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Optimizing Rooftop Solar Panel Deployment: A GIS-Based Analysis at KFUPM

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Abstract

The Geographic Information System (GIS) factor plays a pivotal role in determining the optimal placement and orientation of solar panels to maximize sunlight exposure and energy generation efficiency. This study addresses challenges arising from uneven roof characteristics, such as those in Building 18 KFUPM, which may result in shadows and reduced solar energy production. The research employs Helioscope, a web-based geo software, for simulations to calculate panel requirements and energy generation potential. Using meteorological data from Meteonorm and SolarGIS, the analysis ensures accurate predictions of solar energy output. The study also highlights the use of reliable components like Sunny Tripower 24000TL-US inverters and Trina Solar TSM-PD14 320 modules. Through detailed simulation and analysis, the system, comprising 8,205 panels across ten buildings, achieves a total capacity of 3.00 MW, with an annual energy output of 5.078 GWh. This project marks significant progress toward sustainability goals by optimizing solar PV systems with precise design methodologies and robust component selection.

Keywords*: Solar Panel, KFUPM, Rooftoop, GIS.*

INTRODUCTION

The energy landscape is experiencing profound transformations amidst a backdrop of global challenges and opportunities. As underscored in a recent publication, the world's energy sector grapples with complexities ranging from geopolitical tensions to environmental concerns[1]. Despite a temporary alleviation of some pressures stemming from the global energy crisis, uncertainties persist, accentuated by volatile fossil fuel markets and geopolitical instabilities. Several articles describe the use of GIS-based models to incorporate critical data about residential buildings, as well as gather information about building characteristics and occupancy parameters. This model aims to support decision-making processes related to energy retrofitting [8].

In alignment with Saudi Arabia's Vision 2030, there is a growing emphasis on the development of renewable energy sources and nonassociated natural gas resources across the nation. As part of this vision, the Saudi National Renewable Energy Program (NREP) aims to significantly increase the contribution of renewable energy to the country's electricity generation mix, with a target of achieving 50% of generated electricity from renewable sources by 2030 [2].

Amidst the backdrop of global energy transformation and Saudi Arabia's renewable energy ambitions, this study shifts its focus to the localized context of King Fahd University of Petroleum and Minerals (KFUPM). With the imperative need for sustainable energy solutions to address modern society's growing energy demands while mitigating environmental impacts, Saudi Arabia's abundant solar resources offer a promising avenue for sustainable energy production. This paper delves into the energy landscape of KFUPM, examining its energy consumption trends and assessing the potential of rooftop photovoltaic (PV) systems to harness solar energy. Through the analysis of historical electricity consumption data, alongside forecasting future trends and simulation results of rooftop PV systems, the study aims to provide valuable insights into the feasibility and benefits of solar energy integration within the university campus. Additionally, the examination of temperature and dust effects on solar PV panels seeks to evaluate their implications for system performance and maintenance requirements in the local climate conditions [9].

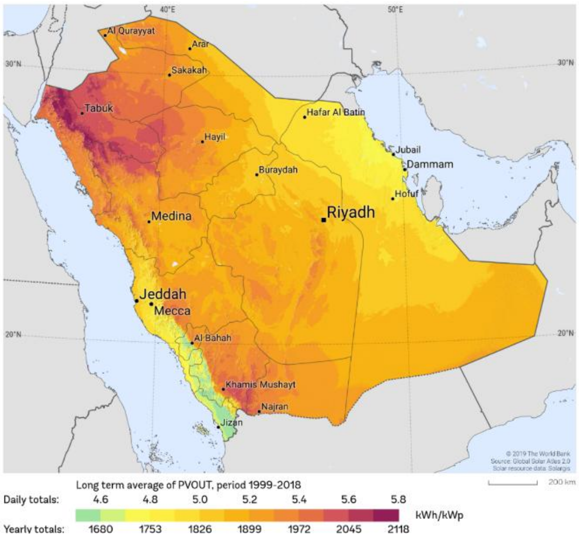

Fig.1 The Photovoltaic Power Potential of Saudi Arabia [5].

