

Feasibility Study of a 1.35 MW Grid-Connected Solar Photovoltaic System for Public Schools in Saudi Arabia

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Cite <https://doi.org/10.64589/juri/231610>

Submitted: March 08, 2026 Revised: May 21, 2026 Accepted: May 25, 2026

ABSTRACT

This study evaluates the technical, economic, and environmental feasibility of deploying a large-scale rooftop solar photovoltaic (PV) system to offset the annual electricity demand of a typical government school in Saudi Arabia. Electricity consumption data measured for a representative school indicated an annual demand of approximately 2.12 GWh, with an applicable government-school electricity tariff of 0.32 SAR/kWh. The system was modeled using RETScreen Expert under site-specific climatic conditions to conduct a feasibility analysis for a school located in Dhahran, Saudi Arabia. Three Tier-1 PV module technologies Jinko Solar, and Trina Solar were assessed under fixed-tilt and single-axis tracking configurations. For fixed-tilt systems, a slope sensitivity analysis was conducted, to identify the optimal tilt angle of 22°, which was adopted across all simulations to maximize the annual energy yield. The results showed that a 1.35 MW PV system could fully offset the school's annual electricity demand. Although all configurations achieved similar annual energy generation, the Jinko Solar modules exhibited the shortest simple payback period of 4.9 years, driven by higher module efficiency. Single-axis tracking improved spatial utilization and financial performance. The proposed PV system achieved annual CO₂ emission reduction of approximately 1,379 t CO₂. Overall, the findings confirm that high-efficiency rooftop PV systems, particularly those based on Jinko Solar modules, are technically feasible, economically attractive, and environmentally beneficial for public educational institutions in Saudi Arabia owing to their relatively high tariff rates.

Keywords: solar PV, RETScreen, net-zero school, single-axis tracking, payback period, rooftop solar

1. INTRODUCTION

The global energy sector is undergoing a major shift in energy generation and use. Accelerating electrification across buildings and light-duty transportation, along with fast-growing loads requiring low-carbon energy sources such as data centers, are sharply increasing electricity demand. In many realistic scenarios, global electricity consumption is expected to exceed twice the 2023 level by 2050. With this transition, electricity is becoming the core of modern energy systems, progressively displacing conventional fossil-fuel-based energy systems and redefining new global energy landscapes¹.

Renewable energy sources, particularly solar photovoltaic (PV) and wind sources, are experiencing rapid expansion worldwide, with solar PV emerging as a leading contributor to new power capacity. In 2024, solar PV power represented the largest addition to global electricity generation, outpacing all other technologies². Renewables are expected to provide an increasing fraction of global electricity supply, as this transition continues³.

In the global context of rising renewable energy use, Saudi Arabia is especially well suited for increasing solar power in its grid mix. It has high levels of solar radiation and wide areas of flat land, both of which favor solar PV deployment⁴. For institutions such

as schools, particularly those with large roof areas and high daytime electricity demand from air conditioning, lighting, and computers, installing PV systems offers an attractive way to reduce both grid electricity dependence and cost (Figure 1).

For this study, the annual electricity demand of a representative school was tracked between 2024 and 2025, and electricity bills were estimated using a public-sector tariff of 0.32 SAR/kWh⁵. During this period, the average monthly consumption was ~176,884 kWh, which amounted to ~2.12 GWh per year. Given this substantial demand, roof-mounted solar PV can play a major role in meeting a substantial share of school energy needs.

Recent progress in PV technology, supported by ongoing research, improved manufacturing, and lower costs, has made solar projects more efficient and affordable. Many Tier-1 companies, including JA Solar, Jinko Solar, and Trina Solar, now offer commercial modules with efficiencies above 21%. These improvements, together with the decreasing installation and balance-of-systems costs⁶, make PV systems a more practical option for institutional buildings.

