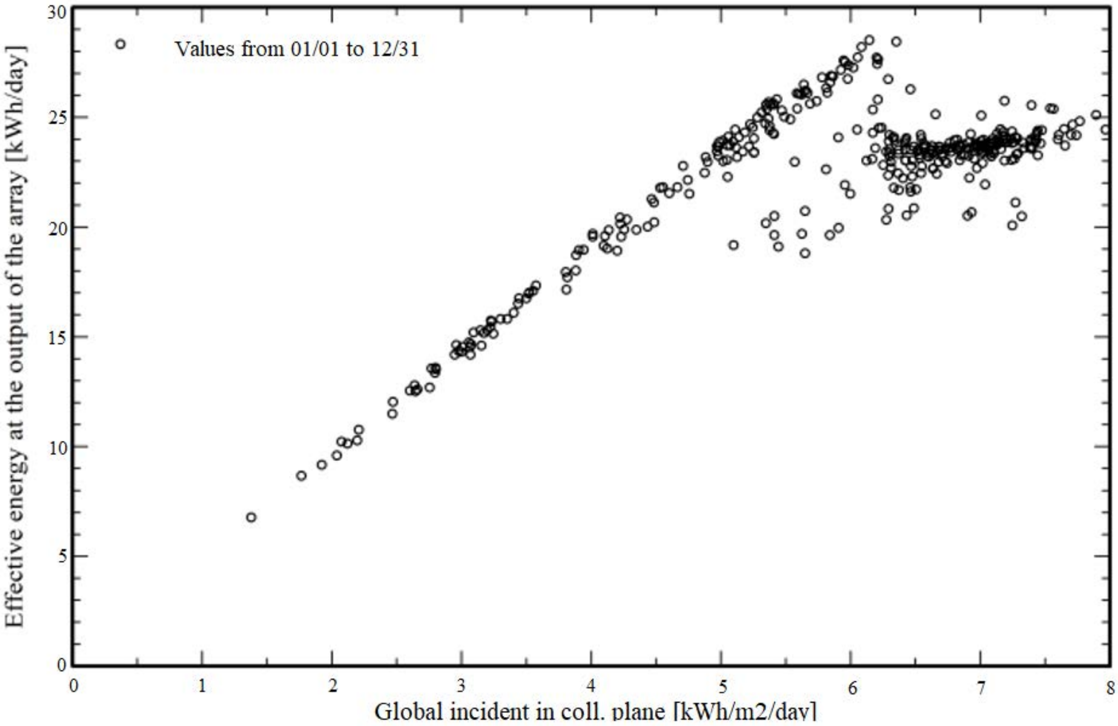


Figure 6. Daily input/output diagram

2.10 Comparative Analysis

Table 6 shows a comparison between the calculated and simulated PV systems.

Table 6. Comparison between the two PV systems

Item	Calculated PV Using Equations	Simulated PV Using PVsyst
Energy consumption/day	21.6 kWh	21.6 kWh
PV sizing (kWp)	5	5.2
Number of PV panels	8	8
Module area	30 m^2	24.9 m^2
Tilt angle	30°	30°
Azimuth	0°	0°
Number of batteries at 80% DOD	14	10

As shown in Table 6, there is a high level of agreement between the calculated and simulated values for both systems. This alignment underscores the accuracy and reliability of the calculations and simulations performed. Therefore, individuals may confidently choose any method without hesitation.

2.11 Case Study 2

This section explains Scenario 6, which is the all-in-one LED solar street light, as shown in Figure 7.

In this case, the PV panel, the light, and the sensors are in one piece. The model used is BW-SSL-05B, which is also available in Gaza. Table 7 presents all the specifications of the all-in-one system.

3 Summary and Comparison of the Different Designs of the Kuwaiti Roundabout

The calculations detailed in the preceding sections were meticulously replicated for each scenario, encompassing all options except for Scenario 6, which was thoroughly elaborated upon in Section 2.11. The results of this study were summarized as follows:

Figure 7. All-in-one LED solar street light

Source: https://www.amazon.co.uk/ZONE-Outdoor-Waterproof-120000LM-Brightness/dp/B0BGP7H3W7.