The findings of this study hold implications for energy policymakers, urban planners, and stake-holders invested in sustainable development, both locally at KFUPM and more broadly within Saudi Arabia's energy landscape. By elucidating the spatial distribution of solar energy potential, this research endeavor endeavors to inform strategic decision-making processes aimed at accelerating the transition towards a cleaner and more resilient energy future [8]. The rooftop locations selected are within the KFUPM campus, located at latitude 26.3464° N and longitude 50.1935° E.

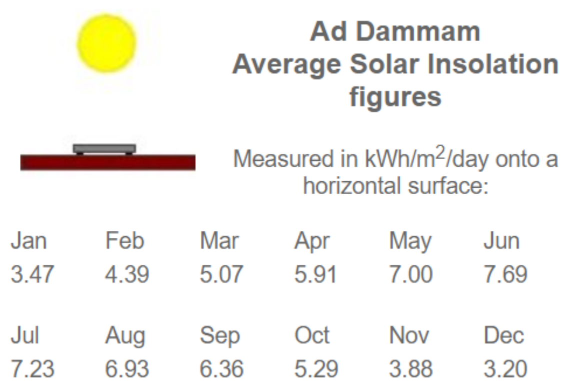

Fig.2 Average Solar Irradiance in Dammam [6].

In some research [3], Helioscope was utilized to conduct calculations aimed at ensuring the optimum power output in a specific area. Helioscope is a software tool commonly employed for solar energy system design and analysis [4]. By leveraging Helioscope, the researchers were able to simulate various scenarios and configurations, considering factors such as panel size, tilt angle, shading, and local weather conditions.

STUDY AREA

In this study, the authors have analyzed the solar PV output for different panel sizes and of identical efficiencies simulated in the same area through Helioscope software. Focusing on the fact that for the fixed area, solar PV generation heavily depends on the optimum panel size and with the variation of the panel size having nearly identical efficiencies, a wide variation in power output has been noticed. The rooftop locations selected are within the KFUPM campus, located at latitude 26.3464° N and longitude 50.1935° E. To utilize the Helioscope software application in determining the solar panels to be used and which buildings will have solar panels installed on their roofs, we will limit this design to 10 buildings at KFUPM. Using Helioscope, we can simulate to determine the solar energy potential on the roof of each building and select the panel size most suitable to optimize the power output of the PV system in each building.

Fig.3 KFUPM Building

COMPONENTS SPECIFICATIONS

The design and implementation of a solar PV system rely heavily on selecting key components like inverters, PV modules, and strings to ensure performance, reliability, and efficiency. This project employs the Sunny Tripower 24000TL-US (SMA) inverter, valued for its reliability, high performance, and advanced grid management, making it ideal for maximizing energy production while maintaining grid stability.

Table 1. Specification of Inverter [7]

Name	Sunny Tripower 24000TL-US
Manufacturer	SMA
Max Power	24.1 kW
Min Power	0
Max Voltage	1,000 V
Max MPPT Voltage	800 V
Min MPPT Voltage	150 V
Min Voltage	150 V

In this project, we have incorporated high-efficiency PV modules equipped with cutting-edge solar cell technology to optimize energy capture and conversion. Specifically, we have employed the TSM-PD14 320 (May16) modules manufactured by Trina Solar. These modules boast a power rating of 320.0 watts and utilize silicon-polymer (Si-Poly) technology with 72 cells.

Table 2. Specification of PV

Name	TSM-PD14 320 (May16)
Manufacturer	TRINA SOLAR
Power	320.0 W
Technology	Si-Poly (72 cells)
Vmp	37.100V
Voc	45.800 V
Isc	9.100 V
Dimensions	0.992m x 1.956m

The utilization of advanced PV modules is essential for maximizing the system's performance and ensuring reliable electricity generation across diverse environmental conditions. These modules are engineered to withstand various weather elements while maintaining peak performance levels, thereby guaranteeing consistent energy production throughout their operational lifespan.

