An-Najah National University
Faculty of Engineering
Energy and Environmental Engineering Department

Techno-economic assessment of on-grid solar PV system in Palestine: A case study in Jerusalem

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Declaration

We hereby announce that the project titled "Techno-economic assessment of on-grid solar PV system in Palestine: A case study in Jerusalem" is submitted to the faculty of Engineering and Information Technology, Energy Engineering and Environment Department at An-Najah National University, to partially achieve the Bachelor's degree in Energy Engineering. In addition, this project will not be submitted to any other place for granting any other degree.

Acknowledgments

We wholeheartedly dedicate this graduation project

To our families and loved ones

To all our doctors and instructors especially Dr. Mohammed Alsayed.

Whom supported us to complete this project

All of your support is highly appreciated

And above all, to our Almighty God, our source of wisdom, knowledge, and understanding

We dedicate this project, asking God to be accept and helpful to our community

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Nomenclature

(AC): Alternating current.

(CIGS): Copper indium gallium selenide.

(CUF): Capacity utilization factor.

(DC): Direct current.

(GW): Gigawatt.

(IEA): Internal Energy Agency.

(IEC): International Electrotechnical Commission

(IRR): Internal Rate of Return.

(kW): kilowatt.

(kWh): Kilo Watt-hour.

(kWp): kilowatt peak.

(LCOE): Levelized Cost of Energy.

(MW): Mega Watt.

(MWh): Mega Watt Hour.

(NIS): New Israeli Shekel.

(NPV): Net Present Value.

(PENRA): Palestinian energy and natural resource authority.

(PR): Performance ratio.

(PSI): Palestine Standards Institution.

(PT): Palestinian territories.

(PV): Photovoltaic.

(PWH): Petawatt Hour.

(SPBP): Simple Payback Period.

(STC): Standard Test Conditions.

(US): United States.

(W): Watt.

(YF): Final yield.

(YR): Reference yield.

Abstract

Palestine has witnessed a great spread in the adaptation of photovoltaic power systems, as it has become an alternative source of energy provider for various applications, due to the low prices of photovoltaic energy. The Palestinian territories are supplied with electricity from neighboring countries, which increases and burdens the Palestinian economy in terms of security in particular. This project presents a 12-month economic and technical evaluation for the year 2021 for an already existing photovoltaic system project located on the rooftop of the Siniora factory building for food products in Jerusalem, connected to the grid with a capacity of 117 KW. The evaluation was carried out by comparing the technical and economic results of the simulated data through the PVsyst program with the real data aquired from the system real outputs, the performance ratio and the present value of the simulated photovoltaic system were 82% and $133,904, respectively, in contrast.the real data was 62% and $111,614 respectively. The main reason for the clear difference between the data is the losses that the PVsyst program does not take precisely because it works on the standard conditions, in contrast to the real data, which takes into account all conditions, including temperatures, solar radiation, and others.

After completing the analysis of the data, it was found that the simulation programs cannot be officially relied upon because there is a large percentage of errors, which leads to an imprecise prefeasibility analysis results and risky decisions.

Ch1. Introduction

Energy consumption worldwide had grown faster than the population in recent decades, and this trend is expected to increase in the coming years. For instance, the world population was 3.7 billion in 1970 and is expected to be 8.5 billion in 2030, with an annual increasing rate of 1.2%. The world energy consumption in 1970 was nearly 64 PWh (Petawatt hour or 10^{15}Wh) and will be around 195 PWh in 2030, with an annual increase rate of 1.9%. [1]

At the present time, renewable energy constitutes 26% of global electricity based on reports by the international energy agency (IEA). In addition, the prospective rate will reach 30% by 2024 with a total installed capacity of 1200 GW, half of which came from solar energy. The IEA expects that solar energy will significantly dominate and can play a major role in jumpstarting the maturity of global renewable energy due to dropping costs and rapid development of photovoltaic (PV) technology, where the costs of solar energy are projected to decline by 15% to 35% by 2024. The utilization of solar energy is one of the most promising solutions for decliningrid power usage and carbon dioxide emission [2].

Renewable energy technologies are clean sources of energy, and the efficient usage of these resources reduces environmental impacts and generates a minimum of waste. Besides, renewable energy systems are considered sustainable resources based on current and future social and economic requirements. Renewable energy technologies present an extraordinary opportunity to minimize greenhouse gas emissions and reduce global warming by substituting traditional energy sources [3].

In recent years, high population growth, growing living standards, and rapid industrial growth have led to raising the demand for energy in the Palestinian Territories. Compared to other countries in the Middle East, the energy situation in Palestine is very different due to theshortage of natural resources, the financial crisis, and uncertain political circumstances. To meet its energy needs, Palestine is highly reliant on Israel. It imports almost all petroleum products through Israeli companies. Israel controls the supply of energy to Palestine and therefore forbids free trade between Palestine and other countries in electricity and petroleum products. Owing to widespread poverty and widespread unemployment, energy is rapidly becoming unaffordable for people living in Palestinian territories. Sadly, the cost of fuel and energy to the

Palestinians are among the highest in the world. The Palestinian energy sector is entirely dependent on imported energy supplies, 87% from Israel, 4% from Jordan and Egypt, andthe remaining 9% are produced locally in Gaza. Consequently, to reduce dependence on the Israeli side of energy sources and contribute to solving the problem of electricity shortage, the photovoltaic systems are the golden solution for the country [4].

As there are different configurations of photovoltaic systems; grid-connected, standalone, and hybrid systems, the most common type in Palestine is the grid-connected PV system. It is an efficient system because it can be easily installed while the power produced in the standalone system must be utilized at the place where it is produced and it is not possible to transmit over a long distance. For that reason, the grid-connected PV system is gaining much attention nowadays [3].

1.1. Background

The project we studied is located in Jerusalem, which is a Palestinian city located in the center of Palestine. Its geographical coordinates are 31.7609° latitude to the north and 35.2159° longitude to the east. Jerusalem city is characterized by a moderate climate; this makes it characterized by hot, dry summers, and mild, rainy winters. The average annual temperature in Jerusalem city is 21.13 °C, and the average annual humidity is 54.15 % [5]. The reason for the establishment of photovoltaic stations and projects in Tubas is its distinction for radiation due to its geographical location and wide lands, and to encourage Jerusalem Electricity Company to invest in these projects. In this research, the focus is on a project based on the roof of a steel structure factory, the total power of the plant is 117 kilowatts. The energy productivity analysis was calculated by taking into account all the necessary variables in addition to the economic analysis of the project, and interest in conducting these analyzes for the existing plants.