Beyond the theoretical potential, rooftop PV systems work effectively in educational settings, both for financial savings and emission reduction. For example, a study conducted at a public

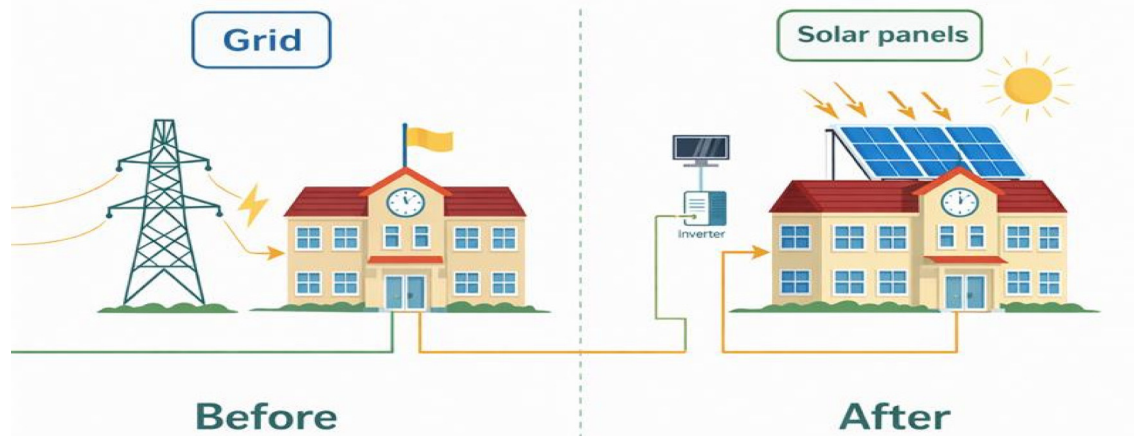


Figure 1. Schematic of school supply transition

institution in Arar City, Saudi Arabia, evaluated a 150-kW grid-connected rooftop PV system and reported a reduction in the annual electricity bill from 138,681 to 39,480 SAR, amounting to annual savings of 99,201 SAR and yielding a simple payback period of ~8.3 years⁷. This study also suggests that combining solar energy adoption with improvements in building insulation and HVAC (heating, ventilation, and air conditioning) efficiency can further enhance economic viability and comfort.

Globally, many schools and universities have adopted rooftop solar power systems. Such installations often supply a substantial portion of daytime load, align well with peak demand periods, reduce operating costs, and markedly reduce CO₂ emissions. These results demonstrate the viability of rooftop PV—technically, economically, and environmentally—for institutional settings. Accordingly, the current study utilized RETScreen Expert software to conduct an integrated analysis of energy yield, financial performance, and emission reduction, as it is well suited to feasibility studies of solar PV projects⁸. The aims of this study are to determine the appropriate size of a PV system that can meet the annual electricity needs of a representative public school; to compare the performance of selected Tier-1 PV modules; to examine fixed-tilt versus single-axis tracking options; to evaluate financial viability based on realistic capital-expenditure (CAPEX) figures; and to estimate CO₂ emission reduction that can be achieved by the proposed PV system.

By integrating regional solar resources, actual electricity demand data, current technological developments, and empirical findings from previous solar PV installations in schools, this study aims to provide a comprehensive assessment of rooftop solar power as a practical, sustainable, and transferable solution for educational facilities in Saudi Arabia. This work is intended to demonstrate technical and financial feasibility and to offer a model that supports the Kingdom's broader sustainability and decarbonization ambitions under Saudi Vision 2030. The novelty of this work lies in providing the first multi-configuration rooftop PV feasibility analysis for a Saudi public school using site-specific RETScreen Expert modeling, thereby enabling direct replication across the national school network. The system loss assumptions

adopted in this study are consistent with values widely cited in the literature. An inverter efficiency of 90% was applied, representing a conservative but industry-standard value for string inverters used in rooftop PV applications.

2. METHODOLOGY

This study adopted a quantitative simulation-based methodology to evaluate the technical, economic, and environmental feasibility of deploying a rooftop solar PV system to offset the annual electricity demand of a representative government school in Saudi Arabia. The methodological framework integrates the measured electricity consumption data, rooftop area assessment, PV system modeling, financial analysis, and emission-reduction evaluation using RETScreen Expert⁸, as shown in Figure 2.

2.1. Slope Analysis. For all fixed-tilt PV system configurations, the module tilt angle (slope) was explicitly considered as the design variable. A sensitivity analysis was conducted by varying the fixed-tilt slope between 18° and 25°, which brackets the latitude of the site and reflects the commonly recommended tilt angles for fixed installations in eastern Saudi Arabia. For each slope value, the annual electricity generation was simulated using RETScreen Expert while keeping all other system parameters constant, including installed capacity, module technology, and system losses. The objective of this analysis was to identify the tilt angle that maximizes annual energy yield under site-specific climatic conditions. The results indicated that the annual electricity generation increased with the tilt angle up to approximately 22°, beyond which a gradual decline was observed, confirming that moderate deviations from the site latitude can influence the annual energy yield. Consequently, a fixed-tilt slope of 22° was selected for all subsequent fixed-tilt simulations because it provided the highest annual energy output while maintaining consistency across all PV module technologies. Figure 3 illustrates the relationship between the fixed-tilt slope and annual electricity generation. The analysis range of 18°–25° was selected to explore the performance of PV systems near the site latitude of approximately 26°N and to represent practically feasible tilt angles for fixed rooftop installations in eastern Saudi Arabia, where very