By integrating high-quality PV modules like the TSM-PD14 320 (May16) from Trina Solar, we aim to enhance the efficiency and longevity of the solar PV system, ultimately contributing to sustainable energy generation and environmental stewardship. Model Characterization of PV in table below:

The information regarding the PV module specifications, including power output, technology, and manufacturer details, was sourced from the Photon Database [7]. The strings utilized in the system are composed of 10 AWG (American Wire Gauge) copper wiring, totaling 500 strings with a cumulative length of approximately 22,596.7 meters.

For the collection of weather data, we relied on the TMY (Typical Meteorological Year) dataset with a 10km grid resolution, obtained from Meteonorm software. The location chosen for data collection was the King Fahd University of Petroleum and Minerals (KFUPM), situated at Academic Belt Road, Dhahran 31261, with coordinates (26.3106378, 50.1482981) in the GMT 3.0 timezone. This dataset includes crucial parameters such as monthly solar radiation data, mean irradiance global horizontal (expressed in KWh/m2), air temperature, and other relevant meteorological variables.

Fig. 4 Meteorological Sources for Dammam

In addition to the Meteonorm dataset, supplementary data for specific parameters may have been sourced from online resources to ensure comprehensive coverage, especially if certain data points were not available through the software. The Helioscope software utilized these meticulously collected weather data to provide accurate predictions of the yearly output for the solar PV system under study.

The solar panel installation consists of multiple buildings and parking areas, each equipped with fixed-tilt racking systems. The orientation of the panels is predominantly landscape (horizontal), except for certain buildings where a portrait (vertical) orientation is utilized. The tilt angle is set at 10 degrees, with an azimuth of 180 degrees. The intrarow spacing between panels is maintained at 0.6 meters, ensuring optimal sunlight exposure while maximizing space efficiency. Each frame size is configured at 1x1, and the installation comprises various numbers of frames and modules across different locations. The total power capacity of the installation is approximately 3.2 MW, with individual buildings contributing varying capacities ranging from 27.2 kW to 505.0 kW. Overall, this comprehensive setup aims to harness solar energy efficiently across diverse structures within the designated area.

The figures below (blue areas) illustrate the extent of land allocation (rooftop buildings) for use as solar PV plants at each of the locations. It's important to note that only a sample of 10 buildings from KFUPM were utilized for this analysis.

Fig .5 Ten Building example of KFUPM

DESIGN AND SIMULATION

The blue areas represent the solar PV panels, while the blue and white areas with circles denote the inverters responsible for converting DC power into AC power.

Simulation models are invaluable tools used in various fields to replicate real-world scenarios and analyze their outcomes in a controlled environment. In the context of solar photovoltaic (PV) systems, simulation models play a crucial role in assessing system performance, optimizing design parameters, and predicting energy generation. By utilizing software such as Autocad, Helioscope, and SolarGIS, researchers and engineers can create accurate representations of solar PV installations, incorporating factors such as geographical positions, panel placements, and inverter configurations. These simulation models enable stakeholders to make informed decisions about system design, component selection, and operational strategies, ultimately contributing to the advancement and optimization of solar energy technologies.

