Received: 6 June 2023 | Revised: 27 June 2023 | Accepted: 9 July 2023 | Published online: 17 July 2023

Archives of Advanced Engineering Science
2023, Vol. 1(1) 63–76
DOI: 10.47852/bonviewAAES32021177

BON VIEW PUBLISHING

RESEARCH ARTICLE

Design and Economic Analysis of On-Grid Solar Rooftop PV System Using PVsyst Software

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Abstract: Most businesses heavily rely on a consistent and reliable supply of electricity to sustain their operations. Unfortunately, the utility grid in Ghazni suffers from poor energy security and high electricity costs. As a result, many of these establishments have resorted to using diesel generators to meet their energy demands. This study focuses on the design and economic analysis of an on-grid solar rooftop photovoltaic (PV) system, utilizing PVsyst software. The research findings indicate that the designed on-grid solar rooftop PV system has a specific solar PV capacity of 10 kW, capable of generating an estimated annual energy output of 19,323 kWh. The economic analysis reveals that the initial capital required to establish this Solar system amounts to US$ 5213. The payback period is estimated to be 6.3 years, with a projected return on investment of 457 %.

Keywords: renewable energy, economic analysis, on-grid solar rooftop PV system, PVsyst software

1. Introduction

Renewable sources offer a more attractive alternative to traditional fuels since they could provide clean energy to meet energy needs and play a crucial part in the future energy supply (Chenic et al., 2022). A photovoltaic (PV) cell is a device that transforms solar energy into electricity, ensuring that the amount of power produced always matches the maximum load requirement (Hassan et al., 2023; Mayer et al., 2023). It produces greater electrical output during sunny days compared to cloudy days, coinciding with the increased demand for electricity from the grid due to different factors (Hassan et al., 2023; Ohba et al., 2023). PV modules, commonly referred to as solar panels, employ semiconductors to seize sunlight and directly transform it into electrical energy (Dewi et al., 2023). When utilizing alternating current (AC) loads, an inverter becomes essential to convert the panels' direct current (DC) output into AC electricity (Jaber & Shakir, 2021; Pandey et al., 2022a). There are two main categories of PV generation systems for buildings: building-integrated photovoltaic (BIPV) and building-applied photovoltaic (BAPV) technologies. BIPV refers to the incorporation of PV technology into building materials and structures, seamlessly integrating renewable energy generation into the built environment. BAPV refers to the integration of PV technology directly into the design and structure of buildings, thereby combining the functions of renewable energy generation and building envelope (Jaber & Shakir, 2021; Ammous et al., 2021). PV systems can be further classified into three types: grid-connected, standalone, and hybrid systems (Gonçalves et al., 2021; Ravyts et al., 2020). In a standalone PV system, it operates independently from the utility grid and typically includes battery storage to power both DC and AC loads (Gonçalves et al., 2021; Okundamiya et al., 2021). Conversely, grid-connected PV systems are gaining significant attention in industries as they provide an alternative to traditional fossil fuels (Barhoumi et al., 2022; Şevik, 2022). These systems comprise PV panels, a bidirectional inverter, a smart meter, a direct DC bus system, a battery system, and an AC bus system (Şevik, 2022). Involves integrating PV panels into various parts of the building envelope, including roofs, windows, facades, balconies, and skylights, effectively replacing traditional building materials with PV panels. On the other hand, BAPV refers to attaching PV materials directly onto the building structure. By combining these two approaches, a more effective integration performance can be achieved (Ibrahim et al., 2023; Subramanian et al., 2023). Grid-connected systems produce environmentally friendly electricity with minimal losses during transmission and distribution. On the other hand, standalone systems operate independently from the utility grid, directly supplying the electricity to the load. In cases where the PV array is not directly connected to the load, an energy storage system becomes necessary (Okundamiya, 2021; Şevik, 2022). Solar energy is harnessed using solar panels, specifically PV systems. These panels are typically made of silicon and come in two main types: polycrystalline and monocrystalline thin films (Okundamiya, 2021; Şevik, 2022; Shah et al., 2023). The solar cells within these panels are created by combining N-type and P-type layers of semiconductors, which generate a built-in electric field (Badal et al., 2023). To understand how solar panels work, let us imagine a scenario where sunlight shines upon a solar panel. The panels utilize the photoelectric effect, a phenomenon in which light energy is converted into electrical energy (Abojela et al., 2023). When sunlight hits the surface of the solar panel, the energy from the

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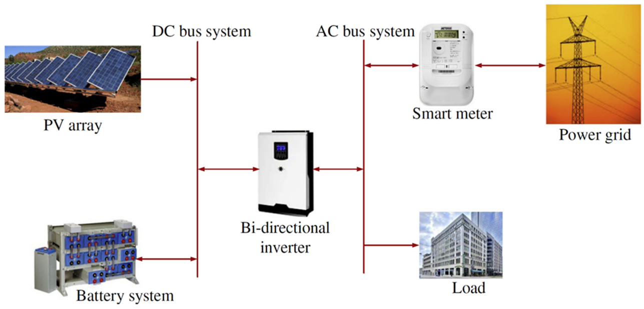
photons (particles of light) is absorbed by the atoms within the panel (Lucchi et al., 2023). As a result, the electrons in the atoms gain extra energy and become excited. This excess energy allows the electrons to break free from their atoms, leading to the dissociation of electron-hole pairs. The electrons, now free to move, create a flow of electricity within the solar panel. This flow of electricity can be harnessed and utilized for various purposes (Şevik, 2022; Kalogirou et al., 2013). By connecting the solar panels to an electrical circuit, the generated electricity can power devices, homes, or even feed into the larger electrical grid (Pandey et al., 2022a, 2022b). In summary, solar energy is derived from the conversion of sunlight into electricity using solar panels. The panels employ the photoelectric effect, whereby photons from sunlight energize electrons in the panel's atoms, leading to the creation of an electric current. A solar cell is like the building block of a solar PV system, which stands for PV system (Khan et al., 2019; Krotkus et al., 2023). Imagine a solar cell as a small unit that can convert sunlight into electricity. To generate more electricity, multiple solar cells are connected, forming a solar PV module (Ling et al., 2022; Kumar, 2023). To increase the voltage output of the module, the solar cells are connected in series. This means that the positive terminal of one cell is connected to the negative terminal of the next cell, creating a chain-like configuration. By doing this, the voltage of each cell adds up, resulting in a higher overall voltage for the module (Chakir et al., 2022; Han & Yi, 2022). On the other hand, if we want to increase the current output of the system, we connect multiple solar modules in parallel. This means that the positive terminals of all the modules are connected, as well as the negative terminals. By doing so, the current produced by each module combines, resulting in a higher overall current for the system. So, by carefully arranging the interconnections between solar cells, we can create solar PV arrays (Chen et al., 2022). These arrays are designed based on the desired output voltage and current. The configuration of the arrays, whether in series or parallel, determines the electrical characteristics of the solar PV system and allows it to generate the desired amount of electricity for specific applications (Song et al., 2022). An article focuses on a specific project in Thu Dau Mot City, Vietnam, which involves the design, simulation, and economic analysis of an 8.36 kWp grid-connected solar power system. The study assesses various aspects of the project, such as electricity generation, the efficiency of the PV system, the reduction of CO_2 emissions, and the economic indicators associated with the undertaking. The objective of the research is to provide valuable insights to stakeholders interested in investing in residential rooftop solar PV systems, as well as to energy policymakers in Vietnam (Ngo & Do, 2022). Grid-connected PV systems are designed to work in conjunction with other distributed energy resources and the utility grid, offering numerous benefits to both utilities and consumers. These systems consist of multiple components, including a bidirectional inverter, PV panels, battery system, smart meter, DC bus system, and AC bus, as illustrated in Figure 1, each serving their respective functions (Pastuszak & Węgierek, 2022).