Table 7. Specifications of the all-in-one LED solar street light model (BW-SSL-05B)

Model	BW-SSL-05B				
Power	50 W	100 W	150 W	200 W	250 W
Size (mm)	200×300	200×390	500×230	620×240	730×230
Solar panel	5 W 5 V	7 W 5 V	9 W 5 V	15 W 6 V	18 W 6 V
Capacity	3.2 V 4.5 AH	3.2 V 5.5 AH	3.2 V 11 AH	3.2 V 13 AH	3.2 V 16 AH
Lighting area (m^2)	40	60	80	100	120
Material	ABS				
Solar panel type	Polycrystalline solar panels				
IP grade	IP65				
Full lighting	6-8 hours				
Rainy day working	2-3 days				
Function	Human sensor remote control				
Working mode	Photocell + sensor + remote control				
Application	Highway, parking lot, courtyard, road, outdoor, etc.				

a) Case study 1

The design was made using the central system in the presence of sodium flashlights. It was found that sodium flashlights consumed a high capacity using manual calculations in addition to simulation, leading to the need for 56 batteries and 20 solar cell panels, in addition to the number of two inverters, as shown in the table. The main problem with this design is that an area of no less than 60 m^2 is needed to place the system components, which is not available for every roundabout on the road, in addition to the high cost.

b) Case study 2

Sodium lamps were replaced with lamps equivalent to the intensity of lighting, which are LED lamps with a capacity of 150 watts. This design shows the advantages of LED lamps, with the number of batteries decreasing from 56 to 22, that of solar cell panels from 20 to 8, and inverters from 2 to 1. The area ranges from 60 m^2 to 30 m^2. It was also found in this design that it is not possible to provide an area of 30 m^2 for each roundabout on the road.

c) Case study 3

The design was made using an independent system to solve the space problem that appeared in the first and second case studies. The independent system means that each lighting pole carries all the components of the system. The Kuwaiti roundabout consists of four columns, with each column consisting of three LED lights with a capacity of 150 watts. It was found that each lighting pole requires two solar panels, six batteries, and one inverter. The cost increased slightly, as indicated in the table, due to the use of an inverter for each lighting pole.

It can be noted that the use of inverters in the first, second, and third study cases provides the possibility for the lamps to operate if electricity and charging are available through the electricity network. However, this leads to an increase in the load on the network due to the charging process of the system.

Table 8. A comparison of the different designs of the Kuwaiti roundabout

System Type	**Scenario 1** Off grid Central systems	**Scenario 2** Off grid Central systems	**Scenario 3** Off grid Distributed independent systems
Load	Sodium light (400 W)	LED lights (150W)	LED lights (150W)
Rated voltage load	$220 - 240\mathrm{AC}$	$\mathrm{AC}85 - 305$	$\mathrm{AC}85 - 305$
Number of LED lights	12	12	12
Type of PV module	Solar panel type Risen 650 wp	Solar panel type Risen 650 wp	Solar panel type Risen 650 wp
Number of PV modules	20	8	8
Type battery	Battery 200AH type FUSION	Battery 200AH type FUSION	Battery 200AH type FUSION
DOD	50%	50%	50%
Number of batteries	56	22	24
Type of controller	Rich solar inverter 6.5 KW	MPS-3500H inverter	Axpert mks 2k-24 plus
Number of controllers	2	1	4
System voltage	48VDC	24VDC	24VDC
Cost for one column ($)	6270	2335	2690
Cost of the system ($)	25080	9340	10760
Lights work if electricity is available	Yes	Yes	Yes
Charging if electricity is available	Yes	Yes	Yes
Ease of maintenance	Yes	Yes	No
Area	60 m^2	30 m^2	No

