Utilizing Solar Energy for Higher Education: Design and Implementation of a 500 kW Rooftop Solar Array for College of Engineering, King Faisal University

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Abstract:

The College of Engineering at King Faisal University in Al-Ahsa, Saudi Arabia, can benefit from reducing its dependence on non-renewable energy sources and transitioning to solar energy, which is a cost-effective alternative. This study explores the feasibility of installing a photovoltaic (PV) solar station on the roof of the college's building, utilizing software such as Google Earth Pro, AutoCAD, SketchUp Pro, Skelion, and system advisor model (SAM) to analyze and design the system. With an available unshaded solar exposure area of 5,669 m^2, the team chose three different types of panels with varying wattages (435, 555, and 720 W) to produce a total of 500 kWp. The results indicated that the 555 W panels were the most economical choice, generating 646.9 MWh annually at a capital cost of 1.25 million SAR. The system is expected to have a payback period of 8.2 years, with a levelized cost of energy (LCOE) of 0.143 SAR/kWh.

Keywords: Solar energy, PV panels, Renewable energy.

1. INTRODUCTION [1]

In recent years, many organizations have shifted their focus towards sustainability and protecting the environment. Universities, like other institutions, contribute significantly to carbon emissions through their consumption of resources such as water, energy, and consumables. Consequently, many universities have made it a priority to reduce their greenhouse gas emissions and adopt eco-friendly practices, aligning with society's broader sustainability goals [1]. As the next generation of leaders, university students have a vital role to play in promoting environmental protection and understanding the sustainability objectives set by the United Nations [2]. It is crucial for them to reflect on these goals as they prepare for life after graduation. Despite facing budget cuts and rising energy costs, universities must prioritize renewable energy programs to overcome the challenges associated with transforming conventional campuses into green and environmentally-friendly ones. Urgent action is needed to develop effective procedures and plans to achieve this transformation.

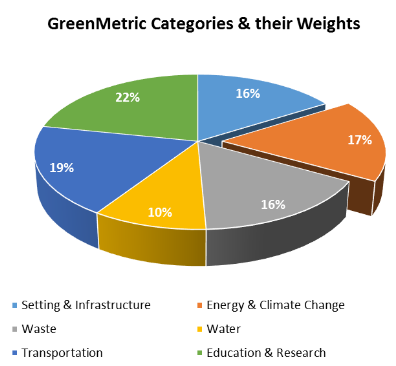
Numerous initiatives worldwide aim to build sustainable campuses. A comprehensive study conducted by [3] revealed that the most common policies implemented globally include increasing the use of renewable energy sources on campus and constructing energy-efficient buildings.

Three solar photovoltaic (PV) systems were designed and implemented for various purposes. Firstly, a 2-kW standalone solar PV system was built on top of the College of Engineering at King Faisal University for research and academic purposes. The system's overall performance was assessed, and it was found that shading reduced solar cell efficiency by up to 16%, with losses varying between 0.70% and 4.2% depending on panel spacing and field location [4]. Secondly, a 200-kW solar power plant was designed and implemented at Vasavi College of Engineering in

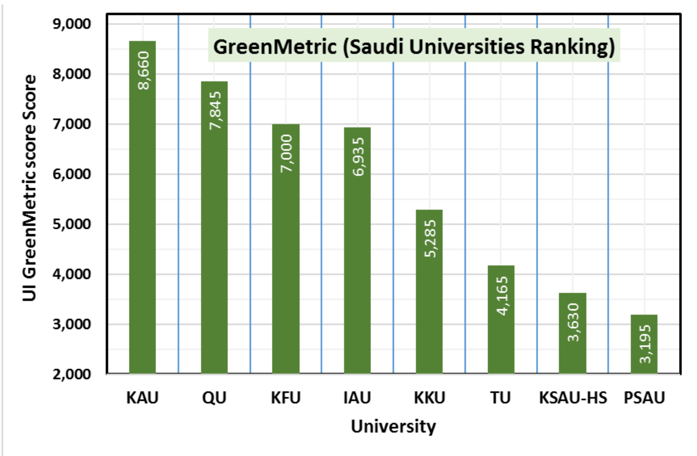
[1]Part of this paper has been presented in the GCC 1st Engineering Symposium, organized by Kuwait University in October 29-31 in Kuwait.