Currently, the Jerusalem Electricity Company does not have its power plant, but more than 95% of its electricity comes from the Israel Electric Company (IEC) and the rest from the Jordanian National Electric Company. The Jerusalem Electric Company supplies electricity to nearly 30% of homes in the West Bank and East Jerusalem [6].

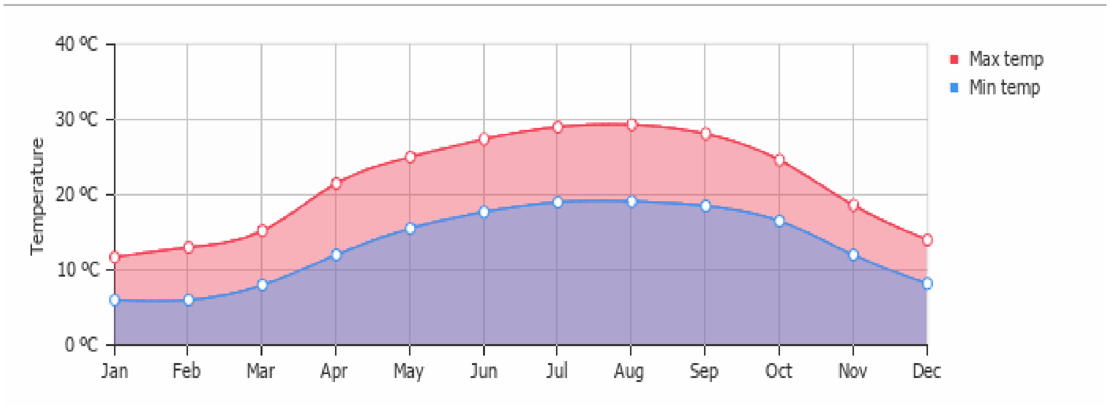

Figure 1. The average monthly temperature in Jerusalem.

1.2. Objectives of the project

The research we are following is related to the Siniora PV project on the roof of a Siniora factory building in Jerusalem. The project consists of 378 Telsun Solar 310 W modules and 3 Sun Grow inverters, each with 33 kW DC power.

The main purpose of this study is to analyze and follow up on the long-term performance of the photovoltaic system connected to the Jerusalem grid, in addition to analyzing the economic feasibility of the project and clarifying its effectiveness. This study was conducted for the year 2021. The simulation results on the PVsyst software are compared with the real data, and the performance, productivity, technical and economic analysis of the grid-connected PV system are obtained, proving the feasibility and technology of the existing project.

1.3. Problem Statement

The problem of the research lies in the dependence of projects owners and people in the economic feasibility calculations on simulation programs in which the capacity of the system to produce is exaggerated, in addition to the lack of analysis of the energy yield in terms of the economic and technical performance of the existing solar power plants.

There is a need for further studies investigating the economic performance to ensure the long-term level of the PV systems installed in Palestine. In particular, knowing that there are no national laboratories to test the quality and performance of all imported PV products, it is only based on the manufacturer's test reports.

1.4. Research Question

How accurate does the technical and economic analysis of the PV stations based on simulation softwares, from a practical and real point of view after the plant production appear?

1.5. Report Structure

The remaining parts of this report are divided as follows: Chapter Two provides a literature review of similar previous contributions, Chapter Three explains the theoretical background, where energy is explained in the Palestinian context, and PV system theory, and Chapter Four explains the methodology that was followed. Followed to complete the project in addition to clarifying the performance parameters and the most important economic parameters of the photovoltaic systems connected to the grid through which the effectiveness of the project is clarified. The fifth chapter discussed the results of the project through the PVsyst report and a sample of accounts, and finally, the sixth chapter talked about the general conclusion about the idea of conducting a technical and economic return analysis for the existing photovoltaic projects, in addition to recommendations and future work.

Ch2. Literature Review

Providing renewable energy and its sources is important for economic growth and its stability, as photovoltaic energy systems have become one of the most costly sources. A technical and economic feasibility study was presented for the parameters of a 5MW farm in the Philippines, and after simulating these parameters through the PVsyst program, the results revealed long-term economic and financial benefits for this farm [7].

Analyzed the continuous monitoring data of a photovoltaic system located on the roof of the Faculty of Pharmacy at An-Najah National University in Palestine with a capacity of 41 kW, tracking the plant's electricity productivity and verifying it through the PVsyst program, in addition to evaluating the yield analysis and comparing it with the Mediterranean countries, the results of the analysis of the station's performance and other parameters Useful in identifying solar energy technologies in Palestine and assessing the feasibility of these projects on the rooftops of Palestinian buildings [8].

At the Norwegian University, a photovoltaic system was installed in the laboratory building for life sciences with a capacity of 2.1kW, the results showed that in the winter the economic feasibility of the system decreases significantly compared to the summer so that the value of the nutrition is approximately US$0.356/kWh [9].

A study was conducted on the evaluation and analysis of the economic and technical feasibility of off-grid photovoltaic systems in Punjab in rural areas in particular, and they were classified as the best systems for these areas due to their ease of installation and maintenance. This study also revealed that carbon dioxide can be reduced by 617,020 metric tons annually by supplying rural homes with fully electric [10].

In Pakistan, a project has been proposed to establish a grid-connected photovoltaic system with a capacity of 150MW on a land area of 750 acres. This plant is considered one of the largest projects connected to the grid, as it highlighted the feasibility study, production, and performancethrough the PVsyst program, where the annual performance rate reached 74.73%, And the annualcapacity factor is approximately 17.7%. These results indicate the effectiveness of the project

and encourage its establishment, and it will feed the network station with the maximum available percentage [11].
Kuwait City is characterized by high solar radiation, which results in the increasing demand for energy and concerns about climate change. Two systems were installed with a capacity of 85.05 kW and 21.6 kW, respectively, with a layer of copper indium gallium selenide (CIGS). These two systems were installed on the roofs of two schools and worked to evaluate Their performance where the performance ratio of the two plants was 74% and 85%, respectively, and the annual energy production of the two photovoltaic systems was 1642.5 kWh / kW [12].

