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Assessments Of School Rooftop Photovoltic Projects In Beit Sahour: A Case Study of Greek Catholic Patriarchate school

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Assessments of School Rooftop Photovoltic Projects In Beit Sahour: A Case Study of Greek Catholic Patriarchate School

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ASSESMENTS OF SCHOOL ROOFTOP PHOTOVOLTIC PROJECTS IN BEIT SAHOUR: A CASE STUDY OF GREEK CATHOLIC PATRIARCHATE SCHOOL

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Jerusalem – Palestine
1446/2024

Declaration

I certify that this thesis submitted for the degree of master is the result of my research, except where otherwise acknowledged, and that this thesis, neither in whole nor in part, has been previously submitted for any degree to any other university or institution.

Signed: Razan

Razan Mohammad Mahmoud Ayesh

Date: 17-05-2025

Dedication

إلى النبع الأول، والظل الوارف، من حملتني دعواته لبلوغ هذا الطريق،
إلى **أبي**، الذي علّمني أن الكفاح يصنع الأمل، وأن العلم زاد لا ينفد.

إلى من كانت دعواتها الصادقة سنداً، كل خطوة على هذا الطريق كانت مدفوعة بدعواتك،
إلى **أمي**، التي احتوتني بحبها، وشدت على يديّ في كل مراحل الطريق.

إلى الغائب الحاضر في القلب، من غيبته القضبان، رمز الصمود والكرامة، حروف هذا العمل تنبض من روح صمودك، وتتشوّق ليوم اللقاء والحرية إلى **أخي** الغالي.

إلى السند الصامت في كل خطوة، رفيقات الدرب والروح، إلى **أخواتي** العزيزات.

إلى شريك الحلم والواقع، وسندي في كل التحديات، إلى **زوجي** شكرًا لصبرك، لدعمك ولإيمانك بي دائما.

لكم جميعاً كل الامتنان، وكل الحب، وكل هذا الإنجاز...فهو منكم ولكم.

الطالبة: رزان عايش

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Abstract

Renewable energy sources have proven their promising potential in meeting energy needs sustainably. The Palestinian territories rely heavily on electricity imports from Israel and neighboring countries, which poses an increasing economic burden due to the insecurity of energy supplies and fluctuating prices, especially in recent years. Despite this, Palestine has abundant solar energy resources, with an average peak sunshine hour of approximately 5.4 hours per day throughout the year, giving it promising potential for developing photovoltaic energy projects and achieving greater energy self-sufficiency.

In this study, an assessment of solar energy potential for Greek Catholic Patriarchate School in Beit Sahour as a case study. Schools are suitable for this type of projects because they are closed for approximately 180 days per year and operate at reduced hours throughout the year, which contributes to a higher annual net solar return.

In this work, an assessment of virtual solar photovoltaic energy project was conducted on the rooftop of the Greek Catholic Patriarchate School in Beit Sahour. The capacity of the system estimated to be 204 KW, over a total area of 909 m^2. The total PV panels used are 352 with an estimated annual electrical energy production of 328440 KWh. The annual consumption of the school in the year 2024 was found to be 39650 KWh, however, the estimated annual surplus is 2887790 KWh.

Therefore, the study concludes that the installation of solar energy units on the roofs of Greek Catholic school's buildings is feasible, according to the cost and payback period. Thus, the study encourages the school to make the decision of installing solar energy units, for its benefits and reducing expenses of the school.

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Abbreviations	Meaning
IEA	International Energy Agency
MWh	Megawatt-Hour
GWh	Gigawatts-Hour
PCBS	Palestinian Central Bureau of Statistics
UNDP	United Nations Development Program
DHI	Diffuse Horizontal Irradiance
GHI	Global Horizontal Irradiation
PV	Photo Voltaic
CSP	Concentrated Solar Power
DC	Direct Current
AC	Alternative Current
SWH	Solar Water Heating
KWP	kilowatt-Peak
PV syst	PV syst Software
KG	Kilo Gram
MJ/m^2	Mega Joules per square meter

Chapter One

Introduction and Literature Review

1.1. Introduction

Electricity is the key element of contemporary life, essential for maintaining comfortable living conditions. It enhances quality of life through economic and industrial ascent activities, both of which depend on electricity. Furthermore, it is vital for providing medical services; additionally, electricity powers educational equipment in academic institutions (Riaz, 2024). The majority of electricity is obtained from power plants that operate turbines connected to electric generators, which convert kinetic energy into electrical energy. The turbines are powered by various resources, including water, wind, heat, and the burning of fossil fuels such as oil, coal, and natural gas (Lumley, 2024). Energy primarily comes from fossil fuels (Nelson, 2015).

Energy production hurts both the environment and human health. Fossil fuels are considered the dirtiest and most dangerous in the immediate future. Air pollution results from burning biomass, including dung, charcoal, and wood. Moreover, greenhouse gas emissions are the main cause of climate change (Ritchie, 2020). For decades, awareness of the issues of climate change and energy has been growing. Climate change leads to disastrous out comes that go beyond what we can comprehend. It is more than just the problem of climate change that disturbs us, but also the rising prices of oil and natural gas, which will not be able to meet future demand. Therefore, it is urgently necessary to find an alternative energy source as a matter of urgency. The key lies in renewable energy (Quaschning, 2015).

Renewable energy is obtained from the continuous and recurring natural flows that occur in the environment, such as wind energy, solar radiation, rivers (hydroelectricity), wind energy, biomass (plant crops), ocean waves, tides, geothermal heat, etc. The efficient use of these materials is more cost-effective and more suitable for sustainable development than fossil fuels (Twidell, 2021).

In 2024, there was an 8% increase in carbon emissions, amounting to 37.8 gigatons of carbon dioxide, 50% above pre-industrial levels. These emissions, resulting from fuel combustion, increased by the equivalent of 375 million tons of carbon dioxide (IEA, 2025). Global energy consumption keeps increasing annually (Ritchie et al., 2020). The buildings sector represents about 36% of global energy consumption and 55% of the worldwide electricity use. Residential buildings account for about 70% of the sector's total energy consumption, mainly due to population growth and the space allocated per person (Santamouris &Vasilakopoulou, 2021). The construction sector is responsible for approximately 37% of global energy-related carbon dioxide (CO_2) emissions. To achieve reductions in CO_2 emissions, the adoption and implementation of low-carbon construction practices are crucial(Nairobi, 2024).

To obtain zero carbon emissions, a sustainable, safe, and efficient energy system needs to be established (Yanget al., 2024). In the majority of countries worldwide, solar energy is the most economical choice for generating electricity and is predicted to become the main source of renewable energy, representing 80% of global renewable energy capacity growth between 2024 and 2030(IEA).

Despite rising imported energy prices, total per capita energy consumption in Palestine is the lowest in the region (0.79 MWh/inhabitant), while the cost of energy is among the highest in comparison to the rest of the Middle East. Palestinian demand for electricity is increasing at a pace of 6-7% (Hammouda, 2023) (Juaidi et al., 2016).According to data from the Palestinian Central Bureau of Statistics, annual electricity consumption in 2022 reached 7,245 GWh, and about 1,214 tons of oil equivalent of Oil derivatives and 231 tons of oil equivalent of energy from renewable energy (PCBS, 2024). To fulfill the requirements of the Palestinian people, the government has begun investing in renewable energy, specifically solar energy. The United Nations Development Program (UNDP) has been instrumental in introducing solar energy in many public buildings in Palestine, such as hospitals, schools, and others. The program introduces a model aimed at investment in solar energy, particularly in villages and towns (Dawabsheh, 2019).

The school's roof is almost empty, so it is crucial to consider using that area above the roof to invest in solar energy. it could be beneficial, where the energy produced by the solar cells may be more than the energy consumed in the school all year round, and think of the large number of schools in Palestine. According to the Palestinian Central Bureau of Statistics (PCBS) in 2022- 2023, there were 3190 schools in the West Bank and Gaza, 2,394 of which are in the West Bank (PCBS, 2023).

The Bethlehem Education Directorate divided the schools into three sections based on the school's size, number of students, and building size. Small schools, which have a roof space of 300 square meters, medium schools, which have 450 square meters, and large schools have a roof space of 750 square meters. These schools consume electricity in winter, 350 KWh, 450 KWh, and 550 KWh, respectively, while the average summer monthly consumption is 300 KWh, 400 KWh, and 500 KWh, respectively (Taqatqa, 2023).

This project will assess the effectiveness of using school rooftops for installing solar panels. The intended outcome is to generate electricity to meet the school’s energy needs, and any extra power produced will be sent back. This study aims to examine the feasibility of relying on solar energy as an alternative to non-renewable energy by analyzing three rooftops belonging to the Greek Catholic Patriarchate School in Beit Sahour, Bethlehem. Given that the school's roof is almost empty, it is important to consider exploiting this space to install a solar energy system, which could be feasible, especially if the amount of energy produced by the solar cells exceeds the school's annual consumption.

1.2. Solar radiation in Palestine

Solar radiation is a renewable energy source. It is the energy emitted by the sun that arrives on Earth in the form of heat and light. Understanding the nature of this radiation and its effective use contributes to developing clean and sustainable energy solutions (Bhavsar, 2024).The types of solar radiation:

1. Diffuse solar radiation (DHI) refers to sunlight that is diffused as it passes through the atmosphere before reaching the Earth's surface.
2. Direct solar radiation reaches the Earth's surface directly from the sun without being dispersed by the atmosphere.
3. Reflected solar radiation, the portion of sunlight that bounces off reflective surfaces like land, buildings, and cars. The amount of reflection depends on the surface's color and material (Stein, 2024; Gostein et al., 2016; Bhavsar, 2024).