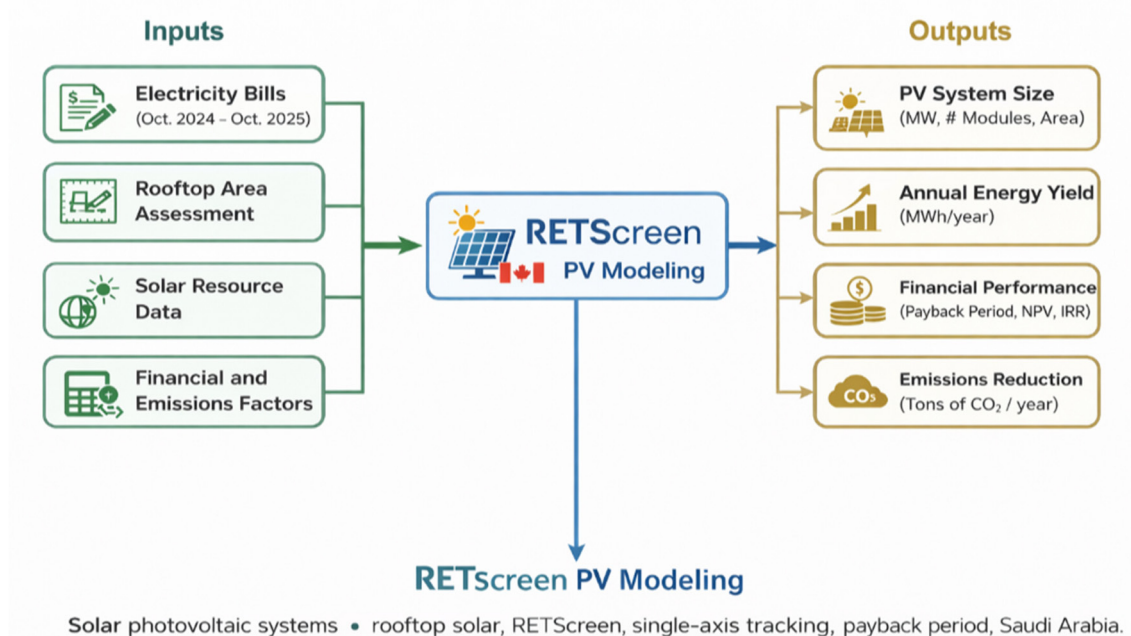


Figure 2. Overview of methodology for evaluating feasibility of rooftop solar PV systems in Saudi Arabia

low tilts are discouraged owing to reduced self-cleaning in dusty environments, and very steep angles impose structural loading constraints. Extending this analysis to 0–35° is recommended for future work, particularly when bifacial module configurations are considered.

2.2. Electricity Consumption Analysis. Monthly electricity invoices for a representative school were collected from October 2024 to October 2025. These invoices were issued by the Saudi Electricity Company (SEC) and included value-added

tax (VAT), which was first excluded to obtain the net electricity cost. Electricity consumption in kWh was subsequently calculated using the applicable government-school tariff of 0.32 SAR/kWh⁵ (Figure 4). This tariff (0.32 SAR/kWh) is a flat energy charge without any fixed connection charges or demand charges. The analysis revealed an annual demand of approximately 2.12 GWh, corresponding to an average monthly electricity consumption of approximately 176,884 kWh. The annual consumption figure was adopted as the baseline demand that the proposed PV system intended to offset.