A study was conducted on the technical and economic impact of grid-connected photovoltaic systems on Palestinian energy security (PV systems in Jericho - case study). This study includes two types of networks, namely low-voltage networks and medium-voltage networks. The systems were designed using the Matlab Simulink program to analyze the technical and economic performance of building these systems based on changing environmental conditions and available climate data such as temperature, radiation, and wind speed. Results from Simulink determined that findings on medium voltage networks were small and imperceptible in terms of technical impact, as they were perceptible on low voltage networks, and made recommendations to reduce negative technical impacts. Regarding the economic analysis, it turns out that the Jericho solar plant generates electricity at $0.18/kWh compared to $0.19/kWh from conventional energy sources [13].

In Palestine, the use of photovoltaic systems on the roofs of residential homes has spread due to the low prices of photovoltaic energy and government support for these systems. Three of these home systems that have been operating for three years have been selected for technical and economic evaluation. The capacity of each of those systems was 5 kW, and the results of the last two years of operation were taken, where the annual rate of return was 1756 kWh/kWp. As for the results of the economic analyzes, they were feasible and encouraging to intensify the use of home photovoltaic energy systems, and this was verified through the payback period, which was 4.9 years, the cost of energy produced (0.43 NIS / kWh) and the internal rate of return of 25%. It was also found that there is no solar PV industry in Palestine, as it imports all PV modules, transformers, and protection devices from foreign countries, but the current low price of PV modules encourages the expansion of the use of PV systems due to its economic and environmental benefits [14].

A study was conducted on the technical and economic aspects of different configurations of PV systems designed to suit the Hungarian renewable energy regulations. Five major technical options for PV systems ranging in size from 50 kW to 500 kW were analyzed. This study helps stakeholders in the labor market to understand the potential trends of PV development. technical and economic. According to the results, the payback periods ranged between 7-9 years in all the studied economic-technical cases. The best IRR was 16.5%. Empirical results show that any investment option under Hungarian regulations is likely to be a good economic and technical decision [15].

A scientific paper was presented that includes an assessment of the technical and economic performance of the photovoltaic systems on the rooftops of three Palestinian schools connected on a grid of 7.68 kWh over 12 months: Al-Razi School for Boys, Al-Mueh School for Boys, and Khawla. Al-Azwar Girls School. When the results came out, it was found that the average performance ratio in the three schools was 78%, and the average annual energy produced for each system was 10.930 MWh/year. These results encourage the implementation of technical and economic analysis studies to increase the use of PV systems in schools, as these systems have a payback period of fewer than 5 years and an internal rate of return of close to 20%. It is clear that solar energy is the best option because it can be used in a cost-effective [16].

Ch3. Theoretical background

3.1. Palestine energy context

The Palestinian territories contain two areas: the West Bank, with an estimated area of 5,949 square kilometers, including Jerusalem, and the Gaza Strip of 365 square kilometers. These lands are also divided into 3 administrative areas: A, B, and C. in Area A, the security and civil control belong to PT, Area B belongs to the security control, and the civilian control belongs to Israel and PT. In Area C, the civil and security control belongs to Israel, where most of the Palestinian lands are classified as area C [17]

Studies indicate that the population density in the Gaza Strip is one of the highest population densities in the world, as the PT is generally an area with a complex political situation, which leads to a slowdown in economic growth, and the energy situation is very difficult, forcing the Palestinians to depend on Israel, as the physical situation in PT, high costs and energy resources are the factors that encourage the creation of alternative opportunities [17]

The electricity supply in the Gaza Strip is very poor because it meets only half of the demand. As for the West Bank, it is generally characterized by the availability of electricity around the clock, regardless of the shortage sometimes in the winter and summer seasons. Energy costs are considered high compared to other countries because they depend on imports from Israel and Egypt [18].

In 2012, PENRA launched a company called PSI, under which Palestinian homeowners purchased photovoltaic systems and sold the surplus to the network. The Energy Authority has set a sectoral framework for the development of the energy sector in the period 2017-2022, including agreements with Israel to transfer electricity distribution to the Palestinian government [17].

In order to increase the energy demand, it is necessary to provide clean energy and reduce the negative effects resulting from the electricity supply in addition to producing and consuming energy as efficiently as possible. [17].

3.2. Photovoltaic system theory

Solar Energy is a type of green and sustainable energy that comes to us from the sunlight, this kind of energy is free and useful by converting it into electric energy, and it had clean emissions to the environment, we can extract this energy by the photovoltaic technique which called PV cells, these cells are combined in a PV module, which injects energy as a Direct Current "DC", these modules are connected by a parallel and series connection, to produce sufficient energy to feed a certain load, which could be a household, traffic signs, commercial building, lighting system, etc.

Three types of PV systems are generally used, namely, standalone PV system, hybrid PV system, and grid-connected PV system. Standalone PV systems are widely used in rural and remote areas. However, grid-connected PV systems are widely used as distributed generation units in power systems.

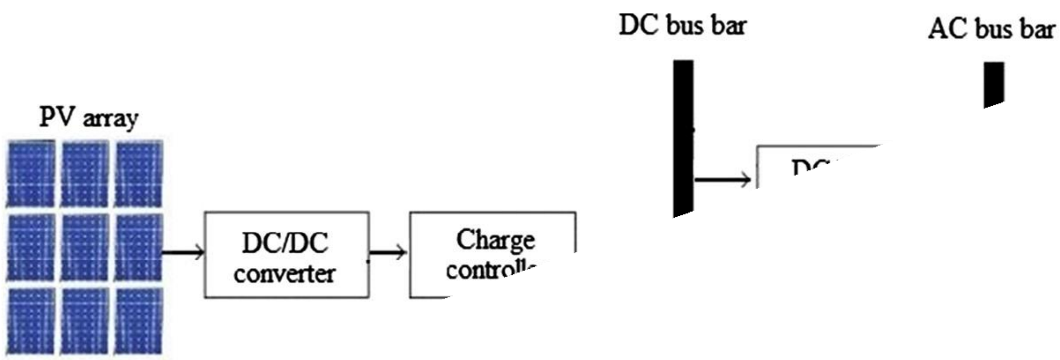

Figure 2. Basic components of Standalone PV systemFigure2. shows the basic components of the standalone PV system. A standalone PV system has no connection with an electric utility grid. A PV generator usually consists of a PV array that is composed of many PV modules, while each PV module is composed of many solar cells. The storage battery stores energy when the power produced by the PV generator exceeds the requiredload demand and emancipates it back when the PV generator production is insufficient. The standalone system has two types of load demand, DC and/or AC load. The DC-DC inverter must be used in the system, whether the DC-AC inverter is used only if the load requires changing the DC to AC [19].