The total solar radiation reaching the earth combination of diffuse and direct radiation known as Global horizontal irradiation (GHI). Most of the global radiation comes from direct radiation on clear days, while the diffuse radiation usually predominates on high cloud cover or cloudy days(Portillo, 2024).

PV panels and solar collectors are usually installed at a tilt angle, which is the angle that provides the best year-round performance. To maximize the total amount of incident solar radiation, the tilt angle is manually adjusted (Machidon & Istrate, 2023). Figure 1.1 shows types of solar radiation (Kanz, 2019).

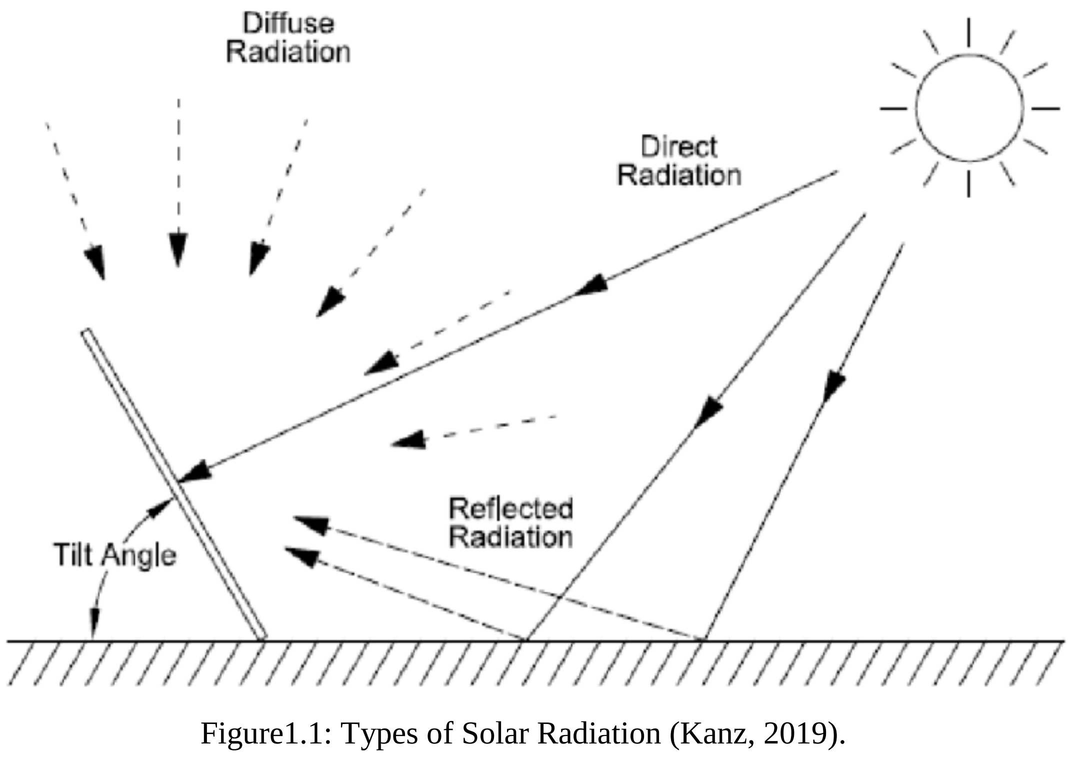


Figure1.1: Types of Solar Radiation (Kanz, 2019).

As an energy source, solar power is considered exceptionally attractive for electricity generation. Community acceptance has increased in recent years because it reduces environmental impacts, generating power from it is relatively Cost-effective, and tropical and subtropical regions receive. Massive amounts of solar radiation. The average solar energy incident on the Earth's surface is 120X105 watts. Therefore, the energy the Earth receives from the sun in one day is sufficient to supply global energy demand for more than 20 years (Ahmadi et al., 2018). There are two main types of solar energy generation. The initial type is concentrated solar power (CSP), also referred to as solar thermal power generation, which transforms heat (steam) into electricity. This type is regarded as more appealing for generating electricity because it can store thermal energy, thus addressing the issue of intermittent solar power supply. However, its high cost and technical complexity, as it relies on a combination of steam and solar energy systems, have impeded its spread. The preferred option is photovoltaic panels, which depend on the electrostatic effect without using heat to generate direct current (DC) from sunlight. Electrical inverters convert the DC into alternating current (AC) for distribution via the power grid. This type of system does not store thermal energy, but it is low-cost (Nwaigweet al., 2019).

In recent years, the demand for solar energy in the Palestinian territories has risen due to rapid population growth. Because of political instability, the Palestinian energy sector is fully reliant on imported energy supplies, 88% of which come from Israel, which governs the energy sector in Palestine, and from other outside sources as in Table 1.1. This necessitates utilizing renewable energy resources, including biomass, geothermal energy, and solar energy. Palestine has significant solar energy potential, receiving 3,000 hours of sunshine annually with an average daily irradiance of 5.4 kilowatt-hours per square meter. Solar water heating (SWH) systems are used for domestic hot water, and 24,000 units are manufactured locally in the West Bank and Gaza Strip (Yamin, 2023; Rabi & Ghanem, 2016).

Table 1.1: Sources of electricity in Palestine based on yearly consumption (PCBS, 2014). (Rabi & Ghanem, 2016)

No.	Electricity source	Quantity (GWh)	Percentage of total supply
1	Israel (IEC)	4702	88.7%
2	Gaza Electricity	392.3	7.4%
3	Egypt	121.9	2.3%
4	Jordan	84.8	1.6%
	Total	5301	100%

The West Bank is located within the Mediterranean basin in the northern hemisphere, specifically between 31.34 and 32.55 north latitude and 34.96 and 35.56 east longitude. The average annual temperature is about 20 degrees Celsius. The monthly solar radiation ranges from 9.4 MJ/m² per day in January to 25.5 MJ/m² per day in June. The duration of sunshine in the region is about 6 hours per day in January, while it rises to 12 hours per day during June and July. (Hamada &Ghodieh, 2021)

- Dust : in air or on surface of PV cells will prevent direct solar irradiation

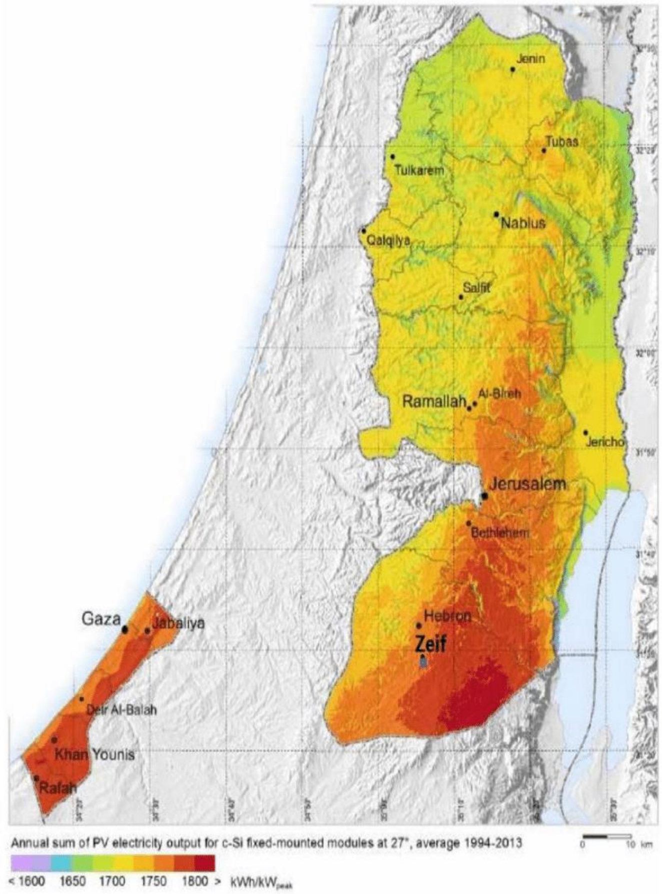


Figure 1.2: Average Irradiation of some parts of Palestine (Ajlouni & Alsamamra, 2019).

According Figure 1.2, the global solar irradiance (GHI) in Palestine is divided into three solar regions as the following:

1. Areas with the highest radiation levels, surpassing 2300 KWh/m2, are concentrated in the central and southern regions of Ramallah, Bethlehem, Jerusalem, and Hebron, as well as all the governorates of the Gaza Strip.
2. Areas with medium radiation (2200-2300) KWh/m^2 include the northern mountainous areas such as Jericho, the southern part of the Jordan Valley, Tubas Governorate, and the north-central areas of the West Bank
3. Low radiation areas below 2200 KWh/m2. The northern West Bank includes Qalqilya, Jenin, Tulkarm, and some rural areas in the western West Bank(Rabi and Ghanem, 2016).

The solar atlas for Palestine demonstrate that solar energy can be applied in various applications (Hamada and Ghodieh, 2021).

1.3. Literature Review

Emerson et al. (2014) examine the possibility of setting up solar photovoltaic (PV) systems on the roofs of educational buildings at various angles. Their study confirms that solar photovoltaic energy is fit for educational buildings, and its results can help support stakeholders' decisions to adopt this solution as part of national efforts toward sustainability and reducing reliance on polluting energy sources. The results demonstrate that even small spaces can significantly contribute to energy generation, meeting the needs of educational institutions while achieving significant savings on electricity bills. The results also demonstrate the potential to reduce carbon dioxide emissions by more than 26,000 tons annually.