System Type	**Scenario 4** Off grid Distributed independent systems	**Scenario 5** Off grid Distributed independent systems	**Scenario 6** Off grid All-in-one
Load	LED lights (150 watts)	LED lights (150 watts)	LED lights (200 watts)
Rated voltage load	DC24	DC24 or AC85-305	All-in-one
Number of LED lights	12	12	All-in-one
Type of PV module	Solar panel type Risen 650 wp	Solar panel type Risen 650 wp	All-in-one
Number of PV modules	8	8	All-in-one
Type battery	Battery 200AH type FUSION	Battery 200AH type FUSION	All-in-one
DOD	50%	50%	All-in-one
Number of batteries	24	24	All-in-one
Type of controller	RS-MPPT40	RS-MPPT40 +Contactor	All-in-one
Number of controllers	4	4	All-in-one
System voltage	24VDC	24VDC	All-in-one
Cost for one column ($)	2540	2560	300
Cost of the system ($)	10160	10240	1200
Lights work if electricity is available	No	Yes	Yes
Charging if electricity is available	No	No	No
Ease of maintenance	No	No	No
Area	No	No	No

d) Case study 4

The inverter was replaced with a charge controller to get rid of the loading problem on the network and disconnect from the network completely. In this case, LED lights operating at a continuous voltage of 24 volts were used, but the lights did not work if electricity was available.

e) Case study 5

The LED lamps were replaced with lamps operating at a constant voltage of 24 volts and an alternating voltage of 220 volts. A switch was used for two sources of electricity, i.e., cells or the electricity network, as shown in the figure. In this case study, the independent system was adopted to get rid of the space problem that appeared in the first and second case studies. A charging controller was used in addition to the switch instead of the inverter, eliminating the loading problem on the network. Floodlights operating with two voltage sources were used to provide the possibility of lighting if electricity was available from the network or through the solar energy system, thereby making it possible to charge the system for an additional day without loading the network. After comparing the designs, it was found that this case study is the best design for the Kuwaiti roundabout in relation to the cases mentioned above.

f) Case study 6

This case study discusses a searchlight that runs entirely on solar energy at a low price, in addition to a set of features, as shown in the above table. This case is considered a proposal for use in the future. No experiment was conducted previously to prove the efficiency of the system.

Table 8 shows an exhaustive comparison of the six scenarios, offering a comprehensive insight into the various factors considered and outcomes observed across the different setups.

4 Conclusion

Various case studies were explored in this study, aiming to optimize solar-powered lighting systems for the Kuwaiti roundabout. A central system utilizing sodium flashlights was initially investigated, which highlighted challenges such as high power consumption, space requirements, and cost implications. The transition to LED lamps in the second case study demonstrated significant improvements in efficiency and cost-effectiveness, albeit with continued spatial constraints. The third case study introduced an independent system design, distributing components across lighting poles to address space limitations. However, this approach slightly increases costs due to the use of individual inverters.

Further improvements were made in the fourth case study, which replaced inverters with charge controllers, alleviating network loading concerns but presenting limitations with LED light operation in the presence of available electricity. The fifth case study showcased an innovative solution with dual-voltage lamps and a switch mechanism, offering versatility in power sources and addressing space constraints effectively. In comparison, this design emerged as the most suitable solution for the Kuwaiti roundabout.

Finally, the proposal of a solar-powered searchlight in the sixth case study presents a promising avenue for future consideration, albeit requiring experimental validation to confirm its efficiency. Overall, this study underscores the importance of considering factors such as power consumption, space utilization, and cost-effectiveness when designing solar lighting systems for urban environments. By exploring various design options and innovative solutions, this study paves the way for sustainable and efficient lighting solutions in the communities in the Gaza Strip.

5 Recommendations

The following recommendations were proposed for further research:

a) Integration of car detection sensors: Future research should include improved sensors capable of detecting approaching automobiles. These sensors may be strategically positioned throughout the roundabout to detect the presence of vehicles. When the sensors detect something, they may activate the lights automatically, providing cars with better visibility and safety while negotiating the roundabout. Furthermore, the incorporation of a sophisticated control system allows the lights to be switched off when no cars are detected, thereby saving energy and minimizing wasteful lighting during low-traffic periods.

b) Development of an early problem detection control system: Another recommendation is to create a complete control system equipped with sensors and monitoring devices to detect and solve possible difficulties early on. By continually monitoring the lighting system's performance, this control system may detect abnormalities, such as faulty components or inconsistencies in energy usage. Early identification of faults enables early intervention and preventative maintenance, reducing the danger of further damage and preserving the lighting infrastructure's dependability and lifetime.

The implementation of these ideas in future studies can considerably enhance the functioning and efficiency of the roundabout's lighting system, resulting in safer travel conditions and optimized energy use.