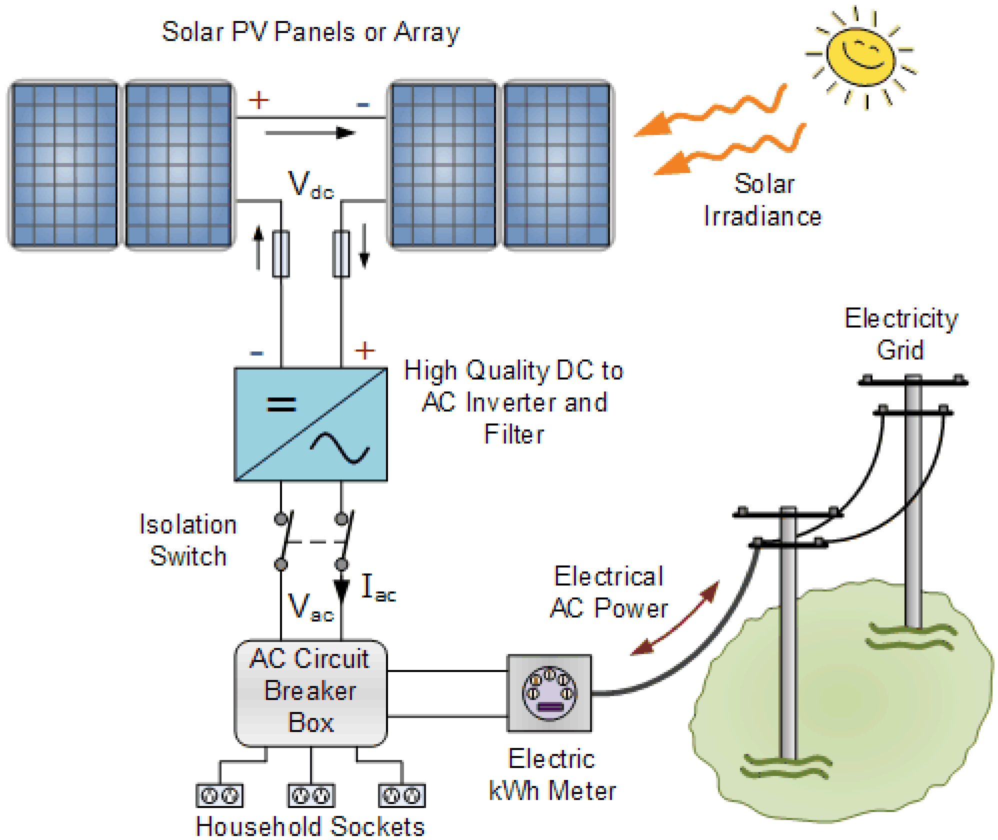

Figure 3. Basic components of a grid-connected system.

Grid-connected PV systems in the world account for about 99% of the installed capacity compared to stand-alone systems, which use batteries. Battery-less grid-connected PV is cost-effective and requires less maintenance. Batteries are not needed for grid-connected PV as shownin Figure3. The main components of a grid-connected system consist of the inverter, PV panels,electric meter, and the load that the system will feed [20].

The most important part of any grid-connected system is the inverter. The inverter converts the DC to AC at the right voltage and frequency for feeding the loads. It is important to choose a good quality inverter that has maximum high power and low voltage, in addition, to have high efficiency to convert as much as possible solar power to AC power.

Coming to the electricity meter is also called Kilowatt-hour (kWh) meter, and it is used to record the flow of electricity being sent to the grid and the electrical energy being consumedfrom the grid [21].

3.3. Economic analysis Theory

Economic Analysis is an important part of any PV project because it is an indicator for the project profit to know if the project is feasible or not. But as we know; many factors affect the PV system which also affects the profit of the project. We listed some of these factors that are represented in the energy losses of the PV system in the following sections.

3.3.1. Irradiation Losses:

Irradiation losses can be caused by many reasons:

- The reflection loss is the loss of irradiation at the surface of the PV modules where a part of the incident light is reflected before being absorbed by the PV modules.
- Irradiation loss caused by shading is the loss when any part of the PV modules got shaded by any shading object, it is the most common loss and causes many problems because if one cell got shaded the current of all the cells will reduce to the least current
- Soiling losses refer to loss in power resulting from snow, dirt, dust, and other particles that cover the surface of the PV module.

3.3.2. System Losses:

- The temperature effect can be in energy loss and energy gain due to module temperatures. Because the modules are tested and manufactured due to an STC temperature of 25 ^{o}C. If it exceeds or is less than the STC temperature, it will cause losses.
- Low irradiance losses are the energy losses in the PV modules at irradiance levels other than the STC irradiance of 1000 W/m^2, at the STC temperature of 25 ^{o}C, and assuming ideal maximum power-point tracking.
- DC-cable losses are defined by the ohmic losses in the wiring, on the assumption that parts of the PV array are uncoupled and that maximum power-point tracking is ideal.

- Energy losses occurring in the inverter refer to losses caused by DC/AC energy conversion and losses caused by inverter control. Effect resulting from inverter control is from the protective cut-off procedure at high input powers and increased inverter temperatures.

Ch4. Methodology

The site of the photovoltaic project used in this simulation is located in Palestine, specifically Jerusalem. It has relatively mild weather. The targeted project in this study is located on the roof of the Siniora building, with a capacity of 117 kilowatts. Figure 4 shows the existing project taken from the geomolg site.