The technical and economic performance of grid-connected photovoltaic (PV) systems was evaluated by Li et al. (2018) for a 14-family rooftop PV-powered building in five climatic zones in China. Kunming hadthe lowest emissions of carbon dioxide (38,975 kg/year), sulfur dioxide (35.4 kg/year), and nitrogen oxides (165 kg/year), and was the most economical, with the lowest energy production costs (US$0.073/KWh). Economically and environmentally, Kunming is ideal for power generation using grid/PV systems thanks to its mild climate.

As Kuo & Huang (2018) defined PV systems are a green energy source that captures sunlight, free from emissions and noise. These systems are simple and easy to install, and they rarely fail. However, predicting solar radiation is vital to ensuring the smooth operation of these systems, because energy production from PV systems depends heavily on climatic factors. But, the data provided by pyrometers are characterized by nonlinear variation and non-stationary. As a result, Kuo & Huang (2018) propose a high-resolution deep convolution neural network model called Solar Net, which aims to improve the accuracy of solar radiation prediction. Findings from the experiment demonstrated that Solar Net did better than other models in terms of prediction accuracy. The model also demonstrated its ability to handle complex time series characterized by a high degree of volatility and instability.

The energy sector in Palestine faces several obstacles to implementing photovoltaic systems (Ajlouni & Alsamamra, 2019). Despite it being one of the most suitable regions in the eastern Mediterranean for investing in sustainable and alternative energy, especially solar energy, where average solar radiation in most areas ranges between 5.4 and 6 kilowatt-hours per square meter (kWh/m^2). These obstacles are due to the heavy reliance on imported electricity from Israel, limited control over these natural resources, and underdeveloped infrastructure.

Ibrik & Hashaika (2019) presented a research paper assessing the performance of grid-connected solar photovoltaic systems, with a total capacity of 7.68 kilowatt-peak (kWp), installed on three school rooftops in Palestine. The results showed that the average performance of these systems reached about 78%, while the average annual energy production was approximately 10.93 megawatt-hours per system. Economic analyses show the feasibility of these systems, showing a short payback period of within five years, a production cost as low as 0.1 US$ per kilowatt-hour, and an internal rate of return estimated at around 20%.In addition to the positive impact of these systems on the environment by reducing harmful emissions, and on the electrical grid, by improving voltage levels, and reducing electrical losses.

Haffaf et al. (2020) used PV Planner software to evaluate the performance of a grid-connected photovoltaic (PV) system. To determine the best-suited technology for the region, they analyzed the performance of four different PV cell technologies (a-Si, CdTe, CIS, and c-Si). The findings revealedthat a-Si technologies recorded the highest annual average energy efficiency of 83.8%

(18.0 MWh), followed by CdTe at 81.1%, CIS at 78.6%, and c-Si at 77.1%. These results showed the superiority of a-Si cells in the conditions of the studied region.

Photovoltaic systems have become a tool to help achieve a low-carbon future. These systems can be applied to rooftop buildings, thus reducing energy consumption in buildings recently emerging as major energy consumers.Roofs offer themaximum achievable efficiency for photovoltaic power generation systems in buildings due to certain characteristics of roofs, such as good ventilation conditions, the absence of obstructions, good penetration of sunlight, and a flexible tilt angle for the photovoltaic panels(Yao&Zhou, 2023).

1.4. Objectives and the Statement of Problem

Palestine enjoys a relatively high rate of solar energy throughout the year, making it a suitable environment for the exploitation of this natural resource. This study aims to investigate the efficiency of utilizing school rooftops for the installation of photovoltaic solar cells. The purpose is to generate energy to power schools and distribute any excess back to the electrical grid. The research will be carried out within the Bethlehem Education Directorate, focusing on three buildings of the Greek Catholic Patriarchate School- Beit Sahour. To conduct the study, the main simulation programs, such as PVsys and PVCAD software, will be used to obtain the results. An analysis will be carried out to quantify the size of the solar photovoltaic project, the amount of electricity produced, a comparison of the monthly electricity produced versus consumed electricity, energy surplus, and the recovery period.

This work aims to explore the feasibility of securing solar energy instead of non-renewable energy, by conducting the study on three rooftops of the Greek Catholic Patriarchate School in Beit Sahour - Bethlehem. The current study's key objectives are the following:

1) Study the accessibility of solar energy in the Greek Catholic Patriarchate School Beit Sahour - Bethlehem.
2) Study of theoretical applications of solar energy.
3) Solar environmental and economic impact statement
4) Suggest innovative approaches to generate solar energy and eliminate fossil energy sources.
5) Recommendations that encourage the Ministry of Education to implement solar energy systems on school rooftops.

1.5. Justifications

Due to population growth and industrial development, the global energy demand is increasing significantly to meet the needs of this growth (Kannan & Vakeesan, 2016). The significance of seeking alternative sources is growing in light of the scarcity and limited availability of natural resources such as coal, natural gas, and oil. In addition, carbon dioxide emissions from the burning of fossil fuels have a substantial influence on the environment and are a main reason of climate change and global warming (Wang & Azam, 2024).

The world is moving towards renewable energy, or what's known as clean energy, as a source of energy in light of the failure of fossil energies, their high prices, and the monopoly of some countries on them. Energy sources in Palestine are veritably limited, depending on the import of different types of energy from bordering countries, especially Israel, as energy consumption in all sectors in the Palestinian homes is fairly small compared to bordering countries. This study delved into the possibility of applying solar cells as a source of electrical energy on the rooftops of three structures of a Greek Catholic Patriarchate School- Beit Sahour.

Chapter Two

Theoretical Background and Methodology

2.1. Silicon Solar Cell

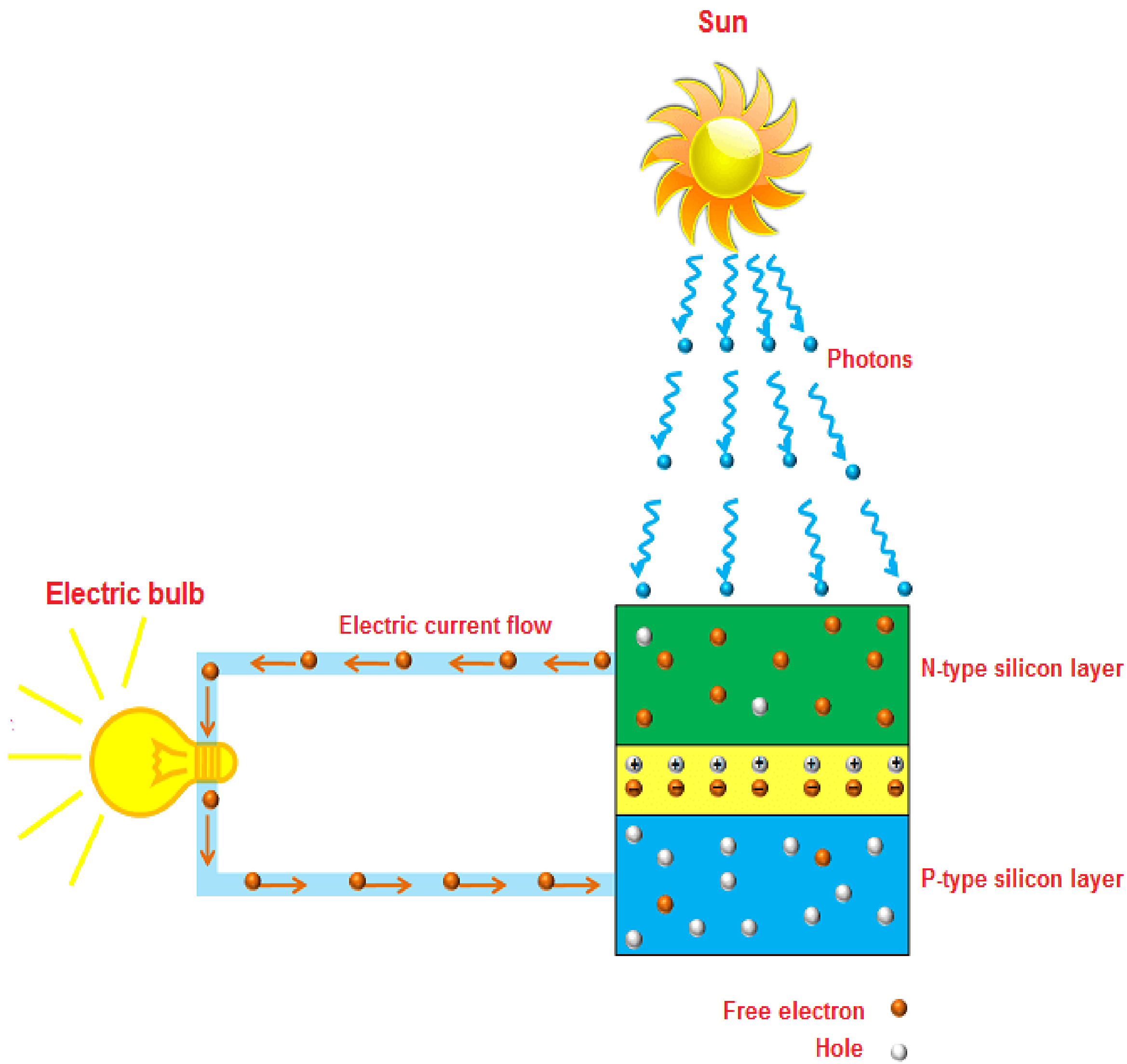
Silicon is the most plentiful semiconductor in the world (Chandler, 2022). In 2023, silicon wafer-based solar photovoltaic technology accounted for approximately 97% ofthe total world PV market. Monocrystalline silicon has also become the dominant technology for solar cell production (Philipps and Warmuth, 2024). Silicon-based photovoltaics are the only ones that meet the low-cost manufacturing standard for clean energy conversion, due to the abundance of raw materials and absence of health or environmental safety concerns (Singh, 2009).