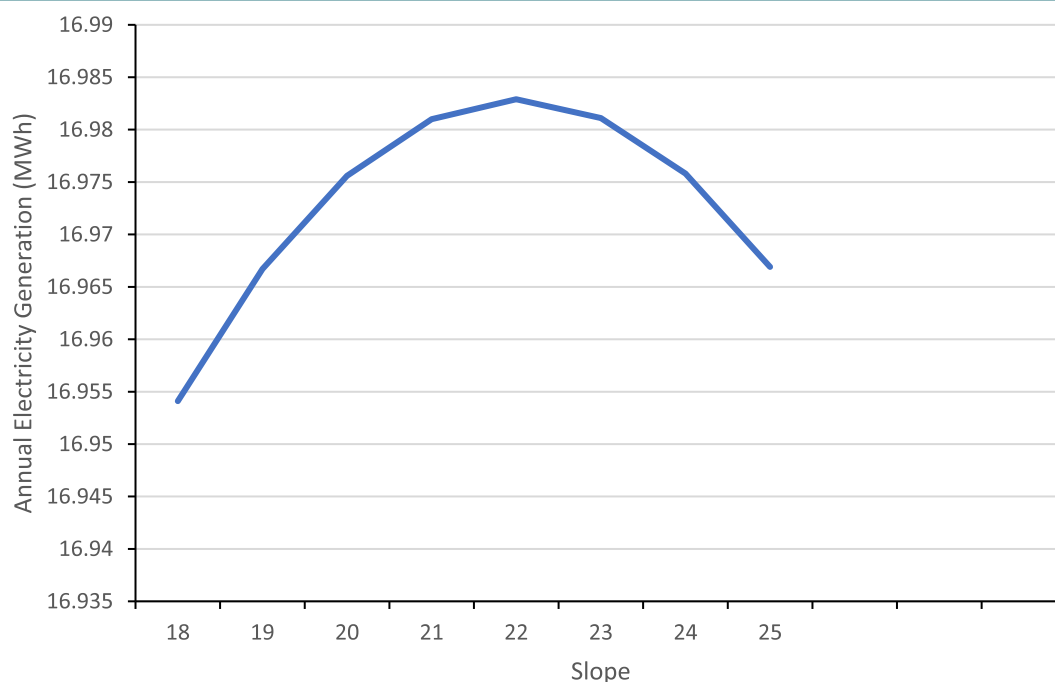


Figure 3. Effect of fixed-tilt slope angle on annual electricity generation for the rooftop PV system. Maximum annual output is achieved at a tilt angle of approximately 22°

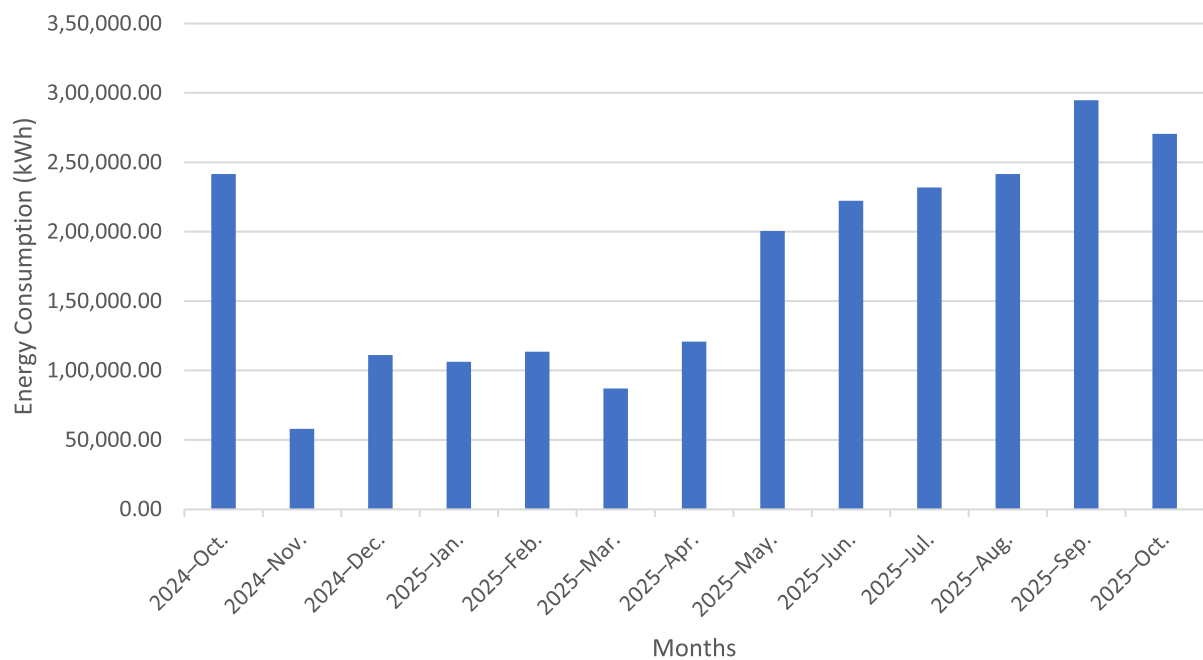


Figure 4. School's monthly energy consumption over a one year period from October 2024 to October 2025