Figure 4. Site of the Siniora building on which the project is based by geomolg.

The information about the power plant was entered into the PVsyst software, and then the results of the program are compared with the real data, in order to analyze the performance and economic analysis of the PV system with its main parameters on the grid. We can summarize the methodology in the following points:

1- Identifying and collecting the information of the power plant taken from the Factory and entering it into the PVsyst program.

2- Analyzing the results of the program and comparing them with the real data.

3- Calculation of economical analysis of the on-grid photovoltaic system using Excel Sheets.

4- Define concusions and recommendations based on the techno-economic comparison.

4.1. Performance and Economic Analysis of on-grid PV system

Determining performance and economic analysis can be done by calculating different parameters at expected conditions of the PV system for the existing project. The following illustrates the calculation procedure that was adopted.

4.1.1. Yield Analysis

There are different categories of on-grid PV system yields that will be determined in the following equations:

The final yield can be defined as the total AC energy during a given period divided by the rated PV array power and is given by Equation (1):

$$Y_F = \frac{E_{AC}}{P_{PV,rated}} (kWh/kWp/year) \quad (1)$$

Where E_{AC} is the total AC energy output from the and it equals (kWh/year) and $P_{PV,\ rated}$ is the rated output power of the PV system (kWp).

The reference yield can be determined as the total plane solar irradiance divided by the reference irradiance under standard temperature (1 kWh/m^2) and is calculated as the Equation (2):

$$Y_R = \frac{H_T}{H_R} \ (kWh/year) \quad (2)$$

Where H_T is the plane solar irradiance (kWh), and H_R is the reference irradiance.

4.1.2. Performance Ratio

The performance ratio (PR) is the ratio of the final energy yield of the PV system to the reference yield; it can be calculated using Equation (3). It provides information about the overall losses incurred in converting DC to AC power. Therefore, it represents the percentage of energy available after deducting energy losses:

$$PR = \frac{Y_F}{Y_R} \times 100\% \tag{3}$$

4.1.3. Capacity Utilization Factor

The capacity utilization factor (CUF) is calculated as the ratio of real annual energy output by the PV system (E_{AC}), to the amount of energy the PV system would generate if it is operated at full rated power for a full day for a year, and it is calculated using Equation (4):

$$CUF = \frac{E_{AC}}{P_{PV,rated} \times 8760} \times 100\% \tag{4}$$

4.1.4. Net Present Value

Net present value (NPV) or present worth can be calculated as a difference between the present worth of cash inflows and the present worth of cash outflows over a period of time.

Production of the Plant is calculated for the first year by the summation of all the months together, then for the next 19 years using Equation (5):

$$Energy\ Production\ = n\ \times (1 - 0.005)\ \ (kWh/year) \tag{5}$$

Where n represents the production of the previous year and 0.005 is how the efficiency of the solar panel reduces every year.

Savings for the first year are calculated based on Equation (6):

$$Savings = kWh\ Production\ \times 0.17\ (\$/Year) \tag{6}$$

Where kWh production is the production in the first year and 0.17 $/kWh is the cost of electricity in Palestine.

Calculating the revenues for the next 19 years based on Equation (7):

$$Savings/Year = n\ \times (1 - 0.005)\ \ (\$/year) \tag{7}$$

Where n represents the savings in the previous year.

Net Present Value is calculated by the Equations (8) & (9):

$$NPV\ = Income\ Cash\ Flow - Outcome\ Cash\ Flow\ (\$) \tag{8}$$

$$NPV\ \ =\ \ Investment -\ \ [F(P/F\ , i, n)]\ (\$) \tag{9}$$

Where F is the revenues per year, (P/F) is the factor from the interest tables, i is the interest rate which is 10%, and n is the number of years.

4.1.5. Simple Payback Period

A simple Payback Period (SPBP) is another technique that can be used to analyze the project feasibility, and it can be defined as the length of time required to recover the capital cost or the (LCC) of an investment. If the SPBP was lower than the project lifetime this means the project is feasible, otherwise is not. The SPBP can be estimated using Equation (10):

$$SPBP = \frac{Investment}{Saving\ cost\ per\ year}\ (Year) \tag{10}$$

4.1.6. Internal Rate of Return

Internal Rate of Return (IRR) is a technique to estimate the profitability of potential investments. It is the rate of return at which the net present value of a project becomes zero, it can be estimated using Equation (11):

$$0 = NPV = \sum_{n=0}^{n} \frac{CF_n}{(1+IRR)^n} \tag{11}$$

Where NPV is the net present value which will be zero, CFn is the cash flow of each year, and n represents the year.

4.1.7. Levelized Cost of Energy

The Levelized Cost of Energy (LCOE) is a ratio that computes the total cost of the facility during its cycle of life by dividing it by the energy produced at the same time, it can be estimated using Equation (12):

$$LCOE = \frac{Investment}{\sum [F(P/F,i,n)]} \ (\$/kWh) \tag{12}$$

Where the F represents the energy production of each year, (P/F) is the factor from the interest tables, i is the interest rate which is 10%, and n is the number of years.

Ch5. Result and discussion

5.1. Data Collection

By reviewing the literature, we arrive at a specific data flow that must be considered in this analysis. The research is based on identifying the main parameters of the plant. These data are categorized into different groups which can be represented in Figure 5.