Significant advancements in solar cell design have increased light absorption and decreased surface reflectivity, improving cell efficiency. Additional advancements have also helped reduce costs by decreasing the cost of silicon production, reducing the amount of silicon used in cell manufacturing, and enhancing manufacturing processes to become highly automated and less expensive (Gambhir et al., 2018).

A collection of solar cells makes the solar panel. Each solar cell is made up of two different layers of silicon, a layer of free electrons (n junction) and a layer of holes (p junction). N junction, electrons are the majority, is made of embedding atoms, which have 5 valence electrons; like phosphorus, the fifth electron requires little energy to separate from the atom since it's free to move within the silicon structure, and this embedding atom is known as (n-doping), called a donor electron, surplus of positively charged holes (holes from missing valence electrons).The second layer, electrons are the minority, is made of embedding atoms, which have 3 valence electrons; known as (n-doping), called an acceptor.

Solar radiation consists of photons (tiny packets of energy) - only photons that contain band gap energy - and when these photons hit the solar panels, a large number of valence electrons gain enough energy to break bonds with the parent atom and move to the conduction band, known as free electrons. As these free electrons are electrically conductive, in an n-type semiconductor, a large number of free electrons are generated, which collide with other valence electrons and cause them to move, resulting in the generation of millions of free electrons. When a conducting wire is connected between the two silicon layers (p-type and n-type), an electrical path is formed that allows free electrons to flow from the n-side to the p-side as shown in figure 2.1 (Abdelhady et al., 2017; Shaik, 2016):

Figure 2.1: The solar panels generate electricity as long as the sun hits them (Shaik, 2016).



2.2. Types of PV systems.

Lately, the photovoltaic (PV)system has become one of the most widely adopted renewable energy technologies that collect solar power for various applications (Usman et al., 2020). There are three types of PV systems:

1) The Off-Grid Solar Power System:

As presented in Figure 2.2, this system generates energy directly from the sun, independently of the local electricity grid, then stores it in batteries and uses it as needed. The battery capacity must be sufficient to provide the home's energy needs, even during periods of low sunlight (winter days or at night). Off-grid systems have key advantages. These systems are most suitable for use in geographically isolated remote areas or those with unstable or weak electrical grid connectivity, due to their ability to operate independently without relying on the traditional grid. Access to electricity is difficult for residents because there is no infrastructure. Although the initial installation cost may be relatively high because the batteries and inverters are high-cost components of solar energy systems, it is gradually counteracted by the complete elimination of electricity bills. These systems contribute to the production of clean, renewable energy with no direct emissions. They are estimated to prevent the emission of between 4 and 5 tons of carbon dioxide annually.

The charge controller regulates the battery charging process using solar energy, then converts the stored DC to AC via an off-grid inverter, and distributes it to power household appliances (Neufin, 2025; PVcase Team, 2023; Servotech, 2021) as shown in figure 2.2.

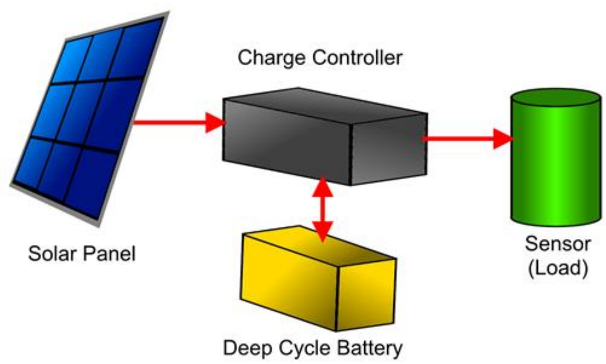


Figure 2.2: Typical Solar-Powered Remote Installation (Wall, 2020).

2) Hybrid Solar Energy System:

Continuous electricity generation can be achieved when another renewable energy source is combined with solar power systems, and wind power is a preferred option in this context due to its ease of installation and availability, similar to solar power. Wind energy can be utilized at any time of the day (Aktaş and Kirçiçek, 2021). This system provides better reliability and is more economical, as it allows the reduced output of one system to be compensated by the increased production of the other, ensuring continuity of power supply and minimizing the storage capacity required to ensure continuous power supply, reducing the heavy reliance on batteries (even at night) (Al Badwawi et al, 2016).

As shown in Figure 2.3, a hybrid solar system combines the advantages of a grid-connected and standalone system, providing continuous power even during power outages thanks to the batteries, and allowing the surplus to be exported to the grid or imported when needed, making it an economical and efficient option. The hybrid inverter is a piece of equipment that is created by combining a solar inverter and a battery inverter into a single unit. This allows the hybrid solar inverter to intelligently handle power coming from your solar panels, solar batteries, and the utility grid all at the same time (Nuetech Solar, n.d.).

Figure 2.3: Solar Hybrid PV System (Nuetech Solar, n.d.).

3) On-grid System:

This system connects to the local electricity grid; it works in harmony with the power source to provide the maximum amount of energy possible. This system is widely used in homes and businesses (Brian, 2023). On-grid systems have Key advantages; these systems are less expensive because not need to purchase a battery backup device to store extra energy, excess power can be sold back, and even if the solar system isn't producing enough energy, the power is still accessible (PVcase Team, 2023).

2.2.1. Components of an On-Grid Solar System:

Selecting and investing in the right components is a crucial step to ensuring the effective use of solar energy. On-grid solar system contains:

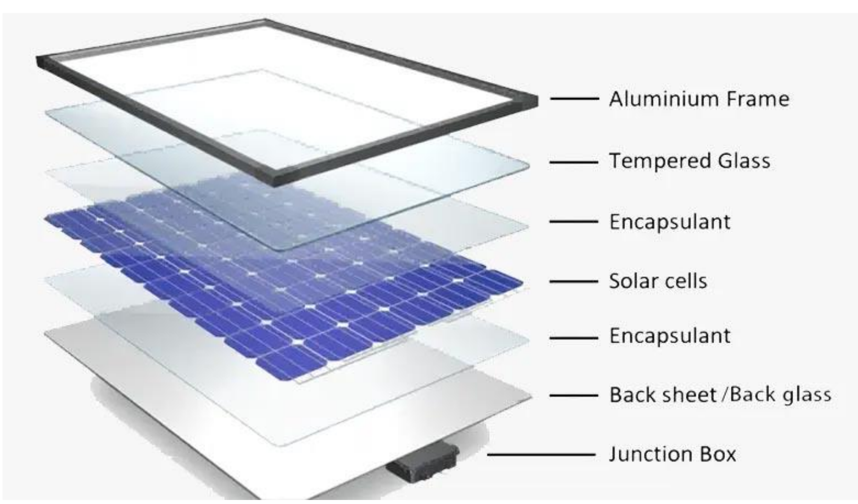


Figure 2.4: Solar panels (Mibet Energy, 2024)

1) Solar panels

Solar panels are the core component of any grid-connected solar energy system, converting sunlight into direct current (DC) electricity. Therefore, proper installation, proper placement, and maintenance are essential to achieving maximum energy production. Panels are typically made of individual silicon solar cells, and the more panels connected, the more electricity they can generate (Yasaswini, 2023).

Solar panel types:

1. Polycrystalline solar panels: Made of multiple crystal structures, they are more expensive and less efficient.

2. Thin-film solar panels: Made of a thin layer of photovoltaic material, they are typically less efficient.

3. Monocrystalline solar panels: Made of a single crystal structure, they are highly efficient.

4. TOPC on solar panels: Inert tunnel oxide contact material (Solar, 2024).

2) Inverter

It is a device that converts the current generated by solar panels, direct current (DC),into alternating current (AC) (Brian, 2023). There are three types of Inverters:

1. String Inverters: widely used in commercial and residential installations

2. Micro Inverters: Ideal for installations with shading issues.

3. Hybrid Inverters: Combines the functions of string inverters and battery inverters, enabling energy storage and integration with the electrical grid. (Solar, 2024)

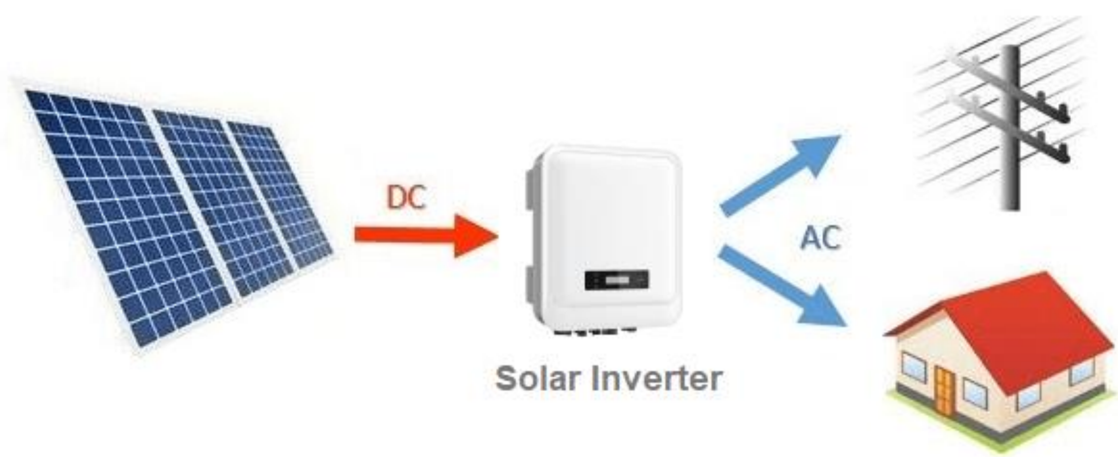


Figure 2.5: Solar Inverter converted to alternating current (AC) electricity (Svarc, 2020)

3) Cables:

It's important to use cables specifically designed and certified for solar energy to evade considerable voltage drops and preventable malfunctions within the solar PV system. Solar cables are commonly mounted outside, so they need protection from wetness, direct sunlight, ultraviolet rays, and low temperatures (Solis, 2021). There are three core types of cables (Kumar, 2023), each type has advantages (Zi, 2024) as shown in table 2.1 below:

Table 2.1: Types of cables integral to any solar power system (Kumar, 2023).