2.3. Rooftop Area Assessment. A thorough examination of available rooftop space was performed using satellite images from a representative school site. The campus comprises three primary structures with non-rectangular shapes (Figure 5). The usable surface area of each building was determined from the measured dimensions, and an additional central rooftop section was included to reflect the usable installation space. After accounting for structural constraints and geometric overlaps, the total available rooftop area was determined to be approximately 8,349 m² of net usable area. This figure already reflects an estimated 15% reduction for inter-row spacing, edge setbacks, access pathways, and shading exclusion zones, applied to the gross rooftop measurement. This area was subsequently used to assess the physical feasibility of accommodating the required PV system under different configuration scenarios.

2.4. Solar Resource and Climate Data. Location-specific solar and climatic data were extracted from the RETScreen climate database, which incorporates long-term meteorological records sourced from satellite observations and ground-based measurements. These values were verified against the Global Solar Atlas to confirm the reliability of global horizontal irradiance figures for the school's geographical location¹⁰. The adopted dataset encompassed solar radiation levels, ambient temperature readings, and system loss parameters, all of which had a direct impact on PV energy output estimations. The PV system modeling was performed using location-specific climatic inputs from Dhahran, Saudi Arabia. The monthly mean daily global horizontal solar radiation and ambient air temperature values were obtained from the RETScreen database, as illustrated in Figure 6.

2.5. PV System Modeling. The PV system was modeled using RETScreen Expert, a validated clean-energy decision-support tool developed by Natural Resources Canada and widely

used in academic and professional energy studies. Three Tier-1 PV module technologies were examined: JA Solar (540 W), Jinko Solar (530–555 W), and Trina Solar (505–515 W). These modules were selected based on their high conversion efficiency, widespread commercial availability, and suitability for utility-scale rooftop applications. For each module type, two installation configurations were modeled: a fixed-tilt rooftop arrangement and a single-axis tracking setup. The simulations were designed to meet the school's full annual electricity demand, allowing a direct comparison of the energy yield, required installation area, system efficiency, and performance improvements associated with tracking. RETScreen's built-in performance models were used to account for temperature effects, system losses, inverter efficiency, and degradation. It is important to note that single-axis tracking systems may impose additional dynamic mechanical loads (gravitational, wind, and seismic) on rooftop structures that may not have been designed for such equipment. A site-specific structural assessment was not conducted within the scope of this study, and it is recommended that an independent structural evaluation be conducted prior to the deployment of rooftop PV systems with single-axis tracking. The system loss assumptions adopted in this study are consistent with values widely cited in the literature. An inverter efficiency of 90% was applied, representing a conservative but industry-standard value for string inverters used in rooftop PV applications^{8,10}. A miscellaneous loss factor of 10% was incorporated to account for wiring losses, module mismatch, shading, and soiling, in line with common practices in regional rooftop PV studies^{8,10}. It should be noted that these values were not derived from on-site measurements at the study location. Dhahran's climate includes periods of elevated dust loading and coastal humidity, which can compound soiling effects and lead to a more persistent performance degradation than would be expected at purely arid inland sites. Summer ambient temperatures regularly exceeding 45 °C may also cause cell temperatures to surpass the nominal operating conditions



Figure 5. Rooftop areas for the school building⁹

assumed in the model, thus reducing the output through the temperature coefficient of power. These factors represent sources of uncertainty in energy yield estimates and should be investigated with site-measured data in any detailed design study.

2.6. Financial Analysis. The financial feasibility of the PV system was evaluated using two CAPEX scenarios. The first scenario applied RETScreen's conservative default value of 5,000 USD/kW, representing small-scale or less-optimized installations. The second scenario adopted the 2023 global benchmark for utility-scale PV systems reported by the International Renewable Energy Agency (IRENA)¹¹, equal to 652 USD/kW, reflecting the current market conditions and cost reduction. Rooftop installations typically carry a cost premium over ground-mounted PV systems; accordingly, 652 USD/kW represents a lower bound for capital expenditure, and the actual rooftop-specific costs may be higher.