Ibrahimbagh, Hyderabad. The plant's sizing involved specifying various equipment, including PV modules, inverters, MCCB, cables, and protective equipment. The plant generates an average of 25,000 kWh per month, resulting in a monthly saving of Rs 2.5 lakhs in electricity bills [5]. Lastly, a stand-alone 1143.6 KWh solar PV system was designed and installed at the Engineering College in Bikaner to fulfill the average annual energy requirement of the mechanical engineering department. The system was designed based on load requirements and generates an average annual energy of 1086.24 kWh [6]. Overall, these systems showcase the potential for solar PV systems to be used for research, academic, and practical purposes.

The UI GreenMetric World University ranking system, developed and managed by Universitas Indonesia in 2010 [7], is a prominent sustainability ranking system. GreenMetric assesses university campus operations' environmental friendliness using six categories (shown in Fig 1-a), which comprise 38 indicators. Energy and climate change carry the highest weight of 21% in the GreenMetric evaluation. In 2022, King Faisal University (KFU) achieved 17% in this category, as shown in Fig 1-a. Figure 1-b illustrates the top Saudi universities based on the UI GreenMetric rankings, with KFU ranked third. However, KFU still needs to improve in the energy and climate category.



(a)



(b)

Fig. 1: (a) GreenMetric categories for KFU and (b) Saudi university ranking.

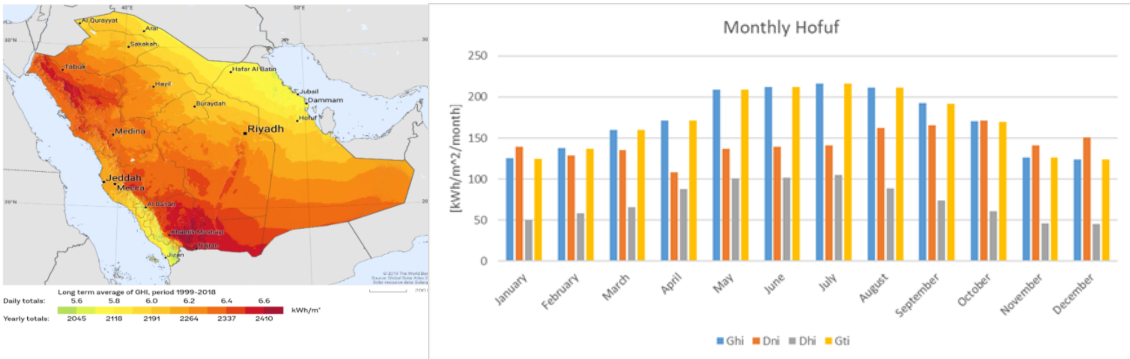
This study aims to improve the sustainability of King Faisal University by designing an additional 500-kW PV system to be installed on the College of Engineering rooftop.

2. SAUDI ARABIA SOLAR ENERGY

In 2021, Saudi Arabia strengthened its commitment to implementing clean and renewable energy resources through several solar sector project financings and the launch of the National Infrastructure Fund (NIF), furthering the country's efforts to diversify its economy. Initially, there were doubts about Saudi Arabia's ability to use solar energy to reduce emissions and transition away from liquid fuel for electricity production when it first announced its Vision 2030 economic development plan. However, solar targets for 2023 and 2030 were updated in 2019 to 20 GW and 40 GW, respectively, for solar photovoltaics (PV).

Understanding the Global Horizontal Irradiation (GHI) is crucial in planning and implementing PV technology. GHI measures the total incoming radiation on a horizontal surface. In Saudi Arabia, the annual GHI is around 2,290 kWh/m^2, as shown in Figure 2-a [8]. The PV power output, also known as the specific yield, is measured in kilowatt hours per installed kilowatt-peak of the system capacity (kWh/kWp). This parameter illustrates the amount of electricity produced per unit of installed PV capacity over the long term. Saudi Arabia has an average of 1,850 kWh/kWp annually. Figure 2-b demonstrates the monthly solar radiation in Hofuf city, where KFU is located. The direct normal irradiation (DNI) has the lowest value during winter and begins to increase during summer months, such as September, with a value of 165 kWh/m^2/month. Both global horizontal irradiation (GHI) and direct horizontal irradiation (DHI) have similar trends, with values of 216 kWh/m^2/month (GHI) and 104 kWh/m^2/month (DHI). These values increase during the summer months, with a GHI value around 215 kWh/m^2/month.