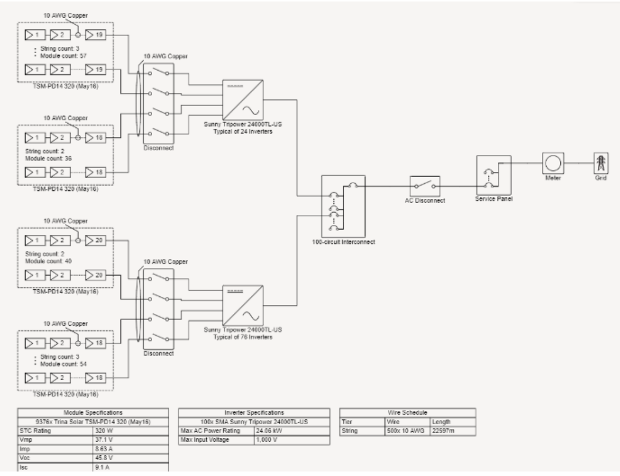

Fig. 6. Single Line Diagram of The Model in KFUPM With Panel Model SM-PD14 320

Furthermore, the uneven roof characteristics of buildings like Building 19 can result in less efficient placement of solar panels and reduce the potential for solar energy production. This is due to shadows cast by the uneven roof relief, which may obstruct direct sunlight exposure to the solar panels during certain periods of the day. Therefore, a thorough evaluation of the building roof conditions is advisable before deciding to proceed with a solar panel installation project. As shown in the Figure below, the roof shape of Building 18 is irregular, which poses challenges for efficient solar panel installation.

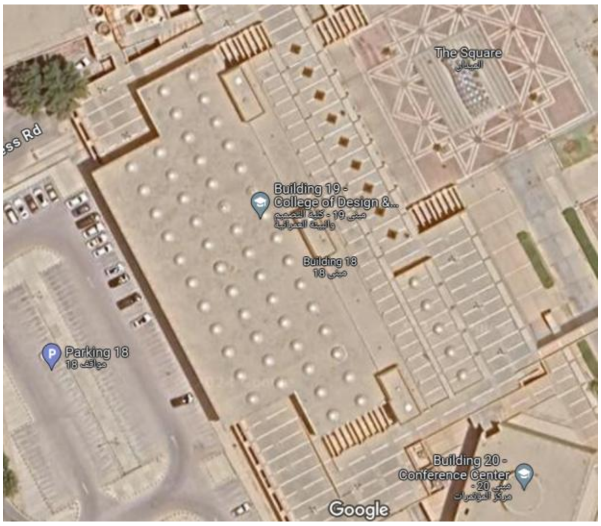

Fig. 7. Building 18

METHODOLOGY AND RESULT

The simulation was conducted using the web geo software called Helioscope (see Figure 6) to calculate the number of panels needed on each building's rooftop. Here, we utilized 10 buildings to represent KFUPM. We estimated the amount of kilowatts per hour, per day, and even per year that can be generated using the solar panels and inverters employed. Additionally, we relied on meteorological data for weather conditions, including solar radiation levels, temperature, and other relevant parameters, obtained from sources such as Meteonorm software and the SolarGIS map for Saudi Arabia. These data were crucial for accurately predicting the annual and daily energy generation potential of the solar PV system.

Building 19, located in the College of Design and Built Environment vicinity, was equipped with a fixed-tilt racking system for the installation of solar panels. The orientation of the panels was set to landscape (horizontal), ensuring optimal exposure to sunlight. A tilt angle of 10 degrees and an azimuth of 180 degrees were chosen to maximize solar energy capture. The intrarow spacing between panels was maintained at 0.6 meters to optimize space efficiency. Each frame had a size of 1x1, and a total of 1,060 frames were installed on Building 19. These frames supported a corresponding number of modules, totaling 1,060 modules. The power capacity of the solar panel installation on Building 19 amounted to 339.2 kilowatts (kW), contributing significantly to the overall energy generation potential of the system.

Fig. 8. Building 19

Among the buildings assessed, Building 21 exhibited the lowest power capacity at 27.2 kW, while Building 24 boasted the highest capacity at 505.0 kW.

Fig.9. Building 21 (Smallest Area)

Together, the collective power capacity of these ten buildings amounts to 3,000.3 kW (3MW), representing a substantial stride towards fulfilling the energy requirements of the KFUPM campus and advancing sustainability goals by diminishing dependence on traditional energy outlets and curbing environmental repercussions. This installation is facilitated by a total of 8,205 solar panels distributed across the rooftops of the buildings.

The Helioscope simulation provides valuable insights into the various sources contributing to system loss. Shading and reflection represent minor percentages at 1.1% and 3.0%, respectively. Soiling and irradiance contribute 2.0% and 0.3% to the overall loss, while temperature fluctuations significantly account for 9.3%. Mismatch and inverters contribute 2.9% and 1.9%, respectively. Wiring and the AC system have minimal impacts, with 0.3% and 0.5%, respectively. Notably, clipping does not contribute to loss in this evaluation, as depicted in the figure below.