Annual electricity savings were calculated based on the offset energy and applicable electricity tariff. All financial results are converted to U.S. dollars using an exchange rate of 1 USD = 3.75 SAR. A simple payback period was used as the primary economic indicator as it is widely applied in institutional energy investment decisions and provides a clear measure of cost recovery.

2.7. Environmental Impact Assessment. The environmental benefits of the PV system were quantified by estimating

annual CO₂ emission reduction. An emission factor of 0.65 kg CO₂/kWh was adopted from literature representing the emission factor for power plants in Saudi Arabia¹². Annual emission savings were calculated by multiplying the simulated annual PV electricity generation by this emission factor, yielding the total avoided CO₂ emissions in metric tons per year.

2.8. Comparative Evaluation. Finally, the results from all simulations were systematically compared across the PV module types and system configurations. The key performance indicators included annual energy output, required rooftop area, system efficiency, payback period, and CO₂ emission reduction. This comparative approach enabled the identification of the optimal PV technology and configuration for the given site constraints and energy demands. The CO₂ emissions can be calculated as follows:

$$\Delta CO_2 = E_{Annual} \times EF_{Grid} \quad (1)$$

where ΔCO_2 is the annual CO₂ emissions attributable to the electricity used, E_{Annual} is the total electrical energy associated with the system over a year, and EF_{Grid} is the CO₂ emitted per unit of grid electricity delivered.

Table 1. Annual electricity generation for different PV manufacturers

Solar Panel Type	Electricity Exported to Grid (kWh/year)	Efficiency (%)	Area (m ²)	Payback Period (Years)
JA Solar	2,122,765	21.1	6729	5.1
Jinko Solar	2,122,740	22	6136	4.9
Trina Solar	2,122,779	21.4	6308	4.9

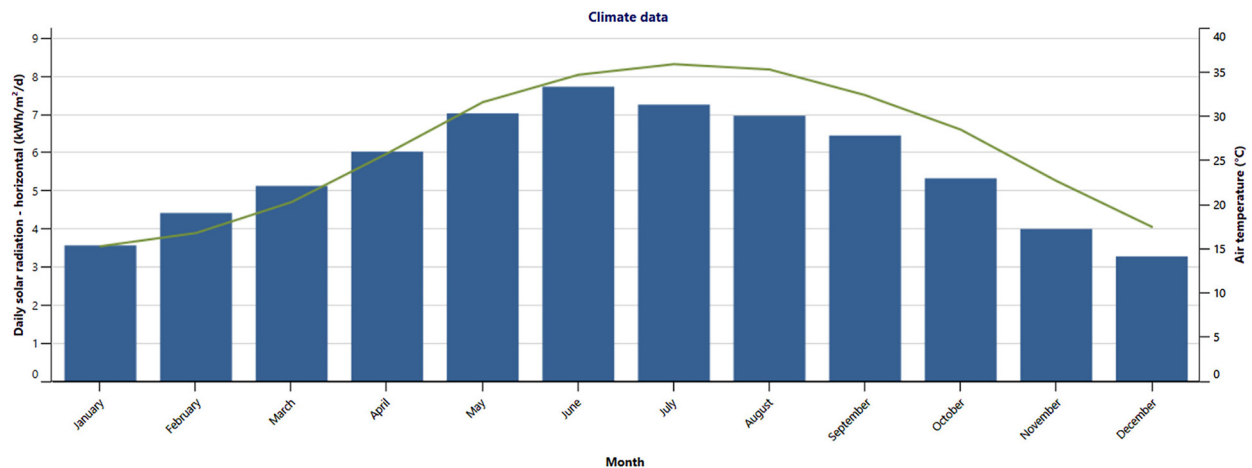


Figure 6. Climate data used in RETScreen for Dhahran, Saudi Arabia, showing monthly average daily global horizontal solar radiation and ambient air temperature (data source: RETScreen Expert)⁸

3. RESULTS AND DISCUSSION

The RETScreen Expert simulations provided a comprehensive assessment of the technical, spatial, economic, and environmental performance of rooftop solar PV deployment at the representative government school studied. The results demonstrated that under the assumed conditions of this study, a properly sized PV system could fully offset a school's annual electricity demand while offering attractive financial returns and substantial environmental benefits^{13,14}.