Apart from the semi-arid climate in the southwest, Saudi Arabia is predominantly known for its desert climate. In the central region, summers are characterized by high temperatures and dry conditions, with average temperatures ranging from 27 to 43 degrees Celsius inland and 27 to 38 degrees Celsius along the coast. The city of Al-Hofuf experienced its highest average daytime temperature between 1945 and 2018, which was recorded as 44.4 °C during July and the lowest average temperature of 15.2 °C during January [9].



(a) **(b)**

Fig. 2: (a) Global horizontal radiation and (b) Monthly solar irradiation in Hofuf.

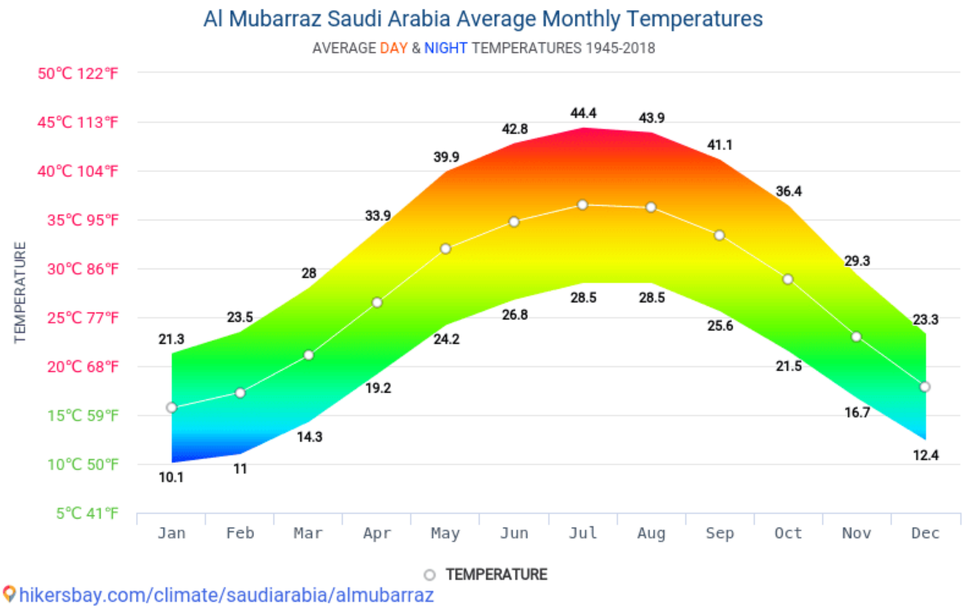


Fig. 3: Air temperature in Al- Hofuf [9].

3. METHODOLOGY

To begin the system design process, a combination of professional licensed software packages is utilized. Firstly, the KFU campus plan areas are projected through Google Earth Pro and AutoCAD software, which aids in identifying the surface area available for PV installation on the College of Engineering (CoE) building. The 3D projection of the building is then carried out using SketchUp, assisted by laser meter to measure building height. From this, the possible roof area can be calculated and summarized on **Table 1**. In order to minimize shading losses, a shading analysis is conducted using the Curic Sun extension plug-in for SketchUp shadow simulation tool, which calculates the net roof area with minimal shadow over the panel. The Optimum Orientation angles of the modules are then calculated using the Skelion [10] plugin within SketchUp, to maximize the energy yield. The resulting 3D layout of the CoE buildings with shadow analysis is shown in Figure 4, calculated on the day of December 21 at 9:00 am. Also, system advisor model (SAM) is used to find the energy production during all the year.