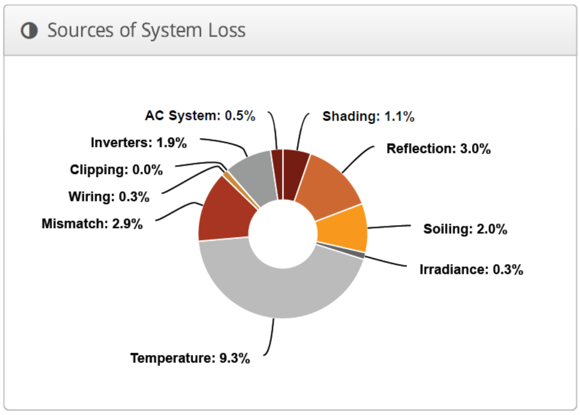

Fig. 10. Sources of System Loss

The HelioScope simulation used precise parameters to model the solar PV system accurately. Weather data from the TMY dataset, processed via Meteonorm software with a 10km grid, informed solar angles and transposition calculations using the Perez Model. Temperature modeling applied the Sandia Model with rack-specific coefficients. Monthly soiling was set at 2%, irradiation variance at 5%, and cell temperature spread at 4°C. The module binning range was -2.5% to 2.5%, with an AC system derate of 0.50%.

Annual Production

	Description	Output	% Delta
Irradiance (kWh/m²)	Annual Global Horizontal Irradiance	2,004.2	
	POA Irradiance	2,105.9	5.1%
	Shaded Irradiance	2,082.0	-1.1%
	Irradiance after Reflection	2,020.4	-3.0%
	Irradiance after Soiling	1,980.0	-2.0%
	Total Collector Irradiance	**1,980.0**	**0.0%**
Energy (kWh)	Nameplate	5,943,882.3	
	Output at Irradiance Levels	5,927,609.9	-0.3%
	Output at Cell Temperature Derate	5,374,823.5	-9.3%
	Output After Mismatch	5,218,685.6	-2.9%
	Optimal DC Output	5,204,674.0	-0.3%
	Constrained DC Output	5,204,368.2	0.0%
	Inverter Output	5,103,365.6	-1.9%
	Energy to Grid	**5,077,849.0**	**-0.5%**
Temperature Metrics			
	Avg. Operating Ambient Temp		30.1 °C
	Avg. Operating Cell Temp		40.0 °C
Simulation Metrics			
		Operating Hours	4591
		Solved Hours	4591

Fig. 11. Annual Production.

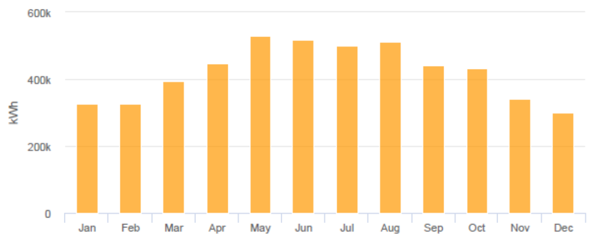

Fig. 12. Monthly Production Bar

Month	GHI (kWh/m^2)	POA (kWh/m^2)	Shaded (kWh/m^2)	Nameplate (kWh)	Grid (kWh)
January	111.8	129.5	125.6	357,338.9	326,591.4
February	116.5	128.8	127.4	362,761.5	328,971.3
March	149.8	158.6	157.5	449,077.0	396,550.6
April	178.2	182.4	181.2	517,368.9	447,782.1
May	223.3	222.2	220.9	631,660.0	528,347.6
June	225.4	221.0	219.8	628,657.2	519,301.4
July	216.1	213.9	212.6	607,538.3	499,196.2
August	217.0	220.4	219.3	627,875.0	512,474.2
September	177.5	187.2	186.2	532,287.1	442,872.7
October	162.8	180.2	178.8	510,349.5	433,570.8
November	121.9	140.3	136.4	388,589.1	343,477.4
December	104.0	121.2	116.2	330,379.8	298,713.2