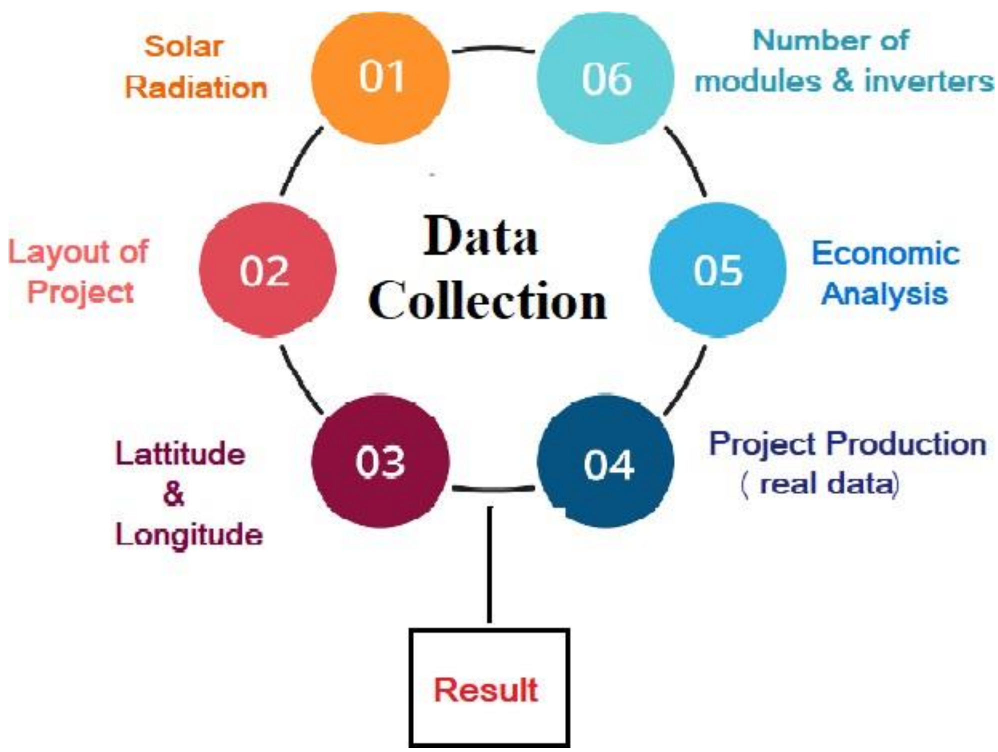

Figure 5. The general structure of data flow.

For this on-grid system, a grid-tie inverter has been used which takes the reference input voltage, phase angle, and frequency from the grid. The site has its monitoring system to collect solar radiation data in units of W/m^2, unit temperature (°C) and ambient temperature (°C), and energy output.

5.2. Project Information:

The specifications of the installed solar PV modules and inverters have been collected and shown in Table 1.

Table 1. The specification of solar PV modules and Inverters of the Plant.

Number of panels	378
PV Manufacturer	Telsun Solar
Cell Type	Mono-Crystalline
Wp/panel	310 Wp
Inverter Type	SunGrow
Rated Power	33 kW

The photovoltaic array is connected to the inverter through a DC junction box so that it contains all protection systems from circuit breakers, fuses, and surge arrestors. The inverter converts the DC coming from the array into an alternating current.

5.2.1 Layout PV power project using AutoCAD

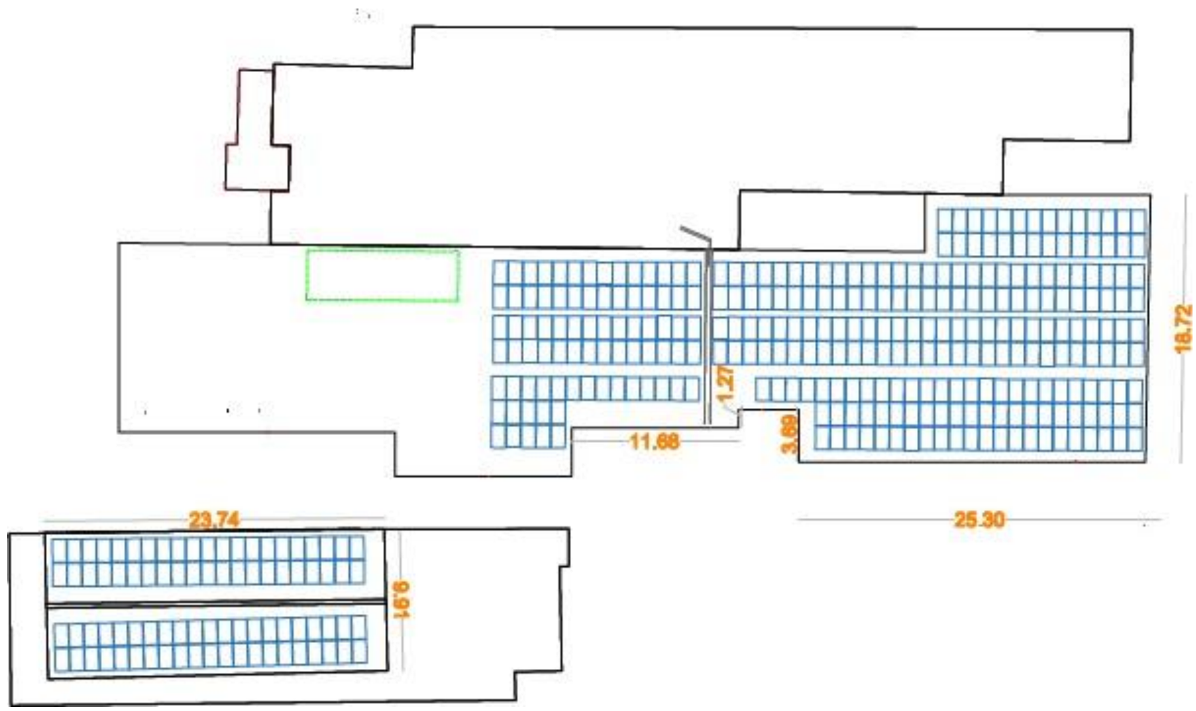

Figure 6. Layout for a PV power plant using AutoCAD.

Figure 6. shows a detailed diagram of the project existing, containing 378 cells and 3 inverters. The PV modules are fixed on seven galvanized steel tables facing straight to the south with a tilt angle of 25°. The system is divided into 2 flats, the first one contains 290 modules, and the second one contains 88 modules. The inverters are fixed on the chassis behind the PV modules distributed throughout PV power plant tables.

5.2.2 Simulation results of PV system

A software program PVsys have been used for the design and simulation of the above-mentioned system. The expected energy output from PV simulation is illustrated over the year 2020 in Figure 7.