	Type of cable	Function	Characteristics	Importance
1	DC (Direct Current) Cable	connects solar panels directly to inverters. It is used to transmit the direct current generated by the panels.	They can withstand the high voltage generated by photovoltaic panels, and are often made of materials that are resistant to UV rays and weather conditions, making them highly efficient.	Reducing energy loss between the solar panels and the inverter
2	AC (Alternating current) Cable	Transfers the alternating current (converted by the inverter from the solar panels) to the electricity grid	Insulated and thick to withstand higher voltage	Efficiency and safety of the electricity supplied.
3	Earthling Cable	Safeguards the system from lightning power and surges.	Safely divert excess electricity into the ground.	Protecting the solar system and its operators

2.3. Methodology

This section provides an explanation for the site chosen to perform the project, in which the characteristics of the school, working steps and computer tools used to prepare the final feasibility of the project.

2.3.1. Characterization of the Study location and site:

Palestine is located in what is known as the sun belt (the area between latitudes 40 degrees north and 40 degrees south). As shown in figure 2.6 below:

Figure 2.6: Map of the West Bank and Gaza

The location of the study is the city of Beit Sahour. The area of Bethlehem Governorate is 575 km², and the Beit Sahour Municipality is located within its borders**.** Beit Sahour is located 1.5 km east of Bethlehem and is also called the Shepherds' Town. Its area is about 8306 dunums. It is located at a height of about 650-700 meters above sea level. Its climate is generally moderate, with pleasant weather prevailing most days of the year. Winter lasts for 3 months, from mid-December to mid-March. Beit Sahour lies in the rain shadow, as the Bethlehem highlands block out rain. The average rainfall is about 375.5 mm. Average temperatures range between 10°C and 25°C in summer. in July and August, the climate is very hot.

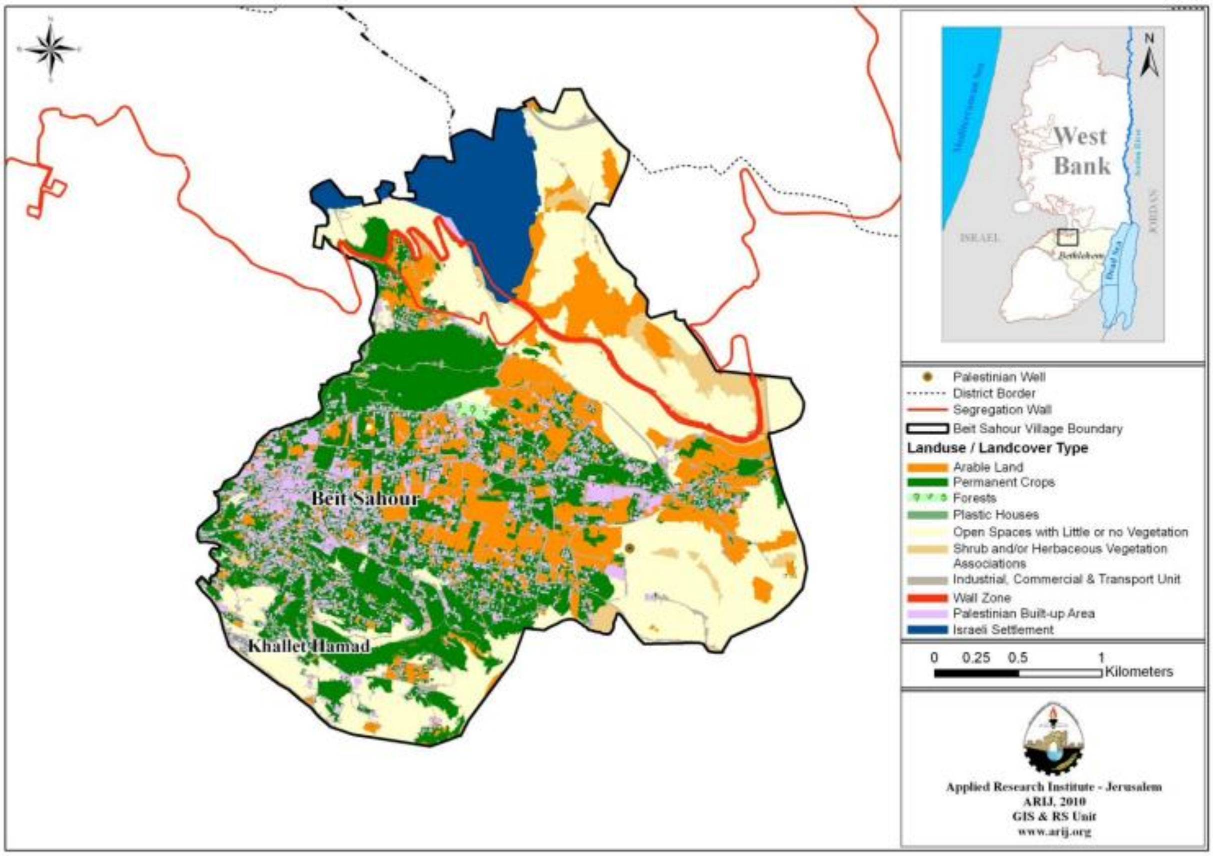


Figure 2.7: Map of Beit Sahour

Greek Catholic Patriarchate School:

The study took place at the Greek Catholic Patriarchate School (Figure 2.8), which consists of three buildings: the Kindergarten and Administration Building, the Primary School Building, Upper Primary and Secondary School Building. This school belongs to the Greek Catholic Patriarchate of Jerusalem. The Greek Catholic Patriarchal School is distinguished by its strategic location in the heart of Beit Sahour town, 100 meters to the east of the People's Market in Beit Sahour.

Figure 2.8: Greek Catholic Patriarchate School.

2.3.2. Working Steps and Computer Tools:

The photovoltaic energy system will be examined using the following software applications:

1. PVsyst software v. 7.4

PVsyst is intended for engineers, architects, and researchers and is an effective educational tool. It offers an easy-to-use interface with detailed instructions, allows the import of meteorological and other data from multiple sources, and presents results in reports and graphs that can be exported to other programs. The solar system simulation was performed using PVsyst, as this version provides features and improvements suitable for the study objective, which allowed the researcher to calculate the amount of the PV system needed and calculate the power output.

2. AutoCAD software v. 2024

AutoCAD is a computer-aided design (CAD) software developed by Autodesk since 1982. It is used to create precise two- and three-dimensional drawings and is an essential tool in fields such as architecture, construction, design, and manufacturing. AutoCAD was used in this research to draw the engineering designs for installing solar cells on the school roof, which used to calculate the amount of the PV system needed, calculate the power output, and represent solar panels on school rooftops.

3. Excel Program

Write the spreadsheets representing the output of electricity as well as the intensity of solar radiation, the amount of energy consumed, and the representation of different graphs.

For the selected school, the Greek Catholic Patriarchate School, data was gathered regarding the school's area, geographical location, and annual electricity consumption. This data was then used to approximate the potential energy output of the proposed solar project and to determine the appropriate type and number of solar panels required, utilizing the modeling tools previously outlined. Additionally, the total cost of implementing the solar energy system was calculated, along with an analysis of the expected payback period for the investment.

The study included collecting basic data about the school, such as its area, geographical location, and annual electricity consumption. This data was used to estimate the energy generation potential of the proposed solar energy project and determine the appropriate type and number of solar panels using the PVsyst modeling tool.

The total cost of implementing the system was also calculated, and the expected payback period for the investment was analyzed. To conduct the study, the following steps were followed:

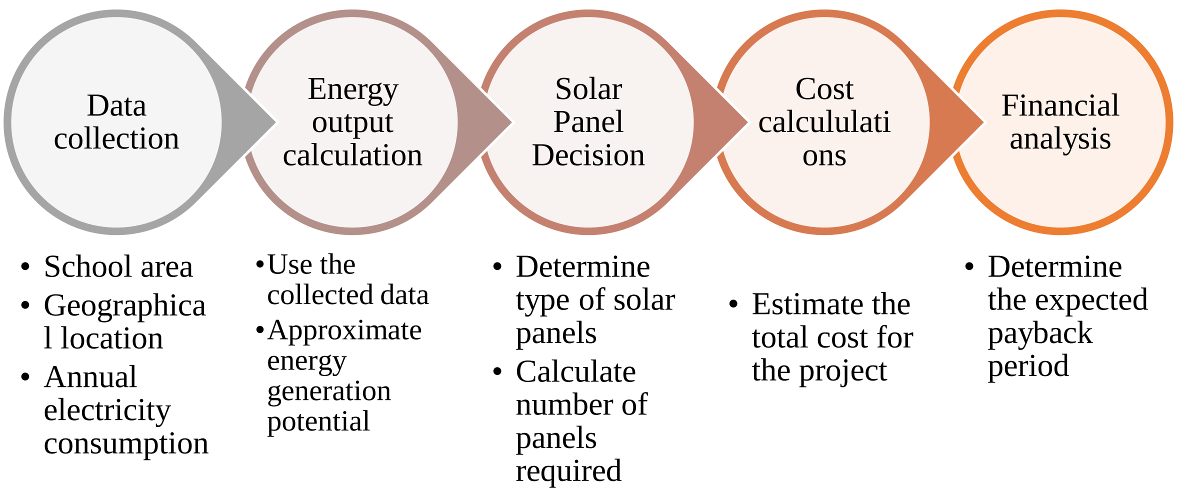


Figure 2.9: Working Steps of the project

Chapter Three

Result and Discussion

3.1. Introduction

This study aims to Feasibility study for installing photovoltaic solar energy systems on the roofs of Palestinian schools, because energy represents one of the fundamental challenges facing Palestine at present, and is a pivotal obstacle to achieving sustainable political and economic independence. Utilizing the school's rooftops will help Palestinians advance towards energy independence and create environmental education on green energy in schools.