3.1. Energy Yield and System Sizing. The simulation results indicated that a PV system with a nominal capacity of approximately 1.35 MW was sufficient to generate approximately 2.12 GWh per year, which closely matched the school's measured annual electricity consumption. This strong alignment between the annual electricity generation and demand confirmed the technical feasibility of achieving near-net-zero annual electricity consumption. Such load matching is particularly favorable in educational buildings, where the peak electricity demand occurs during daytime hours and coincides well with solar PV production, especially in high-irradiance regions such as Saudi Arabia. A net-metering framework was assumed in this study, whereby electricity exported to and imported from the grid was accounted for using the same tariff structure on an annual energy basis. Under this assumption, any mismatch between the electricity demand and PV electricity generation was balanced through grid imports and exports. Net metering for public-sector facilities is progressively being implemented in Saudi Arabia under the National Renewable Energy Program (NREP); however, its availability may vary across school sites. Consequently, if net metering is unavailable or subject to regulatory restrictions, the effective financial savings and annual energy-offset benefits of the proposed PV system are correspondingly reduced.

3.2. Comparison of PV Module Technologies. Table 1 compares the performance of three Tier-1 PV manufacturers, JA Solar, Jinko Solar, and Trina Solar, under fixed-tilt rooftop installation conditions.

All three PV systems export approximately 2.12 GWh of electricity annually, demonstrating that each configuration can fully

offset the annual electricity demand of a school. This confirms that the system size and total installed capacity, rather than the module brand, primarily govern the total annual energy output when the designs are constrained to meet a fixed load target and similar irradiance conditions.

Despite similar energy outputs, notable differences emerge in the module efficiency and required rooftop area. Based on simulation results, the configuration using Jinko Solar modules has the highest module efficiency (22.0%), and accordingly requires the smallest installation area (6,136 m²) to produce the target annual energy. The Trina Solar configuration follows with an area of 6,308 m² (21.4% efficiency), whereas the JA Solar configuration requires the largest area of 6,729 m² (21.1% efficiency) to achieve the same annual electricity export. In this set of results, the JA Solar layout requires approximately 9.7% more rooftop area than the Jinko Solar layout owing to its lower module efficiency.

This distinction is particularly important in rooftop-constrained environments, such as schools, where usable areas may be limited by structural geometry, shading, safety setbacks, and maintenance access. High-efficiency modules can reduce the footprint required for a given energy target, which is often a key constraint in urban and rooftop PV applications. Similarly, studies on PV system design show that module efficiency directly affects area requirements and land-use optimization for fixed-energy goals.

3.3. Financial Performance. The financial performance of the three PV system configurations was evaluated using a simple payback period, which represents the time required for cumulative electricity cost savings to recover the initial capital investment. As shown in Table 1, all configurations exhibit attractive payback periods of less than 6 years, indicating the strong economic feasibility of rooftop PV deployment in educational buildings.

The Jinko Solar and Trina Solar systems achieve the shortest payback periods of 4.9 years, whereas the JA Solar system shows a slightly longer payback period of 5.1 years. This difference is primarily attributable to variations in module efficiency and

Table 2. Comparison of key performance indicators with prior studies on PV systems at Saudi schools^{15,16}

Study	Location	Size (MWp)	Payback (yr)
This study (2025)	Dhahran	1.35	4.9–5.1
Alfaraidy & Sulieman (2019) ⁷	Arar	0.15	8.26
Almotairy & Almarshoud (2024) ¹³	Buraidah	0.160–0.430 (3 schools)	Feasible (zero-energy); infeasible/extended (zero-bill)

required installation area, which directly influence the balance-of-system costs, mounting requirements, and overall capital expenditure. High-efficiency modules reduce the number of panels and rooftop area required to meet the same energy target, leading to marginally lower installation costs and improved financial returns.

Despite these differences, the payback periods across all three systems remain closely clustered, indicating that the annual energy exports are nearly identical (approximately 2.12 GWh/year) for all configurations. This confirms that, when systems are designed to meet a fixed electricity demand, financial performance is influenced more by system efficiency and area utilization than by energy yield differences alone.

These results are consistent with findings reported in the literature, which show that rooftop PV systems in high-irradiance regions typically achieve payback periods in the range of four to seven years, particularly when offsetting retail electricity tariffs. Previous studies also emphasized that higher module efficiency can modestly improve project economics by reducing the installation footprint and associated costs, especially in space-constrained urban environments, such as schools and commercial buildings.

Table 2 provides a comparison of the performance indicators from this study against selected prior works on rooftop PV systems at Saudi educational facilities.