Table 1: Area distribution on top of the college's roof

Total area	16,074 m^2
Tanks area	118 m^2
Chillers area	1,983 m^2
Rooms area	1,396 m^2
The free area	12,577 m^2

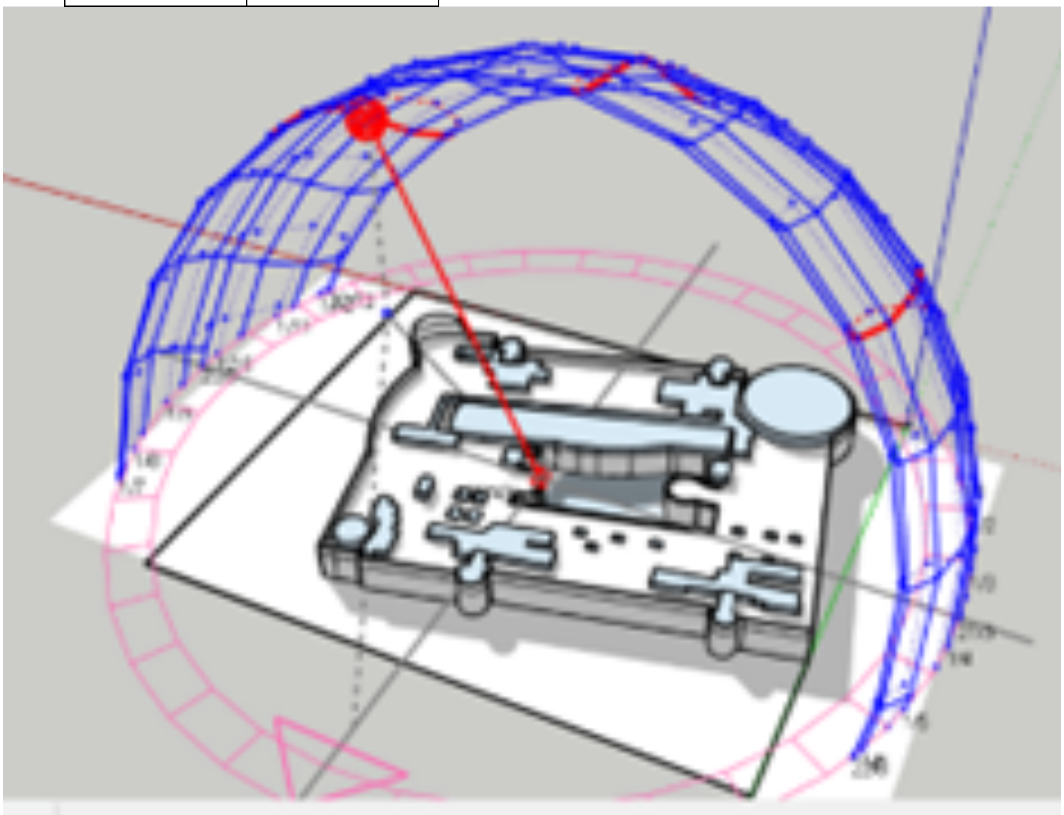


Fig. 3: Shadow analysis of the CoE building.

4. SYSTEM DESIGN

The design of a PV solar system involves several stages, beginning with a thorough analysis of the building's structure and surrounding area. In this case, the team started by using Google Earth Pro, a web-based tool that provides high-resolution images of locations around the world. By using this tool to zoom in on the university and CoE building, they were able to identify the precise coordinates of the building and surrounding area.

Once they had a clear picture of the building's layout, the team imported the Google Earth Pro image into AutoCAD, a computer-aided design (CAD) software program that enables users to create 2-D design, as shown in Fig. 4. By overlaying the image onto a 2-D plane, they were able to sketch on top of it and draw out the building's dimensions and features.

From there, the team analyzed the 2-D image to identify all of the different areas of the building rooftop. By referring to **Table 1**, they were able to break down the rooftop into different sections and calculate the total area of the rooftop. Based on their calculations, they determined that the rooftop had a total area of 16,074 m^2, with 12,577 m^2 of that area being unoccupied.

After obtaining the 2-D image of the building, it can be imported into SketchUp software to create a 3-D model of the building. To create the 3-D model, the building height and heights of all objects on the rooftop are required. The heights of the walls are measured using a laser meter and are summarized in Table 2. The resulting 3-D model is illustrated in Fig. 5-a.