This study is to assess and evaluate the feasibility of implementing a solar rooftop PV system at Ghazni Technical University. The study aims to design the system using PVsyst software, considering factors such as solar potential (the solar potential, designers can determine the optimum tilt and azimuth angles for solar panels, identify potential shading issues, and estimate the expected energy output of the system). Additionally, the economic analysis will be conducted to determine the financial viability and cost-effectiveness of the proposed solar PV system at the university.

Figure 1
Grid connected solar PV system diagram and components (Adefarati & Bansal, 2019)



2. Research Methodology

2.1. Data collection

A. Solar resource data

Ghazni is one of the southeastern provinces of Afghanistan, with an altitude of 2219 m above sea level. The humidity level in the air is 8.59% in winter and 6.17% in summer. Figure 2 illustrates the variations in temperature throughout the year, displaying seasonal trends and fluctuations. We observe that the temperature tends to reach its peak during the summer months, while it drops to its lowest point during the winter. Figure 3 represents the solar irradiation levels over an annual period, providing valuable insights into the intensity of solar radiation received at different months of the year. Figure 4 depicts the sun's position angle during various times of the year, indicating the sun's elevation and azimuth angles. These figures collectively contribute to our understanding of the solar resource data and aid in analyzing the potential for solar energy harnessing in the given location.

Figure 2
Average high and low temperature in Ghazni (Weatherspark.com)

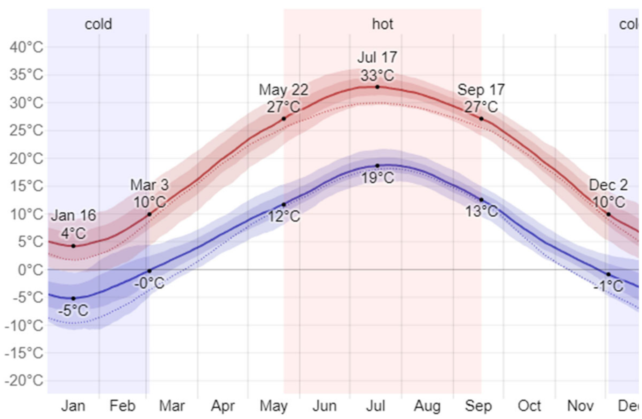


Figure 3
Average daily incident shortwave solar energy in Ghazni (Weatherspark.com)

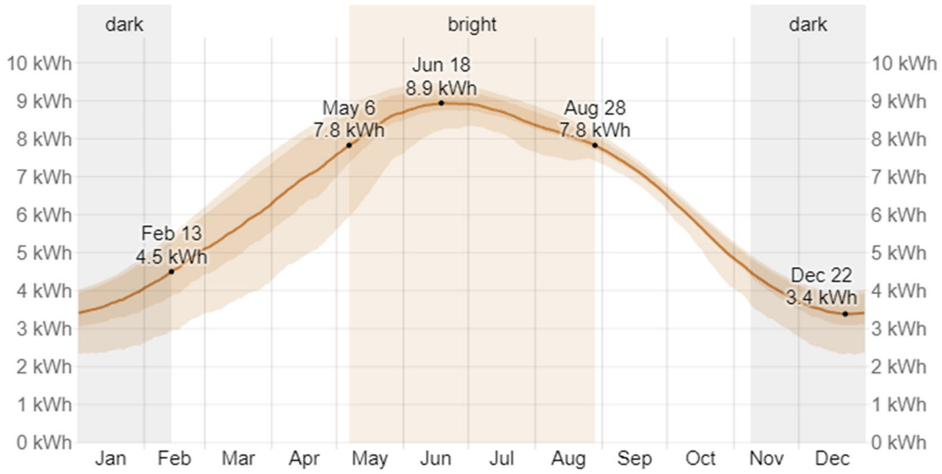
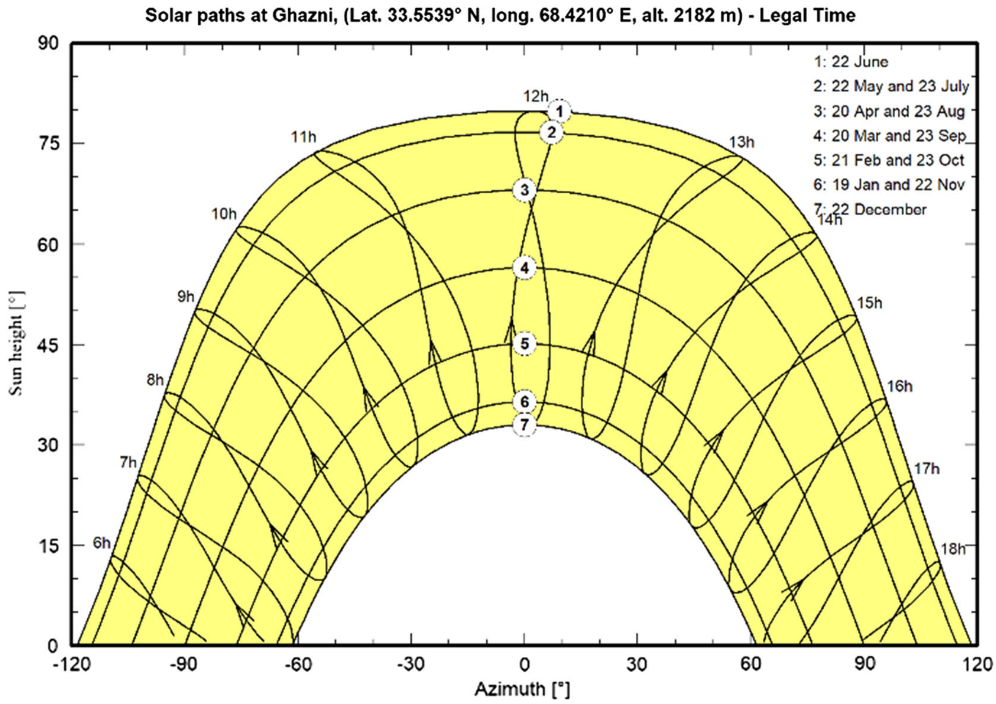


Figure 4
Solar elevation and azimuth in Ghazni (Source: Author)



The sun path diagram shown in Figure 4 for Ghazni illustrates the path that the sun follows across the sky for a day. It provides valuable information about the position of the sun at various times, enabling us to understand the duration and intensity of sunlight throughout the year. In Ghazni, the azimuth represents the horizontal angle of the sun's position, measured in degrees clockwise from true north. The sun's height, on the other hand, indicates the vertical angle of the sun above the horizon. These variations in the sun's path and its azimuth and height values throughout the year have important implications for various activities, such as solar panel orientation, and outdoor lighting. Understanding the sun's position at various times of the year in Ghazni helps in maximizing sunlight exposure or minimizing it, depending on the specific needs. Overall, the sun path diagram, azimuth, and sun height for Ghazni provide valuable insights into the sun's movement and positioning throughout the year, enabling us to make informed decisions related to solar energy.