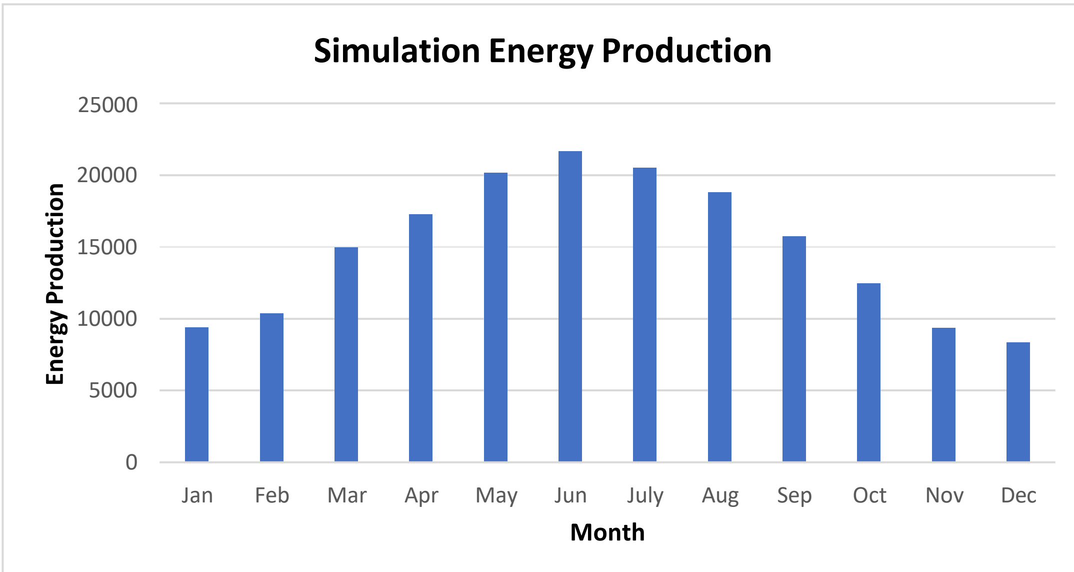

Figure 7. Monthly energy expected output for the Plant in 2021.

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	91.5	34.24	12.53	91.4	86.7	9544	9407	0.878
February	100.7	45.87	13.81	100.6	96.8	10501	10357	0.878
March	148.5	65.83	16.86	148.5	144.2	15177	14970	0.860
April	175.7	71.25	19.87	175.6	171.5	17506	17268	0.839
May	210.4	84.25	23.65	210.3	205.7	20437	20170	0.819
June	231.8	66.49	26.34	231.7	227.2	21971	21676	0.798
July	220.9	75.76	28.84	220.9	216.1	20783	20503	0.792
August	200.9	78.87	29.21	200.8	196.3	19047	18794	0.799
September	166.2	57.12	27.06	166.0	161.7	15958	15744	0.809
October	127.8	53.51	24.08	127.8	123.1	12611	12440	0.831
November	93.6	38.63	18.61	93.5	89.2	9509	9371	0.856
December	81.8	36.04	14.35	81.7	77.1	8465	8346	0.872
Year	1849.8	707.87	21.31	1848.8	1795.5	181508	179047	0.826

Figure 8. Main results for each month in 2017 from the PVsyst software.

Through Figure 8, we can know that the output energy of the array and the energy injected into the grid, as well as the performance ratio of the solar modules and the absorbed solar radiation value, are the main parameters required for the analysis and calculation of the yield for the Plant.

5.3. Sample of Calculations

5.3.1. System yields:

The different parameters have been determined by the following equations for the plant (117 kW):

- The final yield is defined by equation (1):

$$Y_F = \frac{163142.79}{117}\ (kWh/kWp/year) \tag{1}$$

$$Y_F = 1394.38\ (kWh/kWp/year)$$

The reference yield is calculated as the equation (2):

$$Y_R = \frac{2240.62}{1}\ (kWh/year) \tag{2}$$

$$Y_R = 2240.62\ (kWh/year)$$

5.3.2. Performance Ratio:

The performance ratio (PR) is calculated using equation (3):

$$PR = \frac{1394.38}{2240.62} \times 100\% \tag{3}$$

$$PR = 62.2\ \%$$

5.3.3. Capacity Utilization Factor

The capacity utilization factor (CUF) is calculated using equation (4).

$$CUF = \frac{163142.797}{117 \times 8760} \times 100\% \tag{4}$$

$$CUF = 16\ \%$$

5.3.4. Net Present Value:

Energy Production for the first year equals 163143 kWh/Year, Energy Production for the next 19 years is determined by equation (5), and the total energy production is represented in the following chart:

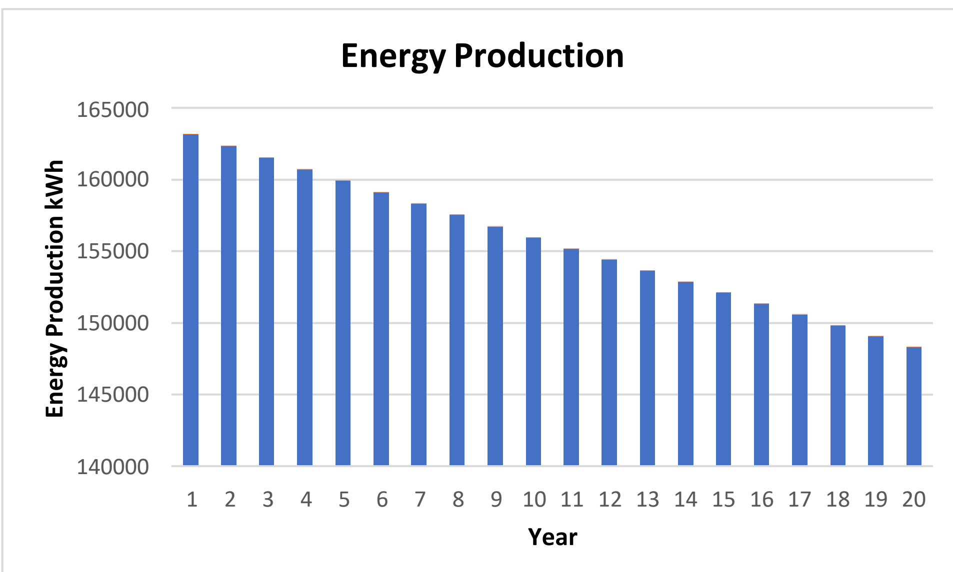

Figure 9. Energy Production of the plant for 20 Years.