As a case study, the exploitation of the roofs of three buildings of the Greek Catholic Patriarchate School in Beit Sahour was assessed to assess the efficiency of solar systems in generating electrical energy on the roofs. Schools are the best options for these projects for several reasons, including: Over the years, the schools closed their doors more than 180 days every year, the school's roof is almost empty, and there are more than 3000 schools in the West Bank and Gaza.

In this study, the Beit Sahour Municipality collected the school's electricity bills over a full year. A photovoltaic system simulation program was then used to create a virtual solar energy system, considering the nature of the solar system components and the school's location. System costs and payback periods were calculated, and a comparison was made between monthly electricity consumption and project productivity.

3.2.School Specification

The data on the school shown in Table 3.1 was gathered according to the Greek Catholic Patriarchate school.

Table 3.1: Specifications of the Greek Catholic Patriarchate school buildings.

Type of building	**Co-ed private school**
The surface area of the school (3 buildings)	3280m^2
The monthly bill range	26 - 3124 NIS
Location	Bethlehem – Beit Sahour

3.3 PV systems and revenues

Table 3 and Figure 8 show the school's annual electricity consumption and the financial costs. This data is essential for estimating the capacity of the power system required to meet the school's electricity needs and is also used to calculate the financial cost required to install this system.

Table 3.2: Electricity consumption and financial cost (KWh and NIS) for the Greek Catholic Patriarchate School.

Month	The consumption value (KWh)	The bill value (NIS)
Apr - 2024	2724	1124
May - 2024	1901	36
Jun - 2024	2484	317
Jul - 2024	2247	29
Aug –2024	1104	26
Sep - 2024	1675	27
Oct - 2024	6841	2832
Nov - 2024	5378	2810
Dec - 2024	3282	1575
Jan - 2025	3668	1853
Feb - 2025	3042	1168
Mar - 2025	5304	3124
Annual total	39 650	14 921

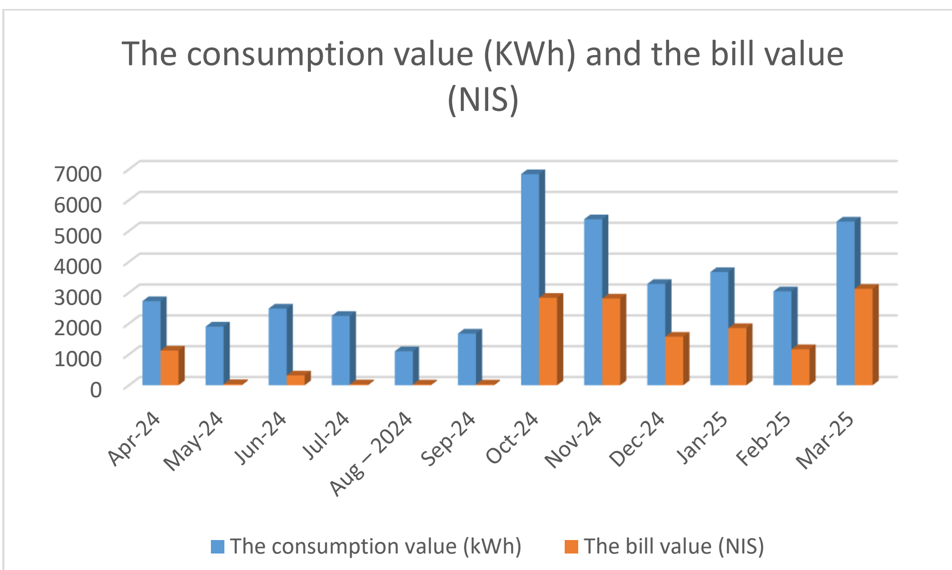


Figure 3.1: Electricity consumption and financial cost (KWh and NIS) for the Greek Catholic Patriarchate School.

3.4. Values of Monthly Global Horizontal Irradiation in Beit Sahour

Bethlehem -Beit Sahour's average daily sunlight hours and monthly global Horizontal irradiation are shown in Table 3.3. According to the input Ret screen expert software.

Table 3.3: Monthly global solar insolation at Beit Sahour.

Month	Global Horizontal Irradiation (KWh/m²)
January	93.0
February	102.2
March	149.2
April	176.6
May	209.3
June	231.8
July	220.1
August	200.1
September	165.8
October	128.7
November	95.3
December	83.5
Total/ year	1855.6
Average global horizontal irradiation	154.63

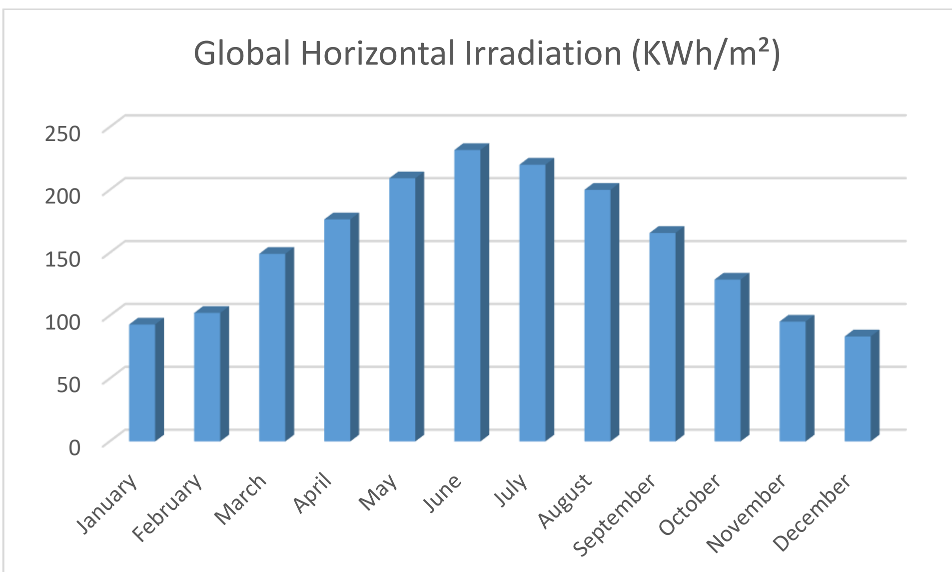


Figure 3.2: Global horizontal irradiation (KWh/m^2) in Beit Sahour.

3.5 System Details

PVsyst collects detailed data related to the solar installation site, such as the building's geographic location and architectural design (using AutoCAD). Table 3.4 shows the data entered into PVsyst for simulation and analysis purposes.

Table 3.4: Information entered into PVsyst software for the Greek Catholic Patriarchate school

Coordinate	31.70°N 35.22°E
Altitude	641 m
Azimuth Angle	11.4°
Tilt Angle	15°

3.6. The photovoltaic solar module specifications

Tables 3.5 and 3.6 show the technical characteristics of both the grid-connected inverter and the solar cells used in the photovoltaic system, while the inverter specifications is presented in Table 3.7. These characteristics are essential when designing and installing the system, as they are used to determine the optimal system capacity, in addition to determining the minimum and maximum number of cells that can be connected in series or parallel, as well as the system's output voltage and current. This data is also used to compare system outputs with the inverter's capabilities and transformations to ensure safe and efficient operation.

Table 3.5: The photovoltaic solar module specifications for the Greek Catholic Patriarchate school.