B. Site assessment

The provided Figure 5 illustrates a group of buildings, each of which is specifically constructed to accommodate solar installations. These buildings have been designed with the unique purpose of harnessing solar energy. In Figure 5, we can observe 20 such

Figure 5
Building map

buildings, and each building possesses a roof area measuring 150 square meters. These buildings have been strategically constructed to maximize the utilization of solar power. By dedicating a separate structure solely for solar installations, it allows for efficient placement and arrangement of solar panels on the rooftops. This arrangement ensures optimal exposure to sunlight, enabling the maximum capture of solar energy. The buildings' design incorporates features that facilitate the installation and operation of solar panels, such as sturdy frameworks, appropriate angles for panel placement, and secure anchoring systems. Additionally, the roofs of these buildings are engineered to bear the weight and provide the necessary support for the solar panels. This dedicated approach to solar installation offers several advantages. Firstly, it ensures that the buildings' primary functions remain unaffected, as the solar panels are situated separately from the principal areas of the structures. Secondly, it allows for scalability, as additional buildings can be constructed in the future, expanding the solar capacity of the installation. Moreover, it provides an organized and systematic layout, making maintenance and servicing of the solar panels more convenient. By utilizing these specialized buildings for solar installation, the depicted scenario indicates a strong commitment to renewable energy and sustainability. It demonstrates a conscious effort to harness solar power efficiently and contribute to a greener and more environmentally friendly future.

Table 1
Specification of building roof

No.	Items	Level
1	Dimensions	15 m, 10 m, 3 m
2	Available area	60 m^2
3	Orientation	South
4	Tilt angle	30°
5	Total area	150 m^2

Table 1 shows the dimensions of each roof, including length, width, and height, and the total surface area available for solar installation. Observe the orientation of each building's roof relative to the cardinal directions (north, south, east, and west). The inclination or tilt angle of the roof, which affects the angle at which solar panels can be installed for optimal sunlight exposure. The building in question has specific dimensions of 15 m in length, 10 m in width, and 3 m in height. The total area of the building is 150 square meters, meaning it occupies that amount of space. However, when it comes to installing solar panels on the building, the available area for solar panel placement is only 60 square meters. This limited area needs to be considered when determining solar energy potential. The building is oriented toward the south, which means the longer side or facade of the building faces south. This orientation is important for maximizing solar energy capture, as the south-facing side receives the most sunlight throughout the day. To optimize solar energy production, the solar panels on the building should be installed at an angle of 30°.

2.2. System design

A. Energy demand analysis:

To explain the energy consumption patterns and requirements of the selected block for analysis, let us refer to Table 2. First, it is important to note that there are a total of 20 identical blocks, all of which have the capacity for solar installation. However, for the purpose of analysis, we have chosen one specific block to focus on. Table 2 presents various data points related to the energy consumption of the block. This includes information on the patterns and requirements of energy usage within the block. By analyzing the table, we can gather insights about how the block consumes energy. It may provide details such as the total energy consumed by the block over a certain period, which could be measured in kWh.

Table 2 represents the energy consumption in a particular block. Different appliances in the block contribute to the overall energy usage. The first row of the table shows the energy consumption of a lamp, which is 1400 Wh. Moving on to the second row, we have the personal computer (PC) with an energy consumption of 1200 Wh. The third row represents the energy consumption of a fan, which is 1120 Wh. The fourth row corresponds to the refrigerant, with an energy consumption of 735 Wh. Lastly, the fifth row represents the energy consumption of a TV, which is 175 Wh. Adding up the energy consumption of all these appliances, we reach a total energy consumption of 4630 Wh, as indicated in the "Total" row. Therefore, based on the table, we can conclude that the combined energy usage of the lamp, PC, fan, refrigerant, and TV in the block is 4630 Wh.

Table 2
Block energy consumption

No.	Items	No#	Power (W)	Power total (W)	Run time	Energy (Wh)
1	Lamp	10	20	200	7	1400
2	PC	3	80	240	5	1200
3	Fan	4	70	280	4	1120
4	Refrigerant	1	245	245	3	735
5	TV	1	35	35	5	175
	Total	22	450	1000	24	4630

B. Component selection:

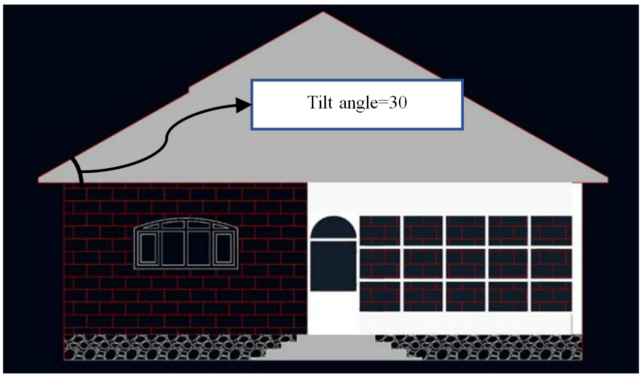
It displays the crucial components required for the proper functioning of a PV system. These components primarily include PV modules and inverters. PV modules, also known as solar panels, are responsible for converting sunlight into electricity. They consist of interconnected solar cells that generate DC when exposed to sunlight. PV modules are the primary energy-generating units in a PV system and come in many sizes and technologies to meet specific energy requirements. Inverters play a vital role in the PV system by converting the DC electricity produced by the PV modules into AC electricity, which is compatible with the electrical grid and most electrical appliances. Inverters ensure that the electricity generated by the PV modules can be efficiently utilized, distributed within the system, or fed back into the grid.

For the PV module, we have chosen a Si-poly module from Jinko Solar with a power rating of 280 W. Si-poly refers to the type of silicon material used in the PV module, which is known for its high efficiency in converting sunlight into electricity. Jinko Solar is the manufacturer of the module, known for its reliable and high-quality products. As for the inverter, we have selected a grid-tied inverter from SMA with a capacity of 10,000 W. The inverter plays a crucial role in converting the DC electricity generated by the PV module into AC electricity that can be used in homes or fed back into the electrical grid. The grid-tied feature means that the inverter is designed to synchronize with the utility grid, allowing excess electricity to be exported to the grid when the PV system produces more power than is being consumed. By combining the Si-poly PV module from Jinko Solar with the grid-tied inverter from SMA, we ensure a reliable and efficient solar energy system. The PV module's high-power rating of 280 W ensures a good electricity generation capacity, while the SMA inverter's 10,000-W capacity allows for efficient conversion and utilization of the generated electricity. Together, these components form a well-integrated system for harnessing solar energy and contributing to a sustainable and renewable energy source.