The Curicsun extension in SketchUp is utilized to track the sun's movement throughout the year at different times of the day, which enables the identification of shadows that fall on the building. With the aid of the Skilion extension, the available sunny area was calculated based on 5, 6, and 7 hours of unobstructed sunlight. The unshaded area was determined to be 5,669, 5,078, and 4,573 m^2 for a net sunny period of 5, 6, and 7 hours, respectively. As an unshaded period of 5 hours is commonly accepted, the 5,669 m^2 area was selected for the PV installation design.

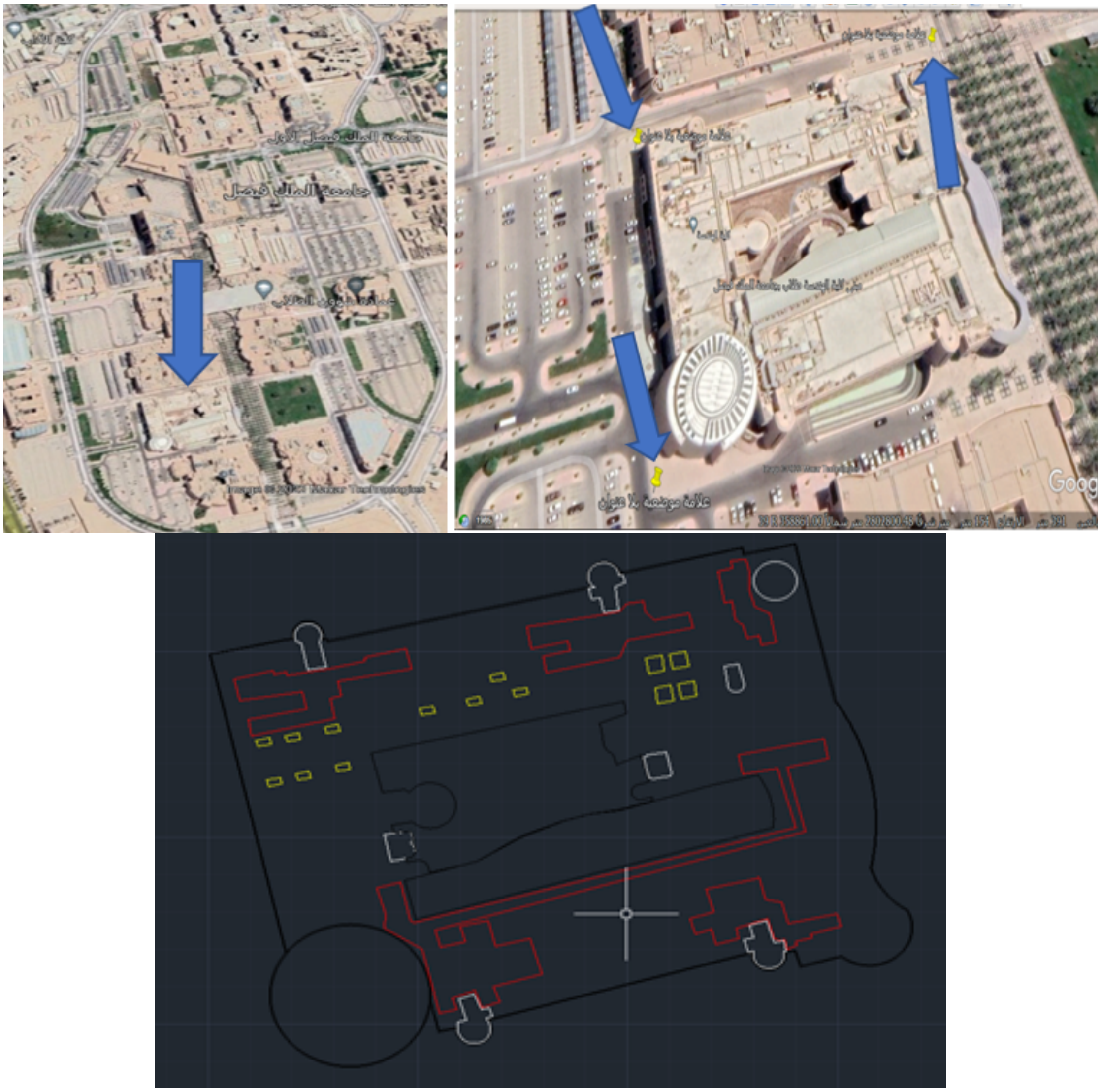
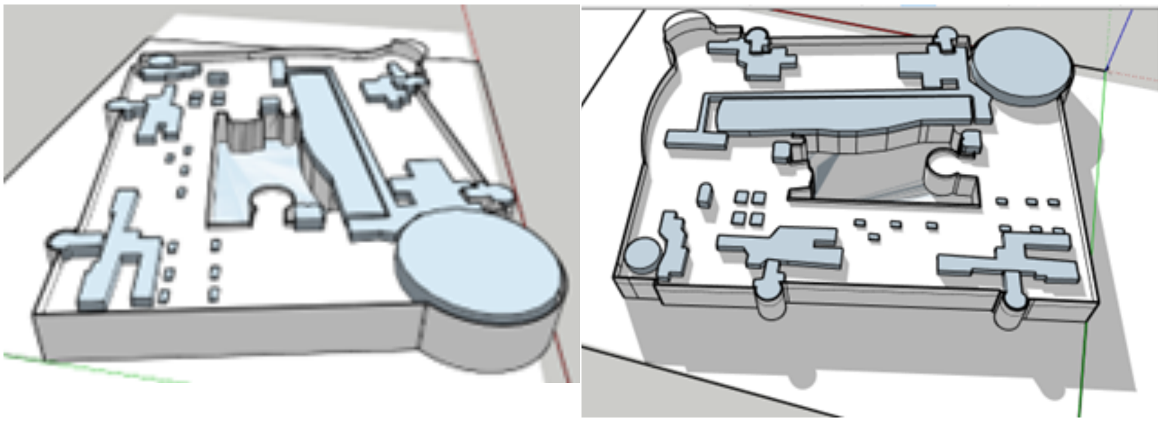