Data Availability

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

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] N. H. Shehadeh, "Assessment of the street lighting in Lebanon," CEDRO/UNDP, 2015. https://pdfroom.com/books/assessment-of-the-street-lighting-in-lebanon/jGk20vwKdpm

[2] Y. Nassar and S. Alsadi, "Economical and environmental feasibility of the renewable energy as a sustainable solution for the electricity crisis in the Gaza Strip," *Int. J. Eng. Res. Dev.*, vol. 12, no. 3, pp. 35–44, 2016.

[3] "Electricity sector in Palestine," WAFA. https://info.wafa.ps/ar_page.aspx?id=B0Uf3Va28106217843aB0Uf3V

[4] A. Mukhtar and R. Kumar, "Advance solar power LED street lighting with auto intensity control," *J. Emerg. Technol. Innov. Res.*, vol. 7, no. 5, pp. 974–983, 2020.

[5] C. Ellis, T. R. Vineetha, S. S. Keerthi, S. P. Kalpana, and R. R. Karen, "Internet of things-based smart street system," *Rev. Gestão Inov. Tecnol.*, vol. 11, no. 4, pp. 5577–5594, 2021.

[6] W. Sutopo, I. S. Mardikaningsih, R. Zakaria, and A. Ali, "A model to improve the implementation standards of street lighting based on solar energy: A case study," *Energies*, vol. 13, no. 3, p. 630, 2020. https://doi.org/10.3390/en13030630

[7] D. Bentabet and S. R. Sonaskar, "Energy efficient: IOT based street lights monitoring system by using solar energy with NodeMCU," in *Second International Conference on Embedded and Distributed Systems*, 2019.

[8] M. M. Hasan, M. K. Hasan, R. Biswan, A. A. Malek, and M. M. Parway, "Design and feasibility analysis of a solar PV system for street lighting in a university campus," *Int. J. Sci. Eng. Appl.*, vol. 8, no. 9, pp. 432–437, 2019. https://doi.org/10.7753/IJSEA0809.1006

[9] "Solar street lighting market to generate $14.6 billion by 2030," P&S Intelligence. https://www.linkedin.com/pulse/solar-street-lighting-market-generate-146-billion-2030-iaoqc/

[10] M. S. Shahat, S. M. Sharaf, M. Edrees, and M. Abdelhalim, "Environmental and economic impacts of lighting highways using photo-voltaic panels," *Int. J. Sci. Adv.*, vol. 2, no. 2, 2021. https://doi.org/10.51542/ijscia.v2i2.8

[11] N. Parween and M. T. Tevatia, "Grid connected solar PV system for street light," *J. Emerg. Technol. Innov. Res.*, vol. 7, no. 9, pp. 81–85, 2020.

[12] A. Khalil, Z. Rajab, M. Amhammed, and A. Asheibi, "The benefits of the transition from fossil fuel to solar energy in Libya: A street lighting system case study," *Appl. Sol. Energy*, vol. 53, pp. 138–151, 2017. https://doi.org/10.3103/S0003701X17020086

[13] M. M. Ibrahim, A. M. Elwany, and L. K. Elansary, "Sustainable technical design and economic–environmental analysis of SMART solar street lighting system in Giza City, Egypt," *Int. J. Energy Environ. Eng.*, vol. 12, pp. 739–750, 2021. https://doi.org/10.1007/s40095-021-00403-2

[14] K. Shahzad, L. Čuček, M. Sagir, A. S. Nizami, T. Iqbal, T. Almeelbi, and I. M. I. Ismail, "A case study for developing eco-efficient street lighting system in Saudi Arabia," *Chem. Eng. Trans.*, vol. 52, pp. 1141–1146, 2016. https://doi.org/10.3303/CET1652191

[15] M. Wadi, A. Shobole, M. R. Tur, and M. Baysal, "Smart hybrid wind-solar street lighting system fuzzy based approach: Case study Istanbul-Turkey," in *2018 6th International Istanbul Smart Grids and Cities Congress and Fair (ICSG), Istanbul, Turkey*, 2018, pp. 71–75. https://doi.org/10.1109/SGCF.2018.8408945