C. System configuration:

At this latitude, the sun's position in the sky varies throughout the year. During the summer months, the sun is higher in the sky, while in the winter months, it is lower. To capture the maximum amount of sunlight throughout the year, it is important to find a balance that allows the solar panels to receive sufficient sunlight during both summer and winter. After careful analysis and calculations, it has been determined that a tilt angle of 30° provides the optimal configuration for this location. This angle strikes a balance between maximizing energy production during the summer months and maintaining a sufficient angle during the winter months. When the solar panels are tilted at 30°, they are inclined enough to capture the maximum amount of sunlight during the summer, when the sun is higher in the sky. This allows the panels to receive direct sunlight for longer periods, resulting in higher energy generation. During the winter, when the sun is lower in the sky, the 30° tilt angle ensures that the panels are still at an angle that allows them to receive a significant amount of sunlight, despite the lower sun position. This prevents a drastic reduction in energy production during the colder months. By setting the solar panels at a fixed tilt angle of 30°, the system can optimize energy generation throughout the year, leading to higher overall efficiency and increased electricity production. The optimal tilt and orientation angles for maximizing solar energy generation are shown in Figure 6.

Figure 6
Building roof tilt angle



2.3. Economic analysis

A. Cost analysis:

To estimate the initial costs of installing a solar rooftop PV system. This includes PV panels, inverters, installation structures, electrical components, installation, and other additional costs such as grid connection fees or permits.

B. Financial metrics:

In the field of renewable energy projects, it is crucial to evaluate their economic viability. One way to achieve this is by calculating key financial metrics. This article aims to explain the meaning and significance of four common financial metrics: payback period, return on investment (ROI), internal rate of return (IRR), and net present value (NPV). Additionally, we will provide calculations based on the project's specific costs and expected energy generation.

1: Payback period:
The payback period is a metric that measures the time required for an investment to recoup its initial cost. It provides an estimate of how long it will take to recover the project's upfront expenses. The shorter the payback period, the quicker the project will generate positive cash flows. To calculate the payback period, divide the initial investment cost by the expected annual cash flows:
Payback Period = Initial Investment Cost/Annual Cash Flows (Asamoah et al., 2022).

2: Return on investment:
ROI measures the profitability of an investment relative to its cost. It indicates the percentage of the initial investment that is returned as profit over a specific period. The formula for ROI is
ROI = (Net Profit/Initial Investment Cost) * 100 (Nakash & Bouhnik 2022)

3: Internal rate of return:
The IRR is the discount rate at which the project's NPV becomes zero. It represents the project's average annual rate of return over its lifetime. The IRR is an essential metric for assessing the project's profitability. To calculate the IRR (Mellichamp, 2017).

4: Net present value:
NPV is a financial metric that measures the value of future cash flows in today's dollars. It helps determine whether an

investment is financially feasible by considering the time value of money. A positive NPV indicates that the project is expected to generate more value than its initial cost, making it potentially profitable. The formula for NPV is

$$\text{NPV} = \text{Sum of}[\text{Cash Flow}/(1 + \text{Discount Rate})\wedge(\text{Time Period})] - \text{Initial Investment Cost}$$

(Torries, 1998).

2.4. PVsyst simulation

PVsyst is a powerful software tool extensively employed in the solar energy industry for simulating the performance of PV systems under various meteorological conditions. Accurate solar resource data are essential for obtaining reliable simulation results. The NREL NSRDB TMY dataset offers a representative set of meteorological parameters derived from historical data from 2000 to 2014. This dataset includes information such as solar irradiance, temperature, wind speed, and other relevant weather variables. This research uses NREL data to obtain precise insights into PV systems' performance and energy generation potential.

3. Results and Discussion

This section discusses the implementation of the research methodology of designing and economic analysis of the rooftop solar PV system presented in the preceding section.

3.1. Design of rooftop solar PV system

A. PV system design

The roof of the selected building has been designated as the location for the installation of solar panels. To accurately determine the optimal configuration, the PVsyst software was utilized. With a tilt angle of 30° selected for the area, the software meticulously calculated the required number of PV panels and their corresponding output power. The valuable information regarding the quantity of PV panels and the power output can be conveniently found in Table 3.

Table 4 represents the capacity of a roof PV installation. It consists of 36 solar panels, each having a power rating of 280 W. The total power output of the entire installation is 10 kW.

Table 3
Grid connected PV system components

No.	Items	Type	Company	Size (W)
1	PV module	Si-poly	Jinko Solar	280
2	Inverter	Grid	SMA	10,000

Table 4
Roof PV installation capacity

No.	Name	No#	Power (W)	Power output (KW)
1	Panel's	36	280	10

Table 5
Grid connected system inverter capacity

No.	Name	No#	Total power (KWac)	Pnom ratio
1	Inverter	1	10	1.01

This means that when all the panels are functioning optimally, they can generate a combined electrical power of 10 kW. The power output is a measure of the amount of electricity the installation can produce under ideal conditions, such as when the sun is shining brightly. It is important to note that the power output is the maximum potential capacity of the installation, and the actual electricity generated may vary based on factors like the amount of sunlight, shading, and efficiency of the panels. However, with 36 panels and a power output of 10 kW, this PV installation has the capability to produce a significant amount of renewable energy, helping to reduce reliance on traditional power sources and contributing to a cleaner and more sustainable energy future.

Also, the specifications of the inverter for the 10-kW system obtained by PVsyst software are shown in Table 5.

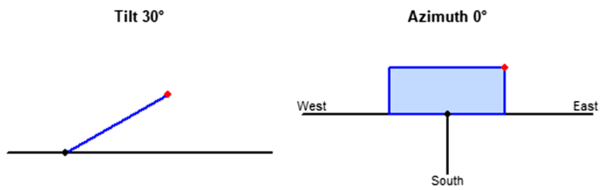
B. Impact of seasonal changes in the tilt angle of the PV panels on the overall system performance

The tilt angle of PV panels plays a crucial role in capturing solar energy and converting it into electricity. Here is how seasonal changes in the tilt angle can impact the overall system performance:

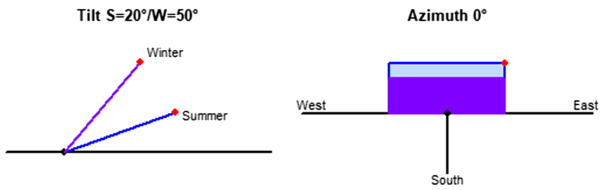
a. **Energy generation:** The tilt angle determines the amount of sunlight incident on the PV panels. By adjusting the tilt angle to match the changing sun angles during different seasons, the panels can optimize their exposure to sunlight. For instance, during winter when the sun is lower in the sky, increasing the tilt angle can help maximize energy generation by capturing more sunlight. Conversely, in summer when the sun is higher, adjusting the tilt angle can avoid overexposure and prevent energy losses due to excessive heat.
b. **System efficiency:** The tilt angle also affects the efficiency of energy conversion within the PV system. By aligning the panels optimally with the sun's rays, the system can maximize the conversion of solar energy into electricity. Adjusting the tilt angle according to seasonal changes helps ensure that the panels operate closer to their peak efficiency throughout the year. This can result in improved overall system efficiency and higher energy output.
c. **Shading mitigation:** Seasonal changes can bring about variations in shading patterns due to factors like vegetation growth or shifting obstructions. By adjusting the tilt angle, it is possible to minimize shading effects on the PV panels and prevent energy losses. For instance, if a nearby tree casts shadows on the panels during a particular season, modifying the tilt angle can reduce the shading impact and maintain optimal system performance.
d. **Snow and debris management:** In regions experiencing snowfall or seasonal debris, changing the tilt angle can help mitigate their effects on the PV panels. Adjusting the tilt angle can facilitate the shedding of snow or debris, preventing their accumulation and ensuring uninterrupted energy generation. This initiative-taking measure can significantly impact the overall system performance, particularly in areas prone to harsh winter conditions.