Fig. 4: King Faisal University images from Google earth pro with focus on the College of Engineering (CoE) building.

Table 2: Measurement of objects height on top of the college roof.

Object	Height
Wall	2 m
Chiller	2 m
Tank	1 m
pipe	0.5 m
Rooms	3 m
Theater dome	5 m

To obtain a comprehensive understanding of the shadow patterns throughout the year, a shadow analysis was conducted for the entire year. Special attention was given to the four eclipse days (Mar. 21, June 21, Sept 21, and Dec 21) to gain a thorough understanding of the shadow patterns on these particular days. Based on the shadow analysis results from Dec 21st, which showed the longest shadow during the year, the unshaded area was selected. The shadow patterns on Dec 21st are illustrated in Fig 5-b.



(a) **(b)**

Fig. 5: (a) 3D sketch resulting from Sketch Up, and (b) Shadow simulation on Dec. 21st.

The rooftop of the building has an available unshaded area that is suitable for the installation of a PV solar system with a capacity of 500 kW. For the purpose of this study, three different PV panels were selected based on the local and international markets. These panels are the Sun Power panels (435 W), Trinasolar panels (555 W), and Helius Sunlink (720 W). The required number of panels and the energy produced by each panel are outlined in **Table 3**.

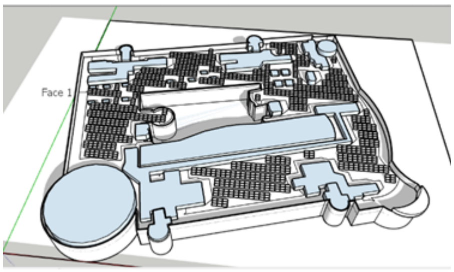
After conducting the analysis, it was found that approximately 900 panels of Trinasolar panels with a power output of 555 W can generate 646,852 kWh per year. Figure 6 depicts the SketchUp simulation of the arrangement of PV panels used, specifically TrinaSolar panels. The panels are positioned solely on the unshaded sections of the rooftop.