The specification of solar PV modules	
Number of panels	352
Module area	909m²
Maximum power (Pmax)	565 Wp
Solar module type	Tiger Neo N-type 72HL4-(V) 565-585 WattMONO-FACIAL MODULE
System capacity	204 kWp
The voltage at Maximum Power (Vmpp)	41.92V
Current at Maximum Power (Impp)	13.48A
Open Circuit Voltage (Voc)	50.60V
Short Circuit Current (Isc)	14.23A
Panel Efficiency (%)	21.87%
Maximum system voltage	1500VDC
Table 3.5. Continued	
Cell type	Mono-crystalline
Panel dimension (m)	2.278×1.134×0.035 m
Panel area (m^2)	2.58 m^2
Panel weight (Kg)	28 kg
Operating Temperature C	-40℃~+85℃

Table 3.6: The characteristics of the Inverter of the introduced system

The characteristics of the Inverter of the introduced system	
System capacity	110 KW
Manufacturer	Huawei Technologies
(ABB Solar inverters) Type code	SUN2000-100KTL-M2-400Vac
Maximum efficiency	98.8%
Input (DC)	
Absolute Maximum Input voltage (Vmax, ab)	1100 V
Modules	22 Strings x 16 In series
Maximum DC Input Current for each MPPT(Idc, max) /MPPT	20 A
Maximum Short Circuit Current for each MPPT(ISC)	40 A
Output (AC)	
Rated AC Output voltage(Vacr)	400 V
Maximum AC Output current(Iac, max)	160.4 A
Rated output Frequency (Fr)	50 Hz / 60Hz
General data	
Dimension	1,035 x 700 x 365mm
Weight	≤93kg
Operating temperature range	-25°C~60°C

Table3.7: Inverter String for the Greek Patriarchate Catholic school

Inverter String for the Greek Patriarchate Catholic school			
MPPT	**String**	**VMPPT**	**Idc (A)**
MPPT (1)	16 Module	16 × 50.60 = 809.6V V (oc) = 809.6V For each module	I = 14.23A
MPPT (2)	16 Module		
MPPT (3)	16 Module		
MPPT (4)	16 Module		
MPPT (5)	16 Module		
MPPT (6)	16 Module		
MPPT (7)	16 Module		
MPPT (8)	16 Module		
MPPT (9)	16 Module		
MPPT (10)	16 Module		
MPPT (11)	16 Module		
MPPT (12)	16 Module		
MPPT (13)	16 Module		
MPPT (14)	16 Module		
MPPT (15)	16 Module		
MPPT (16)	16 Module		
MPPT (17)	16 Module		
MPPT (18)	16 Module		
MPPT (19)	16 Module		
MPPT (20)	16 Module		
MPPT (21)	16 Module		
MPPT (22)	16 Module		

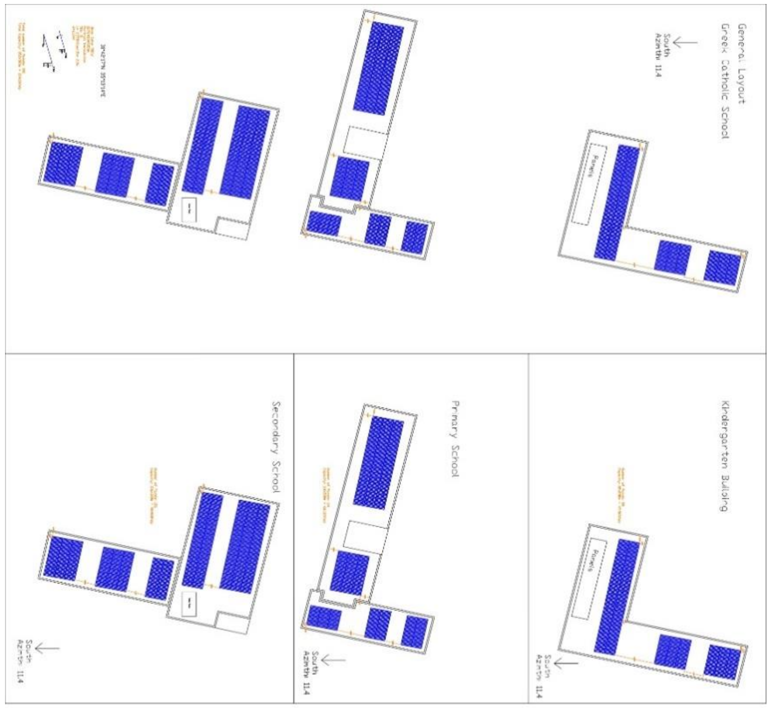


Figure 3.3: Distribution of photovoltaic panels on the roof of the Greek Catholic Patriarchate school buildings (secondary building, primary building, and kindergarten building)

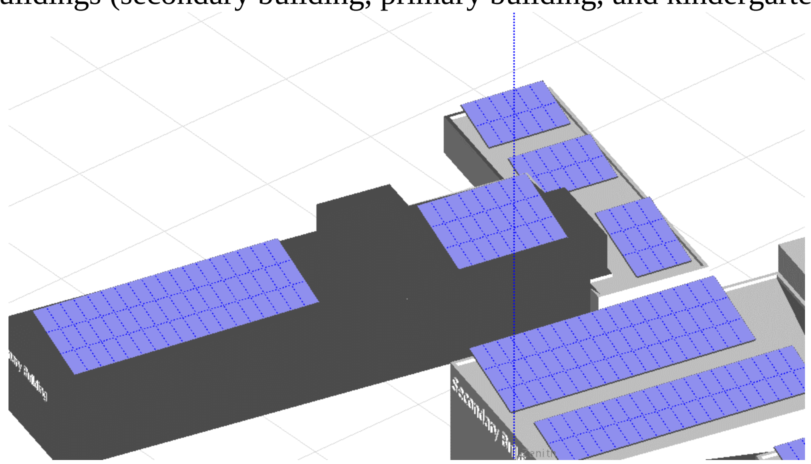


Figure 3.4: shows a perspective of the Greek Catholic Patriarchate school building's roof, including the PV field and surrounding shading.

3.7. Energy output and calculate revenues and payback period for the project

Table 3.8 and Figure 3.4 show the theoretical values of the monthly energy production, using the PV Syst program.

Table 3.8: Monthly AC production of the system

Month	Monthly AC Production(KWh)
January	19538
February	20987
March	28427
April	31155
May	34358
June	36844
July	32681
August	33328
September	29540
October	24757
November	18596
December	18229
Total/ year	328440
Average Monthly AC Production(Kwh)	27370.08

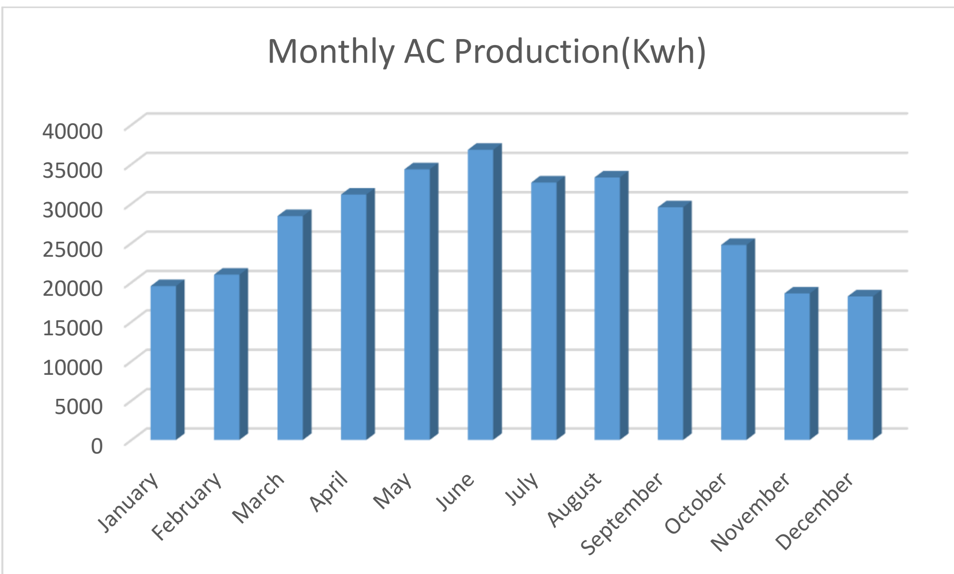


Figure 3.5: Monthly AC production of the Greek Catholic Patriarchate school

The difference between the AC product and the AC consumption is shown in Figure 3.5

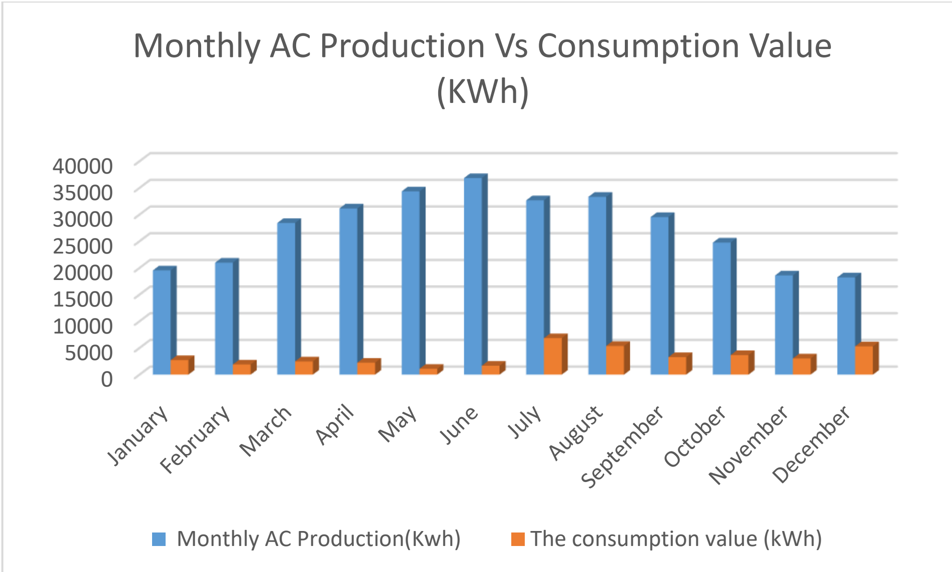


Figure 3.6: The difference between the AC product and the AC consumption

There is a large disparity between energy production and consumption rates, due to the absence of energy-intensive electrical systems in Palestinian schools, such as heating and cooling systems. This absence is due to the mild climate in Palestine during the fall, spring, and summer seasons, which reduces the need to use cooling or heating devices inside schools.

Table 3.9: Monthly AC surplus value (KWh) for the Greek Catholic Patriarchate school.