Figure 7
(a) Tilt angle at 30° and azimuth at zero and (b) Seasonal configuration with tilt angle changes twice a year

(a) **Tilt angle at 30° and azimuth at zero,**



(b) **Seasonal configuration with tilt angle changes twice a year**



By considering and adapting the tilt angle of PV panels to account for seasonal changes, the overall system performance can be optimized. This includes maximizing energy generation, improving system efficiency, reducing shading losses, and managing external factors like snow or debris. Proper tilt angle adjustment throughout the year ensures the PV system operates at its peak potential, leading to enhanced energy output and improved financial returns on the investment. Tilt angles and orientations are illustrated in Figure 7.

C. System energy production and system performance ratio

Figure 8 illustrates the normal monthly energy production for a particular system over the course of a year. The x-axis represents the 12 months, starting in January and ending in December, while the y-axis displays the energy production in kWh. Looking at the graph, we can observe distinct patterns in energy production throughout the year. In January and February, energy production starts at a relatively lower level, indicating a lower overall energy output. This can be attributed to the colder winter months, where energy demand for heating purposes tends to be higher, thus leaving less energy available for other uses. As we move into the spring months of March and April, we notice a gradual increase in energy production. This rise in production can be attributed to the milder weather conditions, which result in reduced energy demands for heating, allowing for more energy to be allocated to other purposes. The graph peaks during the summer months of June, July, and August, when energy production reaches its highest levels. This surge in production is likely due to increased sunlight hours, leading to greater solar energy generation or, in the case of other energy sources, the higher energy demand associated with air conditioning systems during the hot summer months. After the peak in the summer, energy production gradually starts to decline as we enter the fall months. September and October show a slight decrease, which can be attributed to the diminishing sunlight hours and the decreasing demand for cooling. Finally, as we approach the winter months again, energy production returns to the lower levels observed at the beginning of the year. November and December exhibit a decrease in energy production, reflecting the increased energy demands for heating purposes due to colder temperatures. Overall, the graph demonstrates the seasonal variations in energy production for the system, highlighting the impact of weather conditions and energy demands throughout the year.

Figure 8
System monthly normal energy production

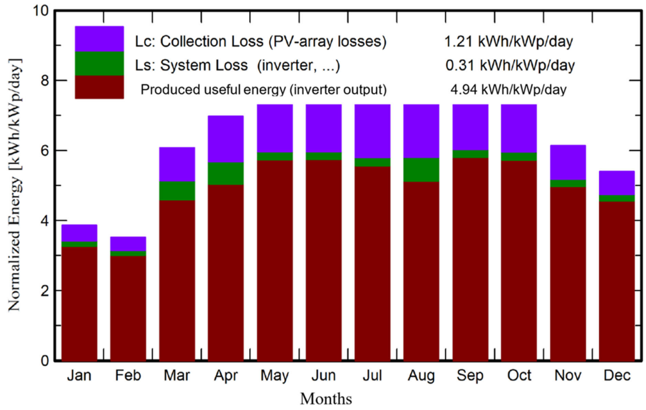


Figure 9
System performance ratio

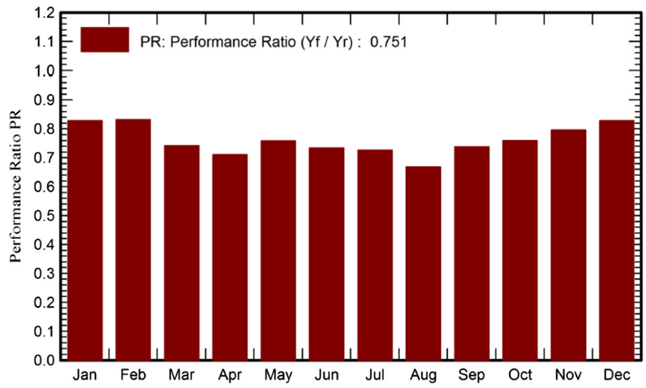


Figure 9 displays the solar rooftop system performance ratio (SPR) for the analyzed period. The SPR represents the efficiency and effectiveness of the solar rooftop system by comparing its actual performance to the expected or theoretical performance. The graph depicts the SPR values over time, allowing for a visual assessment of the system's performance trends. The x-axis of the graph represents the period under consideration, months. The y-axis represents the SPR values, indicating the ratio of actual performance to the expected performance. The graph displays the variations in the SPR throughout the analyzed period. Data points on the graph represent the actual SPR values obtained during specific time intervals. These data points can be located above or below a reference line, which represents the baseline SPR value or expected performance. When the data points fall above the baseline line, it indicates that the solar rooftop system is performing better than expected during those periods. This could be attributed to favorable weather conditions, efficient equipment, or effective maintenance. Conversely, when the data points fall below the baseline line, it suggests that the system's performance is lower than expected, potentially due to factors like poor weather conditions, equipment issues, or maintenance problems.

Table 6 displays the monthly energy generation and grid feed-in of a solar energy system, accounting for variations in solar radiation

Table 6
Roof top PV system monthly energy into grid

Month	Global Hor (kWh/m^2)	DiffHor (kWh/m^2)	T-Amb ©	GlobInc (kWh/m^2)	GlobEff (kWh/m^2)	EArray (kWh)	E-User (kWh)	E-Solar (kWh)	E-Grid (kWh)	EfrGrid (kWh)
January	81.6	36.33	−0.74	119.7	113.4	1070	744.0	440.2	560	303.8
February	82.6	53.18	−1.21	98.6	93.3	889	672.0	421.2	406	250.8
March	159.7	64.98	5.94	188.3	178.8	1606	744.0	491.1	918	252.9
April	198.1	66.61	12.22	209.2	198.3	1718	720.0	504.8	996	215.2
May	239.8	70.42	14.63	230.4	217.8	1866	744.0	580.4	1181	163.6
June	251.9	66.30	21.09	231.3	218.1	1807	720.0	576.7	1132	143.3
July	249.0	68.45	22.71	233.9	220.9	1812	744.0	590.1	1122	153.9
August	229.4	64.89	22.29	234.2	221.8	1815	744.0	529.8	1046	214.2
September	201.2	39.50	18.47	232.6	220.8	1825	720.0	537.3	1192	182.7
October	170.6	30.54	13.47	230.3	219.0	1863	744.0	533.5	1230	210.5
November	120.1	28.56	6.71	184.3	175.3	1566	720.0	476.4	1002	243.6
December	101.0	26.15	0.45	167.4	158.9	1485	744.0	486.1	911	257.9
Year	2085	615.92	11.4	2360.1	2236.3	19,323	8760	6167.5	11,696	2592.5