[16] G. Liu, "Sustainable feasibility of solar photovoltaic powered street lighting systems," *Int. J. Electr. Power Energy Syst.*, vol. 56, pp. 168–174, 2014. https://doi.org/10.1016/j.ijepes.2013.11.004

[17] F. Outferdine, L. Bouhouch, M. Kourchi, M. Ajaamoum, and A. Moudden, "Feasibility of substitution of the conventional street lighting installation by the photovoltaic case study on a municipality in Agadir in Morocco," *Int. J. Electr. Comput. Eng.*, vol. 7, no. 5, pp. 2287–2299, 2017. https://doi.org/10.11591/ijece.v7i5

[18] E. Anoliefo, O. U. Oparaku, S. Egoigwe, and S. Olisa, "Determination of the failure mechanism of stand-alone solar street light," *Niger. J. Technol.*, vol. 39, no. 2, pp. 572–576, 2020. https://doi.org/10.4314/njt.v39i2.28

[19] F. T. K. Wong, "A cost effective solar powered led street light," Doctoral dissertation, Universiti Tun Hussein Onn Malaysia, 2014.

[20] A. H. Alsharif, A. A. Ahmed, Y. F. Nassar, M. M. Khaleel, H. J. El-Khozondar, T. E. Alhoudier, and E. M. Esmail, "Mitigation of dust impact on solar photovoltaics performance considering Libyan climate zone: A review," *Wadi Alshatti Univ. J. Pure Appl. Sci.*, vol. 1, no. 1, pp. 22–27, 2023.

[21] Y. Fathi, H. J. El-khozondar, A. A. Ahmed, A. Alsharif, M. M. Khaleel, and R. J. El-Khozondar, "A new design for a built-in hybrid energy system, parabolic dish solar concentrator and bioenergy (PDSC/BG): A case study–Libya," *J. Clean. Prod.*, vol. 441, p. 140944, 2024. https://doi.org/10.1016/j.jclepro.2024.140944

[22] Y. F. Nassar, S. Y. Alsadi, H. J. El-Khozondar, M. S. Ismail, M. Al-Maghalseh, T. Khatib, J. A. Sa'ed, M. H.

Mushtaha, and T. Djerafi, "Design of an isolated renewable hybrid energy system: A case study," *Mater. Renew. Sustain. Energy*, vol. 11, no. 3, pp. 225–240, 2022. https://doi.org/10.1007/s40243-022-00216-1

[23] A. A. Hafez, Y. F. Nassar, M. I. Hammdan, and S. Y. Alsadi, "Technical and economic feasibility of utility-scale solar energy conversion systems in Saudi Arabia," *Iran. J. Sci. Technol. Trans. Electr. Eng.*, vol. 44, pp. 213–225, 2020. https://doi.org/10.1007/s40998-019-00233-3

[24] H. J. El-Khozondar, F. El-batta, R. J. El-Khozondar, Y. Nassar, M. Alramlawi, and S. Alsadi, "Standalone hybrid PV/wind/diesel-electric generator system for a COVID-19 quarantine center," *Environ. Prog. Sustain. Energy*, vol. 42, no. 3, p. e14049, 2023. https://doi.org/10.1002/ep.14049

[25] Y. F. Nassar, H. J. El-Khozondar, M. Elnaggar, F. F. El-batta, R. J. El-Khozondar, and S. Y. Alsadi, "Renewable energy potential in the State of Palestine: Proposals for sustainability," *Renew. Energy Focus*, vol. 49, p. 100576, 2024. https://doi.org/10.1016/j.ref.2024.100576

[26] Y. F. Nassar and A. A. Salem, "The reliability of the photovoltaic utilization in southern cities of Libya," *Desalination*, vol. 209, no. 1-3, pp. 86–90, 2007. https://doi.org/10.1016/j.desal.2007.04.013

[27] Y. F. Nassar, H. J. El-Khozondar, A. A. Alatrash, B. A. Ahmed, R. S. Elzer, A. A. Ahmed, I. I. Imbayah, A. H. Alsharif, and M. M. Khaleel, "Assessing the viability of solar and wind energy technologies in semi-arid and arid regions: A case study of Libya's climatic conditions," *Appl. Sol. Energy*, vol. 60, pp. 149–170, 2024. https://doi.org/10.3103/S0003701X24600218