Month	AC surplus (KWh)
January	15870
February	17945
March	23123
April	28431
May	32457
June	34360
July	30434
August	32224
September	27865
October	17916
November	13218
December	14947
Total	2887790

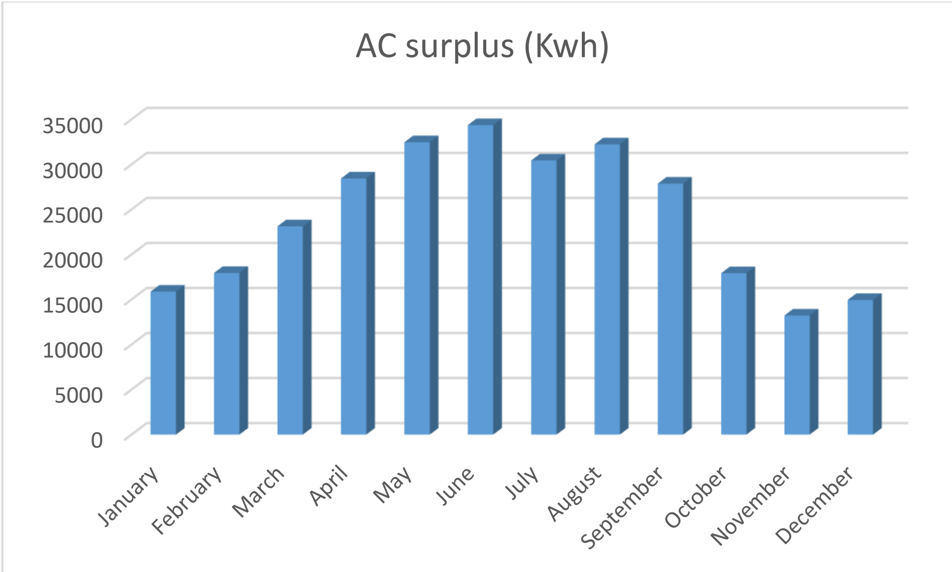


Figure 3.7: AC surplus (kWh) for the Greek Catholic Patriarchate School.

3.8. Project Cost Calculations

Annual revenue =The AC surplus value (KWh) × price of a kilowatt hour (1 KWh)

= 2887790 × 0.64 = 184825.6 NIS

The total cost of the project = cell capacity× number of cells× Kilowatt price in NIS

= 0.58× 352× 2660 =543056.6 NIS

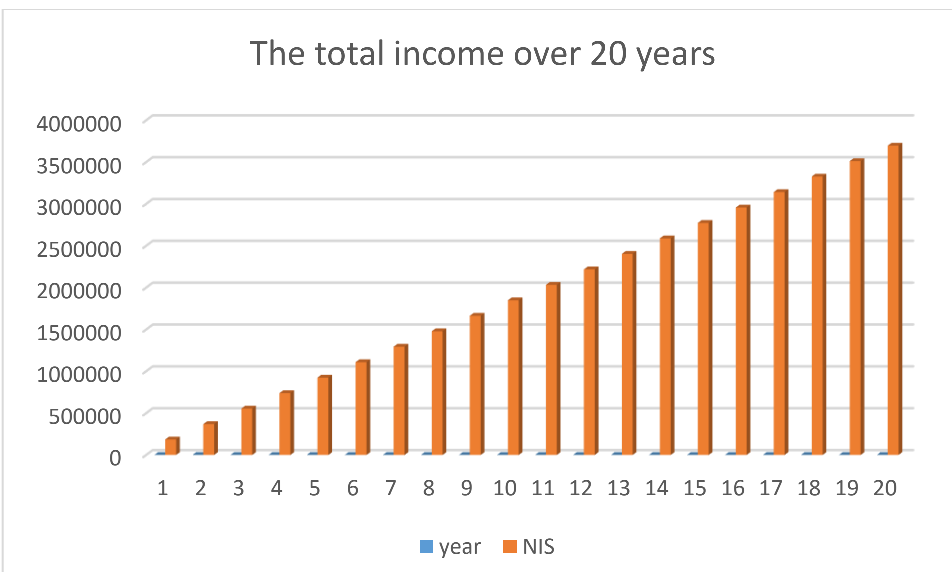


Figure 3.8: Total income over 20 years for the Greek Catholic Patriarchate School.

The payback period is defined as the ratio of the total income over 20 years to the total cost of the project.

Payback period = $\frac{3696512}{543056.6}$

= 6.8 years

Chapter 4

Conclusion and future work

4.1. Conclusion

This study delved into the possibility of applying solar cells as a source of electrical energy on the rooftops of three structures of a Greek Catholic Patriarchate School- Beit Sahour. Energy sources in Palestine are minimal, depending on the import of different types of energy from bordering countries, especially Israel. To promote social and economic growth and sustainable development, Palestine needs renewable energy sources, in particular, solar energy, which has enormous potential in the area. Palestine experiences roughly3,000 hours of sunshine a year. utilizing school rooftops for the installation of photovoltaic solar cells to generate energy to power schools and distribute any excess back to the electrical grid.

Solar energy, in particular, is a promising option given the limited energy resources in Palestine. The country relies on importing various types of energy from neighboring countries, especially Israel. Energy consumption in all sectors, especially in Palestinian homes, is minimal compared to neighboring countries.

The world is undergoing a pivotal moment as a result of the accelerating consumption of non-renewable energy sources, during a continuous increase in global energy demand. This reality is driving a serious search for sustainable alternatives and strengthening the shift toward renewable energy sources. The importance of these sources extends beyond their environmental friendliness. They also offer numerous benefits, such as reducing costs in the long term, enhancing energy security, and reducing greenhouse gas emissions and air pollutants, thus contributing to combating climate change. Renewable energy also helps reduce energy poverty and increase economic productivity by creating new job opportunities and exploiting clean, widely available natural resources.

4.2. Future Work:

Solar energy is one of the most promising renewable energy sources, especially for industrial uses, where it is receiving increasing attention compared to other sources. This energy is abundant, free, and clean, and produces no noise or environmental pollution, making it an ideal choice for achieving sustainable development.

This study delved into the importance of applying solar cells as a source of electrical energy on the rooftops of schools. It is necessary to present a set of recommendations drawn from the implementation of the project, highlighting their importance and potential role in enhancing the results and achieving the desired goals:

1. Providing support for such projects through government policies that encourage investment in renewable energy infrastructure within the education sector, thus promoting energy independence, lowering overhead costs, and enhancing environmental awareness among students.

2. Incorporating renewable energy topics into school and college curricula will enhance students' awareness of sustainability and energy efficiency and encourage them to adopt environmentally friendly practices. This initiative could also pave the way for a future career in renewable energy.

3. Initiating a non-cost program to investigate the potential and types of photovoltaic projects on school rooftops provides valuable insights into the feasibility and obstacles of scaling the initiative to include various schools.

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تقييم مشاريع الطاقة الشمسية على أسطح المدارس في بيت ساحور: دراسة حالة مدرسة البطريركية للروم الكاثوليك

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ملخص

أثبتت مصادر الطاقة المتجددة إمكاناتها الواعدة في تلبية احتياجات الطاقة بشكل مستدام. تعتمد الأراضي الفلسطينية بشكل كبير على واردات الكهرباء من إسرائيل والدول المجاورة، مما يشكل عبئًا اقتصاديًا متزايدًا بسبب انعدام أمن إمدادات الطاقة وتقلب الأسعار، وخاصة في السنوات الأخيرة. على الرغم من ذلك، تتمتع فلسطين بوفرة من موارد الطاقة الشمسية، حيث يبلغ متوسط ساعة ذروة سطوع الشمس حوالي 5.4 ساعة يوميًا على مدار العام، مما يمنحها إمكانات واعدة لتطوير مشاريع الطاقة الكهروضوئية وتحقيق قدر أكبر من الاكتفاء الذاتي من الطاقة.

في هذه الدراسة، تم تقييم إمكانات الطاقة الشمسية لمدرسة بطريركية الروم الكاثوليك في بيت ساحور كدراسة حالة. تُعد المدارس مناسبة لهذا النوع من المشاريع لأنها مغلقة لمدة 180 يومًا تقريبًا في السنة وتعمل لساعات أقل على مدار العام، مما يساهم في زيادة صافي العائد السنوي من الطاقة الشمسية.

في هذا العمل، تم إجراء تقييم لمشروع الطاقة الشمسية الكهروضوئية الافتراضية على سطح مدرسة بطريركية الروم الكاثوليك في بيت ساحور. تُقدر سعة النظام بـ ٢٠٤ كيلوواط، على مساحة إجمالية قدرها ٩٠٩ أمتار مربعة. ويبلغ إجمالي الألواح الكهروضوئية المستخدمة ٣٥٢ لوحة، ويُقدر إنتاجها السنوي من الطاقة الكهربائية بـ ٣٢٨٤٤٠ كيلوواط/ساعة. وبلغ الاستهلاك السنوي للمدرسة في عام ٢٠٢٤ حوالي ٣٩٦٥٠ كيلوواط/ساعة، مع فائض سنوي مُقدر بـ ٢٨٨٧٩٠ كيلوواط/ساعة.

لذلك، خلصت الدراسة إلى أن تركيب وحدات الطاقة الشمسية على أسطح مباني مدارس الروم الكاثوليك أمرٌ مُجدٍ من حيث التكلفة وفترة الاسترداد. لذا، تُشجع الدراسة المدرسة على اتخاذ قرار تركيب وحدات الطاقة الشمسية لما لها من فوائد تُقلل من نفقاتها.