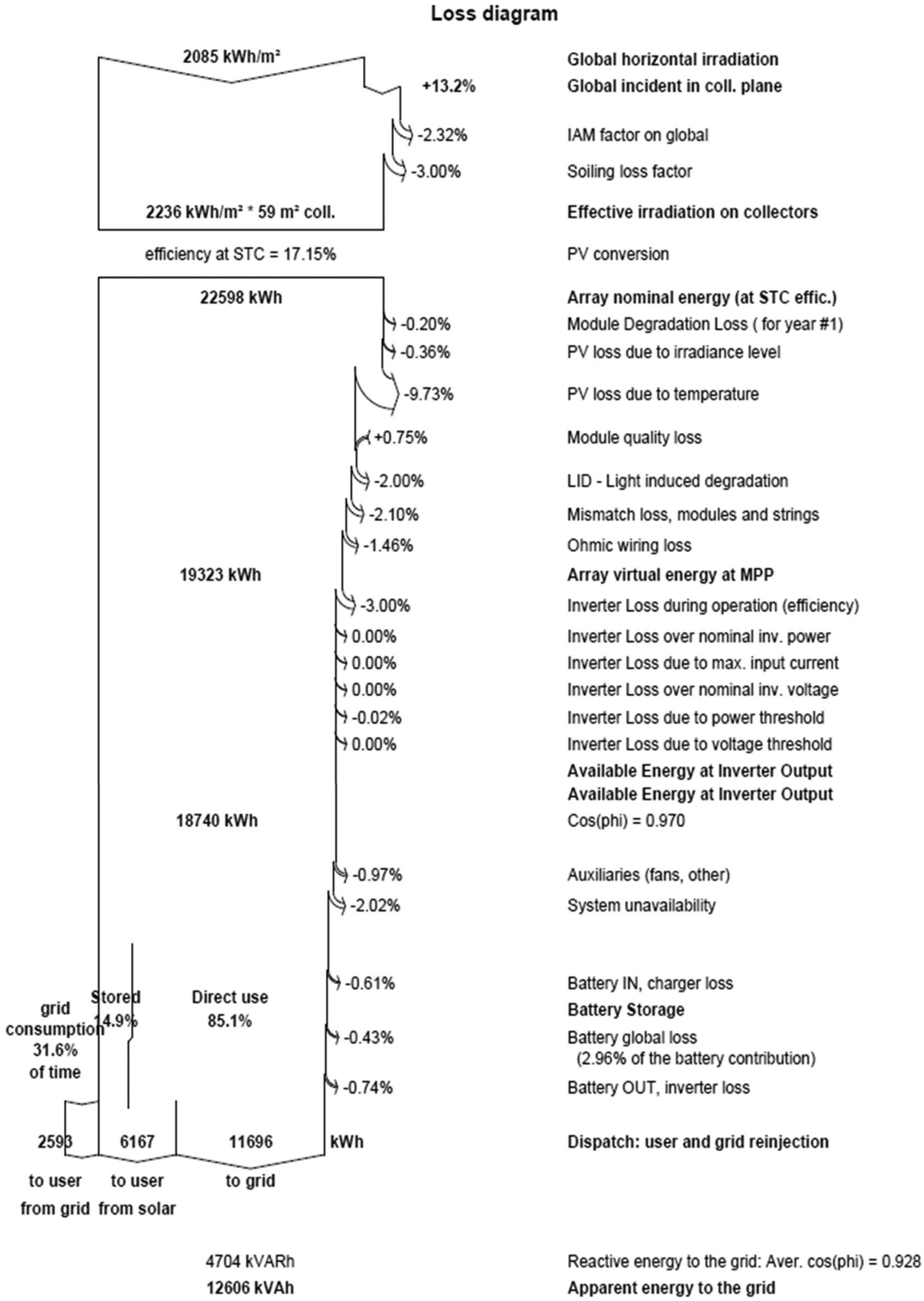
Month: This column represents the months of the year, indicating the specific time for which the data are recorded.
Global Hor (kWh/m^2): This abbreviation stands for global horizontal irradiance and represents the total amount of solar radiation received per square meter on a horizontal surface.
DiffHor (kWh/m^2): DiffHor stands for diffuse horizontal irradiance and refers to the portion of solar radiation that is scattered and diffused in the atmosphere before reaching the Earth's surface.
T-Amb (°C): T-Amb represents the ambient temperature and indicates the temperature of the surrounding air.
GlobInc (kWh/m^2): GlobInc stands for global incident solar radiation, which represents the total amount of solar radiation received on a surface perpendicular to the sun's rays.
GlobEff (kWh/m^2): GlobEff refers to global effective solar radiation, which represents the solar energy that is effectively captured and utilized by a solar energy system or device.
EArray (kWh): EArray represents the energy output generated by a solar array or solar panel system.
E-User (kWh): E-User stands for energy used by the consumer or user.
E-Solar (kWh): E-Solar represents the solar energy consumed or utilized directly from the solar system.
E-Grid (kWh): E-Grid stands for energy from the Grid and represents the amount of electricity consumed or sourced from the electrical grid during the recorded period.
EfrGrid (kWh): EfrGrid represents the energy fed back to the grid by the consumer.

throughout the year. Solar radiation refers to the amount of sunlight received at a specific location, and it directly influences the amount of energy that can be harnessed by the solar panels. In this table, each row corresponds to a specific month, while the columns depict various aspects of the system's performance. The first column lists the months of the year, providing a chronological sequence for easy reference. The next column presents the energy generation values for each month. It represents the total amount of energy produced by the solar panels during that period. This value is influenced by several factors, including the duration of daylight, weather conditions, and the angle and orientation of the solar panels toward the sun. As solar radiation varies across the year due to factors such as seasonal changes, the energy generation values will differ from month to month. The subsequent column displays the energy fed into the grid for each month. This refers to the surplus energy generated by the solar system that exceeds the immediate demand of the associated location. When the solar panels produce more energy than is currently being consumed on-site, the excess is typically fed back into the electrical grid, allowing other consumers to benefit from renewable energy. The grid feed-in values will vary based on the energy generation surplus in each month. By examining this table, one can analyze the monthly fluctuations in energy generation and grid feed-in of the solar energy system. Patterns may emerge, such as higher energy generation during summer months when solar radiation is typically more intense. Conversely, during winter months with reduced solar radiation, the energy generation and grid feed-in values might be comparatively lower.

D. System losses

One crucial aspect of evaluating a solar system is understanding the losses it may experience during operation. PVsyst allows us to calculate and quantify these losses by considering numerous factors that can affect the overall performance of the system. For example, one common type of loss is called "mismatch loss," which happens when the solar panels in a system are not perfectly matched in terms of their electrical characteristics. PVsyst considers the electrical specifications of individual panels and calculates the mismatch loss based on the overall system configuration. Furthermore, PVsyst incorporates the effects of "temperature losses" that arise due to the increase in temperature during operation. Solar panels tend to become less efficient as their temperature rises, and PVsyst considers this aspect by incorporating relevant thermal data and calculating the resulting losses accurately. By employing such comprehensive calculations and simulations, PVsyst provides us with a detailed understanding

Figure 10
System total loss diagram



of the losses encountered by the solar system. The system losses are shown in Figure 10.