3.4. Environmental Benefits and Emission Reduction.

The environmental analysis indicated that the PV system would reduce CO₂ emissions by approximately 1,379 tons of CO₂ per year, based on an emission factor of 0.65 kg CO₂/kWh for grid electricity. This reduction is equivalent to removing several hundred passenger vehicles from the road annually, and represents a considerable contribution to institutional decarbonization efforts.

These findings align with national and international assessments that identify solar PV as one of the most effective technologies for reducing emissions in electricity-intensive buildings, particularly in regions with partially fossil-fuel-based grid electricity. For educational institutions, such emission reductions also provide important non-quantifiable benefits, including enhanced environmental awareness, sustainability leadership, and alignment with Saudi Vision 2030's objectives.

3.5. Broader Implications and Limitations. Overall, the results demonstrate that rooftop solar PV is not only technically feasible for educational institutions in Saudi Arabia but also financially viable and environmentally impactful. The combination of high solar resource availability, declining PV costs, and favorable daytime load profiles makes schools ideal candidates for rooftop PV deployment. When optimized using high-efficiency modules and single-axis tracking, such installations can serve as

scalable and replicable models for wider adoption across the national education sector.

However, the following limitations should be considered when interpreting the results of this study:

1. capital expenditure was based on the IRENA 2023 utility-scale benchmark of 652 USD/kW, which is likely an optimistic lower bound for rooftop institutional installations; actual costs may be higher;
2. a net-metering framework was assumed for annual energy accounting, but net-metering availability for public-sector school facilities in Saudi Arabia is subject to regulatory confirmation;
3. the structural suitability of the school rooftops for single-axis tracking systems was not assessed; a site-specific structural evaluation would be required prior to deployment;
4. results are based on a single representative school in Dhahran and may not generalize across all school types, sizes, and climatic sub-regions of Saudi Arabia;
5. dust and soiling losses were included in the system modeling through RETScreen's default performance parameters, but an optimized cleaning schedule specific to the site was not determined;
6. the tilt sensitivity analysis was limited to a range of 18°–25°; a wider range including very low tilts and steeper angles would provide additional design insight.

4. CONCLUSIONS

This study demonstrated that deploying a rooftop solar PV system at a government school in Saudi Arabia is technically feasible, economically viable, and environmentally beneficial under the assumptions of net-metering availability and utility-scale capital-expenditure benchmarks. Using measured electricity consumption data and RETScreen Expert simulations, a PV system with a nominal capacity of approximately 1.35 MW was shown to fully offset the school's annual electricity demand of ~2.12 GWh under local climatic conditions in Dhahran.

A fixed-tilt slope sensitivity analysis identified an optimal tilt angle of 22°, which maximized the annual energy yield and was consistently applied across all fixed-tilt system configurations. A comparative evaluation of three Tier-1 PV module technologies, JA Solar, Jinko Solar, and Trina Solar, revealed that although all systems achieved similar annual electricity generation, differences in module efficiency markedly influenced the rooftop area requirements and economic performance. The Jinko Solar modules exhibited the shortest simple payback period of 4.9 years, primarily because of their higher efficiency and reduced installation footprint, making them the most favorable option for space-constrained rooftop applications.

A financial analysis based on an electricity tariff of 0.32 SAR/kWh confirmed that rooftop PV systems can deliver

attractive economic returns for educational institutions, with payback periods well within acceptable ranges for institutional investments. In addition, the proposed system offered substantial environmental benefits, reducing CO₂ emission by approximately 1,379 t CO₂ per year, thereby supporting institutional decarbonization efforts and national sustainability objectives.

This study also highlighted the potential for further performance enhancement through system optimization measures such as single-axis tracking and automated self-cleaning mechanisms, which are particularly relevant in dusty and arid environments. Overall, the findings provide a robust and replicable framework for rooftop PV deployment in the Saudi education sector, demonstrating how high-efficiency PV technology, optimized system design, and realistic economic assumptions can enable schools to play an active role in the Kingdom's renewable energy transition under Saudi Vision 2030.

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COMPETING INTERESTS

The authors declare that they have no competing interests.

DATA AVAILABILITY

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

This study did not involve human participants, animals, or identifiable personal data. Therefore, ethical approval was not required.

ACKNOWLEDGEMENTS

The authors acknowledge the Department of Mechanical Engineering at King Fahd University of Petroleum and Minerals (KFUPM) for its support.

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