Savings for the first year are calculated based on Equation (6):

$$Savings = 163143 \times 0.17\ (\$/Year) \tag{6}$$

$$Savings = 27734\ (\$/Year)$$

The savings for the next 19 years are calculated based on Equation (7) with a summation of:

$$Savings = 529112\ (\$) \tag{7}$$

Net Present Value is calculated based on Equations (8) & (9):

$$NPV = -Investment + \sum[F(P/F, i, n)]\ (\$) \tag{9}$$

$$NPV = -117{,}000 + 228{,}615\ (\$)$$

$$NPV = 111{,}615\ (\$)$$

5.3.5. Simple Payback Period

SPBP is calculated based on Equation (10):

$$SPBP = \frac{117{,}000}{27{,}734}\ (Year) \tag{10}$$

$$SPBP = 4.2\ (Year)$$

5.3.6. Internal Rate of Return

Internal Rate of Return (IRR) is calculated based on Equation (11):

$$IRR = 18\ \% \tag{11}$$

5.3.7. Levelized Cost of Energy:

LCOE is calculated based on Equation (12):

$$LCOE = \frac{117{,}000}{1{,}344{,}793}\ (\$/kWh) \tag{12}$$

$$LCOE = 0.087\ (\$/kWh)$$

5.4. Comparison between simulation results and real data

The energy output results from the PVsyst program are compared to the real data that we collected from the plant as shown in Figure 12. It shows that the real data are kind of close to the simulation results, the difference between them comes from the shading problems and the losses calculated above. Overall, the real data are acceptable.

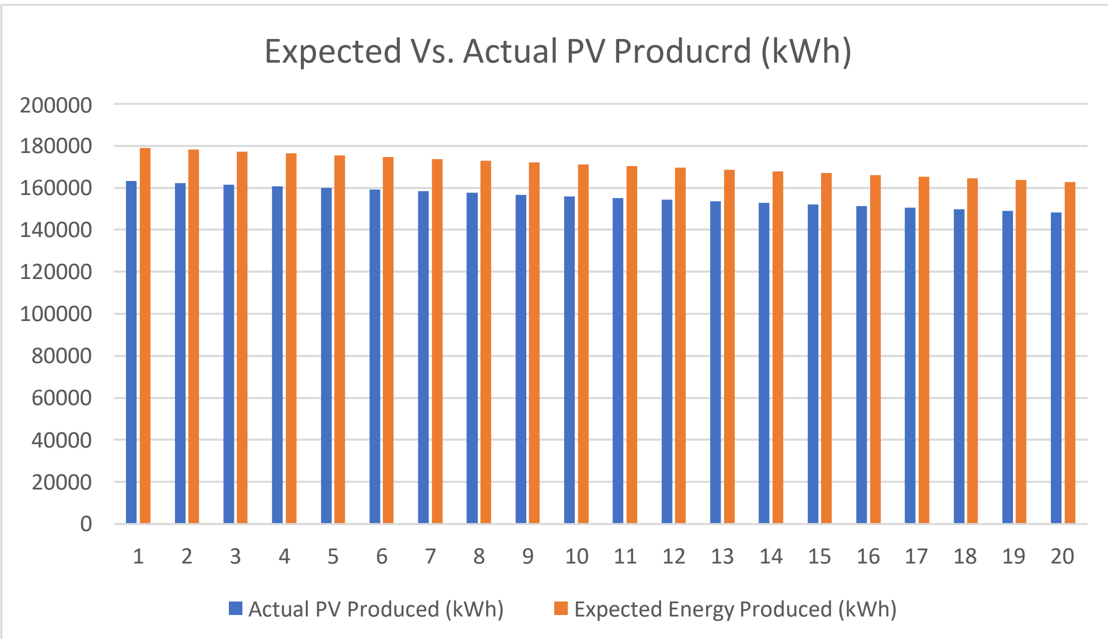

Figure 10. Comparison between Expected and Actual energy output project.

Table 2. Comparison between economic analysis of PVsyst and Real Data.

	Simulation Data	Real Data
PR	82 %	62 %
CUF	17.5 %	16 %
NPV	133,904 $	111,614 $
SPBP	4.2 Years	3.8 Years
IRR	19 %	18 %
LCOE	0.08	0.087

The table shown above compares the data from the PVsyst and the real data from the plant. That explains for us the deviation between the simulation programs and real data. The difference between them is slight so that is a good sign for us to use the simulation programs and design the whole plant.

5.5. Maintenance Checklist

Solar panels are very durable, main warranties last for 15-25 years. However, the efficiency of the PV panels reduces every year because of manufacturing and maintenance reasons. So there are many factors we need to check periodically, some of them are listed down below.

- Cleaning solar panels is important to maximize the amount of light available to turn into electrical power. Making frequent physical inspections can help solar panels absorb light effectively.
- A good monitoring system will provide information on the production, alarms for any problem in the system, and energy management software in a timely, efficient and precise manner to detect any irregularity of the PV plant.
- Avoid any shading object that may be around the panels because it is a severe problem of reducing the production of the panel.

Ch6. Conclusion and, recommendations

In this research, a case study was developed to see the performance and profits of the grid-connected plant that has a nominal power of 117 kWp. PVsyst program was used to perform simulation, calculation, and optimization. Input data such as solar radiation and the number of solar panels were considered in Jerusalem city, Palestine. The comparison was made between the data from the simulation program and the real data and then economic calculations between both of them, and it showsthat there are many differences between the simulation and real data because of many factors that make losses in the system.

In conclusion, the performance ratio for the plant is 62.2 %, which is good for a networked terminal, but it can be better if they make annual monitoring and maintenance to the plant. The Net Present Value of the plant is 111,615 $ which is very good, and the SPBP is 4.2 years. Compared to plants in Palestine, these results are somewhat higher than others, so we recommend engineersperform similar calculations for existing PV projects to check the plant's performance and profits before and after installing the plant to make a plan on how to keep the plant’s performance as good as the first year.

As a result, the plant is economically effective, but it can be more effective by reducing the losses as much as possible by cleaning the panels and avoiding any shading that may be near the panels to increase the performance of the plant, as well as increasing the energy production.

As well as we recommend people who use and rely on software to analyze the data to be warned that there is a deviation between the simulation and real results.

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