E. System daily input and output energy

Figure 11 depicts the relationship between the Global Incident (kWh/m^2/day) and available solar energy (kWh/day). At point 4 on the graph, the Global Incident is 4 kWh/m^2/day, and the available solar energy is 30 kWh/day. This means that on a typical day with a Global Incident of 4 kWh/m^2, there is an average of 50 kWh of solar energy available for use. At point 6, the Global Incident is 6 kWh/m^2/day, and the available solar energy is 45 kWh/day. This indicates that with a higher Global Incident of 6 kWh/m^2, there is a corresponding increase in available solar energy to 45 kWh/day. As we move along the x-axis, representing different values of the Global Incident, we can observe a trend. Higher values of Global

Figure 11
The system daily input and output chart

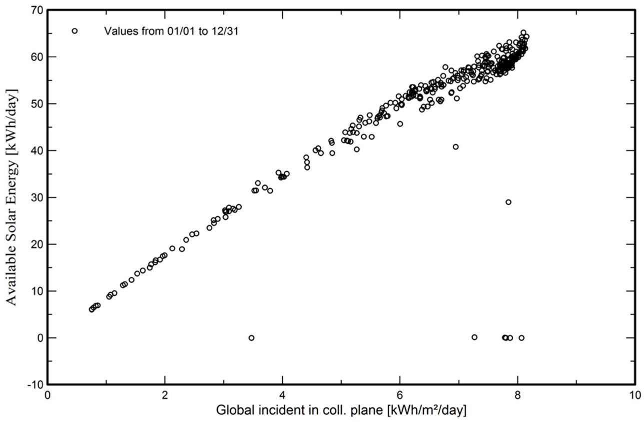
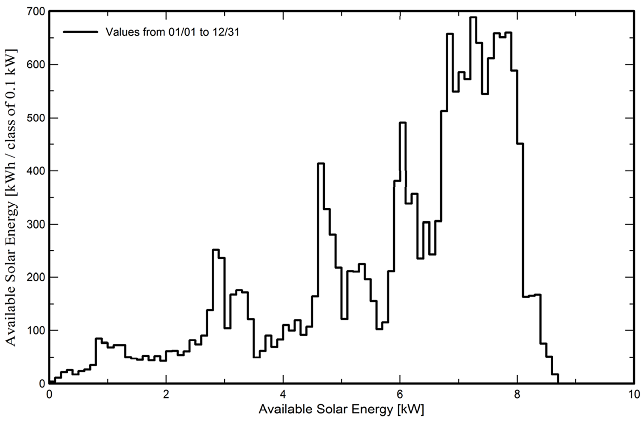


Figure 12
System power output distribution and solar energy



Incident generally led to an increase in available solar energy on the y-axis. This suggests that areas with higher Global Incident receive more solar energy, making them potentially more suitable for harnessing solar power. Conversely, as we move toward lower values on the x-axis, the available solar energy tends to decrease. This indicates that areas with lower Global Incident receive less solar energy, making them relatively less favorable for solar power generation. Overall, Figure 10 represents the relationship between Global Incident and available solar energy, providing valuable insights into the potential solar energy resources in different geographical regions based on their Global Incident values.

Figure 12 displays the available solar energy as a function of the installed solar capacity. The x-axis represents the amount of solar energy available, measured in kW. This indicates the total power output that can be harnessed from solar panels or other solar energy systems. On the other hand, the y-axis represents the available solar energy in kWh/class of 0.1 kW. This metric indicates the energy generated over a specific period, divided into classes with a 0.1 kW capacity increment.

3.2. Economic analysis of a solar PV system

A. Cost of the system:

The cost of a grid-connected PV solar system depends on several factors, including the system size, location, type, and quality of components used, and any additional features or services included. Table 7 illustrates the prices determined for a grid-connected PV solar system.

Table 7
System costs

Items	Quantity units	Cost USD	Total USD
PV modules JKM 280PP-60-V	36	80	2880
Inverters Sunny Tripower 10000TLEE-JP-10	1	900	900
Batteries	4	250	1000
Installation			
Global installation cost per module	36	5	180
Global installation cost per inverter	1	6	6
Transport	30	3	90
Settings	30	3	90
Grid connection	1	60	60
Taxes			
Other taxes	1	0	7
Total			5213
Depreciable asset			4780

Table 7 provides information about the different components involved in the system cost analysis. It includes columns for items, quantity, units, cost in USD, and total cost in USD. The "Items" column lists the components such as PV modules, inverters, batteries, installation, and others. The "Quantity" column specifies the number of units for each item. The "Units" column indicates the unit of measurement for each item. The "Cost USD" column represents the cost in US dollars for each individual unit of the item. The "Total USD" column calculates the total cost for each item by multiplying the quantity with the cost. By using this table, you can analyze and understand the costs associated with different components of the system.

Operating cost refers to the expenses incurred by a business or organization in its day-to-day operations and maintenance of its activities. It includes the various costs associated with running the business or providing a service. Operating costs are essential for the functioning of the organization and are typically incurred regularly. Table 8 shows the operating cost of the system.

Table 8 presents the operating costs related to maintenance, repairs, and cleaning of the system. Maintenance includes regular servicing and accounts for an estimated 180 USD, with provision for inverter replacement. Repairs represent the cost of addressing malfunctions or damage, estimated at 90 USD. Cleaning costs, essential for system efficiency, amount to 70 USD. The total cost,

Table 8
System operating costs

Items	Total USD/Year
Maintenance	
Provision for inverter replacement	180
Repairs	90
cleaning	70
Total	340

340 USD, encompasses these three items and reflects the estimated operating expenses for the system's upkeep during a specific period.

B. System summary:

The system summary Table 9 provides key information about the cost and performance of a specific system. Total installation cost indicates the overall cost of installing the system and is stated as 5,213.00 USD. It includes the expenses associated with equipment, labor, and any additional materials required for installation. Operating costs refers to the expenses incurred to keep the system running efficiently on an annual basis. The operating costs are stated as 340.00 USD per year. Energy sold to the grid indicates the amount of energy generated by the system and sold back to the grid. In this case, the system generates 11,696 kWh of energy per year. Price of energy sold to the grid indicates the rate at which the energy generated by the system is sold to the grid. The price is mentioned as 0.027 USD per kWh. These figures provide a snapshot of the financial and performance aspects of the system. The installation cost and operating costs help gauge the initial investment required and the ongoing expenses associated with the system. The energy sold to the grid and its corresponding price per kWh give an idea of the system's output and the potential revenue from selling the generated energy.

C. Financial analysis:

Financial analysis of a grid-connected solar PV system includes evaluating its economic feasibility and profitability throughout its operational lifetime. This helps determine whether investing in a solar PV system is financially viable and whether it can generate sufficient income or not. Here, a financial analysis for a grid-connected solar PV system is presented using PVsyst, and the system's lifetime and other factors are given in Table 10.

Table 10 provides information on the depreciation of three assets: PV modules, inverters, and batteries. The straight-line method is used for depreciation, evenly spreading the depreciation expense over the asset's useful life. The depreciation period for all assets is 35 years, and there is no expected salvage value at the end of their useful life.

Table 9
System summary

System summary	
Total installation	5,213.00
Operating	340.00
Energy sold to the grid	11,696 kWh/year
	0.027 USD/kWh

Table 10
Depreciation asset

Asset	Depreciation method	Depreciation period (years)	Salvage value (USD)	Depreciation (USD)
PV modules	Straight-line	35	0	2880
Inverters	Straight-line	35	0	900
Batteries	Straight-line	35	0	1000
Total				4,780.00

Table 11
Return on investment

Return on investment	
Payback period	6.3 years
Net present value	23,821.74 USD
Internal rate of return	15.83%
Return on investment	457.0%

Table 11 provides important financial metrics to assess the profitability and efficiency of an investment. The metrics include the payback period, which in this case is 6.3 years. NPV is $23,821.74 USD, indicating that the investment is expected to generate more returns than its initial cost. The IRR is 15.83%, representing the effective interest rate earned on the investment. ROI is 457.0%, indicating that the investment is projected to generate a return 4.57 times larger than the initial investment. These metrics help evaluate the investment's financial viability in a concise manner.