Fig. 13. Annual Prediction

The system comprises 100 Sunny Tripower 24000TL-US inverters, with a total capacity of 2.41 MW, and 9,376 Trina Solar TSM-PD14 320 (May16) modules, collectively providing 3.00 MW of DC power. Additionally, 500 strings of 10 AWG (Copper) wiring, totaling 22,596.7 meters, are employed to connect the modules to the inverters. Among the buildings assessed, Building 21 exhibited the lowest power capacity at 27.2 kW, while Building 24 boasted the highest capacity at 505.0 kW. Together, the collective power capacity of these ten buildings amounts to 3,000.3 kW (3MW), representing a substantial stride towards fulfilling the energy requirements of the KFUPM campus and advancing sustainability goals by diminishing dependence on traditional energy outlets and curbing environmental repercussions. This installation is facilitated by a total of 8,205 solar panels distributed across the rooftops of the buildings. With the 10 buildings considered in the analysis, the rooftop solar system is designed with a total module DC nameplate capacity of 3.00 MW (megawatts) and an inverter AC nameplate capacity of 2.41 MW (megawatts).

The annual production of the rooftop solar system, as reported in the data, is 5.078 GWh (gigawatt-hours), indicating that it is projected to generate 5.078 billion watt-hours of electricity over one year.

Based on the results above, further details can be seen in the table below :

Table 3. Total PV and kWh

Description	Orientation	PV	Power
Building 19	Landscape (Horizontal)	1,060	339.2 kW
Building 7	Landscape (Horizontal)	667	213.4 kW
Building 20	Landscape (Horizontal)	250	80 kW
Building 11	Portrait (Vertical)	652	208.6 kW
Building 24	Portrait (Vertical)	1,578	505 kW
Parking 22-23	Portrait (Vertical)	1,960	627.2 kW
Building 21	Portrait (Vertical)	85	27.2 kW
Building 8	Portrait (Vertical)	296	94.7 kW
Building 76	Portrait (Vertical)	1,165	372.8 kW
Building 59	Portrait (Vertical)	1,663	532.2 kW
Total		**8,205**	**5.078 GW**

The simulation process involved utilizing Helioscope software, a web-based geo software renowned for its capabilities in accurately assessing solar panel requirements. This tool was chosen due to its robust features and ability to provide detailed insights into solar energy generation potential.

To begin, a comprehensive assessment was conducted for 10 buildings situated within the KFUPM campus. These buildings were selected to represent a diverse range of environments and orientations, ensuring a thorough evaluation of solar panel placement across different structures. Key to the accuracy of the simulation were the meteorological data inputs. These data, sourced from reputable sources such as Meteonorm software and the SolarGIS map specific to Saudi

Arabia, provided crucial information regarding weather conditions, solar radiation levels, temperature variations, and other pertinent parameters. By incorporating these data sets, the simulation could precisely model real-world conditions, enhancing the reliability of the predictions.

Overall, the methodology employed a combination of advanced software tools, accurate meteorological data, and detailed analysis techniques to conduct a thorough assessment of solar panel requirements for the KFUPM campus. This approach ensured the reliability and precision of the findings, facilitating informed decision-making regarding the implementation of solar energy systems to advance sustainability goals.

CONCLUTIONS

The Helioscope simulation has demonstrated KFUPM's significant solar energy potential, estimating a total rooftop solar capacity of 3 MW across 10 buildings with individual capacities ranging from 27.2 kW to 505.0 kW, supported by 8,205 solar panels. Critical system losses, including shading, reflection, soiling, and inverter inefficiencies, highlight areas for optimization to enhance energy output.

To improve the system’s effectiveness, shading mitigation strategies and thorough cost-benefit analyses are essential. Exploring financial incentives and diversifying renewable energy sources can further enhance energy resilience. Additionally, fostering research collaborations and implementing educational initiatives can strengthen KFUPM's leadership in sustainable energy practices while supporting its transition towards a greener future.

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