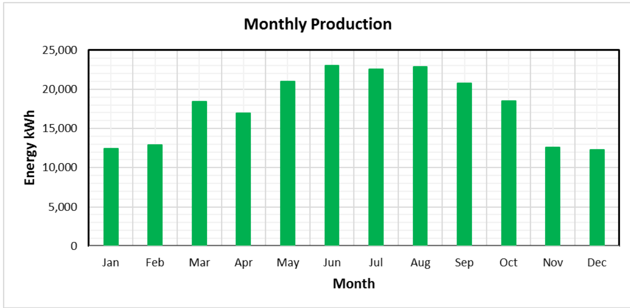
Table 3: Annual production for various panels.

Panel brand	Panel power (W)	Panel number	Installed Power (kWp)	Produced Energy (kWh/yr)
Sun power	435	1150	500.25	647,824
TrinaSolar	555	900	499.5	646,852
Helius sunlink	720	695	500.4	648,018

Weather data file for the College of Engineering at King Faisal University was entered into System Advisor Model (SAM). Additionally, information from the data sheet regarding the module was input into SAM, along with the inverter information. A 110W inverter capacity was selected, and the system was designed by dividing the total power by the inverter capacity to determine the number of parallel strings. The number of panels in each string can be obtained by dividing the total number of panels in the system by the number of strings. Five-110W inverters (HUAWEI SUN2000-100KTL-M1) were used in the simulation.

The study analyzed the energy output of three types of panels and one of them is plotted in Figure 5-b. The results showed that the energy production of all three panel types followed a similar trend over the course of the year, with a minimum output of 13,000 kWh/month during the winter months and a maximum of 23,000 kWh/month during the summer months.





(a) **(b)**

Fig. 6: (a) Panel distribution from SketchUp, and (b) Monthly energy production from SAM.

This information can be useful in assessing the performance of TrinaSolar PV panels in different weather conditions. The fact that all three panel types showed a consistent pattern of energy production suggests that they are reliable and can be expected to perform consistently across various locations and environments. Moreover, the graph provides a clear visual representation of the panel's energy output, making it easy to understand and compare the performance of different types of panels.

By utilizing the details provided in the panel's manual, we can determine that the highest possible open circuit voltage, denoted as V_{OC_max}, amounts to 38.5 V. Additionally, taking into account the maximum average temperature in Al-Hofuf city, which can rise to 44.4 ^{o}C, the module's temperature can reach 73.15 ^{o}C. The optimal number of modules used in one string should range between 8 to 28 modules/string. To prevent shadowing, it's recommended to maintain a spacing of 0.71 m between any two rows.

Table 4 presents the results of the feasibility study conducted to evaluate the installation process. Based on the analysis, the most feasible option for constructing the PV panels is TrinaSolar 555W panels, which requires a total investment of 1.25 million SAR. The system is projected to have a simple payback period of 8.2 years and an internal rate of return of 16.25. Furthermore, the installation of this system is expected to result in an annual savings of 207,000 SAR, and a reduction in annual CO_2 emissions by 296 tons.

Table 4: Financial indicators for various panels.

Indicator	435 W	555 W	720 W
Capital Investment (SAR)	1,428,089	1,254,499	1,599,826
Annual CO_2 reduction (ton)	296.70	296.26	296.79
Annual Savings (SAR)	207,304	206,993	207,366
Simple Payback Period (yr)	9.6	8.2	11.1
Internal Rate of Return	13.91%	16.25%	12.17%
Net Present Value	772,693	1,018,953	532,999
Levelized Cost of Energy (LCOE) (SAR/kWh)	0.1503	0.143	0.1577

5. CONCLUSION

In summary, we created a 500 kW photovoltaic (PV) solar system for the College of Engineering at King Faisal University, utilizing 5,669 m^2 of available space. Our testing showed that Trinasolar 555W panels had the best performance, resulting in an estimated installed capacity of 499.5 kWp with an annual yield of 646.9 MWh. The levelized cost of energy (LCOE) was calculated to be 0.143 SAR/kWh, and we estimate that the project will save approximately 0.157 SAR/kWh. The total cost of the project is expected to be around 1.25 million SAR, with an estimated payback period of 8.2 years. Overall, this solar system will allow the College of Engineering to use renewable energy and benefit from cost savings in the long term.

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