[28] Y. F. Nassar, S. Y. Alsadi, G. M. Miskeen, H. J. El-Khozondar, and N. M. Abuhamoud, "Mapping of PV solar module technologies across Libyan territory," in *2022 Iraqi International Conference on Communication and Information Technologies (IICCIT), Basrah, Iraq*, 2022, pp. 227–232. https://doi.org/10.1109/IICCIT55816.2022.10010476

[29] "Titan RSM132-8-650BMDG-670BMDG," Risen Energy Co., Ltd. https://www.enfsolar.com/pv/panel-datasheet/crystalline/58433

[30] Y. F. Nassar and S. Y. Alsadi, "Assessment of solar energy potential in Gaza Strip-Palestine," *Sustain. Energy Technol. Assess.*, vol. 31, pp. 318–328, 2019. https://www.doi.org/10.1016/j.seta.2018.12.010

[31] Y. F. Nassar, A. A. Hafez, S. Belhaj, S. Y. Alsadi, M. J. Abdunnabi, B. Belgasim, and M. N. Sbeta, "A generic model for optimum tilt angle of flat-plate solar harvesters for middle east and north Africa region," *Appl. Sol. Energy*, vol. 58, no. 6, pp. 800–812, 2022. https://doi.org/10.3103/S0003701X22060135

[32] Y. F. Nassar, H. J. El-Khozondar, S. Y. Alsadi, N. M. Abuhamoud, and G. M. Miskeen, "Atlas of PV solar systems across Libyan territory," in *2022 International Conference on Engineering & MIS (ICEMIS), Istanbul, Turkey*, 2022. https://doi.org/10.1109/ICEMIS56295.2022.9914355

[33] "Skycorp solar MPS-3500H series off grid solar inverter," Ningbo Skycorp Solar Technology Co., Ltd., 2023. https://www.skycorpsolar.com/product/skycorp-solar-mps-3500h-series-off-grid-solar-inverter/

[34] Y. F. Nassar, *Solar Energy Engineering - Active Applications*. Sebha University, Libya, 2006.

[35] H. J. El-Khozenadar, M. A. Albardawil, M. S. Asfour, I. N. Abu-Khater, and Y. F. Nassar, "DC off-grid PV system to supply electricity to 50 boats at Gaza seaport," in *2023 8th International Engineering Conference on Renewable Energy & Sustainability (ieCRES), Gaza, Palestine*, 2023. https://doi.org/10.1109/ieCRES57315.2023.10209467

[36] A. El Halim, Y. Nassar, H. El-Khozondar, and E. Bayoumi, "Fast charging of lithium-ion battery for electric vehicles applications," in *2023 8th International Engineering Conference on Renewable Energy & Sustainability (ieCRES), Gaza, Palestine*, 2023. https://doi.org/10.1109/ieCRES57315.2023.10209433

[37] H. Awad, Y. F. Nassar, R. S. Elzer, I. Mangir, H. J. El-Khozondar, M. Khaleel, A. Ahmed, A. Alsharif, M. Salem, and A. Hafez, "Energy, economic and environmental feasibility of energy recovery from wastewater treatment plants in mountainous areas: A case study of Gharyan city-Libya," *Acta Innov.*, vol. 50, no. 4, pp. 46–56, 2023. https://doi.org/10.32933/ActaInnovations.50.5

[38] "A powerful software for your photovoltaic systems," PVsyst. https://www.pvsyst.com/

[39] J. Jallad, "Performance evaluation, economic assessment and environmental impact of a 134.55 kWp grid connected solar photovoltaic (PV) power plant in Palestine," *Palestine Tech. Univ. Res. J.*, vol. 11, no. 4, pp. 1–23, 2023.

[40] L. Kahana, "Pvsyst-based comparative analysis for bifacial, monofacial PV projects," *PV Mag.*, 2023.

[41] N. F. Nassar, A. A. Hafez, and S. Y. Alsadi, "Multi-factorial comparison for twenty-four distinct transposition models for inclined surface solar irradiance computation, study case: State of Palestine," *Front. Energy Res.*, vol. 7, p. 136, 2019. https://doi.org/10.3389/fenrg.2019.00163