Yearly net profit refers to the amount of profit generated by a business or investment project each year after deducting all expenses and taxes. In the context of a grid-connected solar PV system, the yearly net profit represents the income generated from the system's electricity production minus the costs associated with its operation, maintenance, and any applicable taxes. Figure 13 shows solar grid connected PV system yearly net profit.

Figure 13 illustrates the annual net profit of a system over a span of 8 years, from 2022 to 2057. The net profit is represented on the y-axis, while the years are depicted on the x-axis.

Cumulative cash flow refers to the total sum of cash inflows and outflows over a given period. It is a measure used in financial analysis to assess the net cash position of a project, investment, or business venture. Cumulative cash flow of the system is shown in figure 14.

Figure 13 shows the cumulative cash flow of a grid-connected system over time. Initially, there were expenses for setting up the system, resulting in a negative trend. As the system becomes operational, it generates revenue, leading to a positive trend. The graph reflects the financial performance of the system, providing insights into profitability and viability.

Figure 13
Yearly net profit of the system

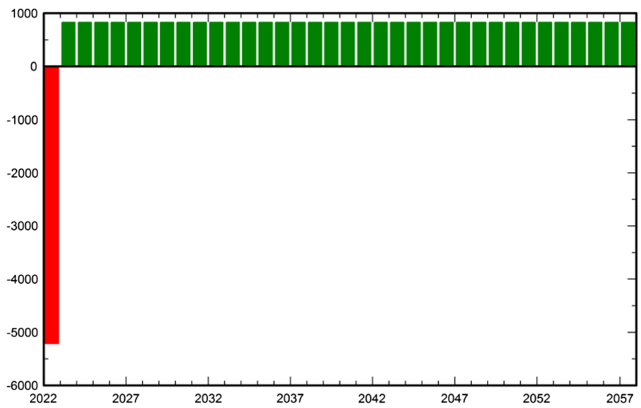


Figure 14
Grid connected system cumulative cash flow

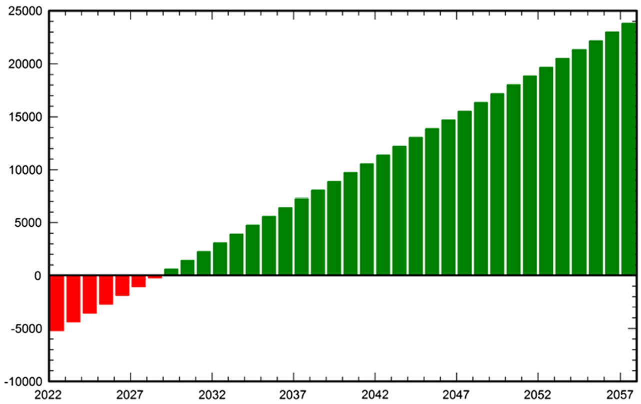
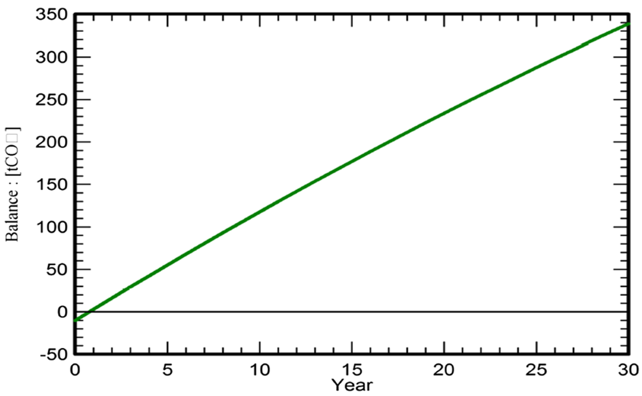


Figure 15
Yearly net profit of the system



D. CO_2 emission balance

A grid-connected solar PV system plays a crucial role in achieving a favorable CO_2 emission balance by reducing greenhouse gas emissions and promoting clean energy generation. Here is an explanation of the CO_2 emission balance in such a system. Figure 15 shows the system CO_2 emission versus time.

Figure 14 discusses the environmental benefits and long-term sustainability of solar PV systems in reducing CO_2 emissions. The graph presented in the paragraph shows the relationship between time and the amount of CO_2 emissions saved by a solar PV system. It demonstrates a progressive reduction in CO_2 emissions as the system operates and generates clean energy. The decline in emissions is attributed to displacing conventional energy sources, primarily fossil fuels, with solar energy. Over time, the system reaches optimal efficiency, maximizing the reduction in CO_2 emissions. The graph also illustrates the cumulative nature of emission savings, highlighting the long-term sustainability of solar energy. In conclusion, the graph emphasizes the decreasing CO_2 emissions associated with solar PV systems, supporting the importance of transitioning to renewable energy to mitigate climate change.

4. Conclusion

In this study, we conducted a comprehensive design and economic analysis of an on-grid solar rooftop PV system using PVsyst software. The objective was to evaluate the feasibility and financial viability of implementing such a system. The design phase involved assessing the solar potential of the rooftop, determining the optimal tilt and orientation of the panels, and sizing the system components. Through the PVsyst software, we were able to accurately model the system's performance, considering factors such as shading, temperature, and panel efficiency. This enabled us to design an efficient and optimized system that maximizes solar energy generation. The economic analysis focused on evaluating the financial aspects of the project. We considered the initial investment cost, including the purchase and installation of solar panels, inverters, and other necessary equipment. Additionally, we accounted for ongoing maintenance and operation costs, such as cleaning, monitoring, and potential repairs.

Based on analysis, the results demonstrate the following key findings:

1: Energy generation: The designed on-grid solar rooftop PV system is estimated to generate 19,323 kWh of electricity annually. This would contribute significantly to reducing the reliance on conventional grid power and decreasing greenhouse gas emissions.

2: Financial viability: The calculated payback period for the system is 6.3 years. This indicates the time required for the cumulative savings from electricity bills to equal the initial investment. The shorter the payback period, the more financially feasible the project becomes.

3: Return on investment: The ROI for the system is estimated to be 457%. This indicates the percentage of the initial investment that is recovered annually through electricity bill savings. A higher ROI signifies better economic returns and increased cost-effectiveness.

4: Environmental benefits: The on-grid solar rooftop PV system is expected to reduce CO_2 emissions by 10.53 metric tons per year, contributing to a greener and more sustainable environment.

The design and economic analysis results can be concluded that implementing an on-grid solar rooftop PV system using PVsyst software is a technically feasible and financially viable solution. The system not only generates clean and renewable energy but also offers significant long-term savings on electricity bills. Moreover, it contributes to reducing carbon emissions and promotes environmental sustainability.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

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How to Cite: Serat, Z., Fatemi, S. A.Z., & Shirzad, S. (2023). Design and Economic Analysis of On-Grid Solar Rooftop PV System Using PVsyst Software. *Archives of Advanced Engineering Science* 1(1), 63–76, https://doi.org/10.47852/bonviewAAES32021177