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Article

Achieving zero-bill for the grid-connected PV systems in Saudi Arabia governmental schools: a techno-economic analysis

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ABSTRACT

Governmental schools are characterized as ideal places for installing grid-connected PV systems due to the availability of large spaces on their roofs. Schools are also characterized by their good annual load profile, in which most of the loads occur during the day, and there are no loads on nights or weekends or during summer and vacations. Moreover, in the winter, the loads drop dramatically due to the lack of air conditioning. This special annual load profile provides a relative property to government schools with regard to exporting the energy generated during off days to the general electricity grid. The main objective of this research is to attempt to design a grid-connected PV system that can balance imported and exported energy to the grid to achieve an annual zero bill based on the energy exchange tariff in Saudi Arabia. Three different schools in Buraidah City were selected for investigation. The annual energy consumption was estimated from energy bills for 3 years and compared with actual installed loads. The performance analysis was done by applying three widely used indicators: yield factor, capacity factor, and performance ratio. Also, the economic analysis was done using the life cycle analysis methodology based on the local market prices to find the levelized cost of energy (LCOE) and the payback time. The results of economic and performance analysis revealed the professionality of installing grid-connected PV systems in government schools.

1. Introduction

The constant increase in the population of the world has resulted in a high demand for water, food, and energy sectors [1]. The process of generating energy is facing significant challenges, such as fluctuations in market price, security, cost, and sustainability [2, 3]. Moreover, the rise in awareness of environmental issues has directed the scientific circle to develop sustainable and alternative energy sources [4-6]. With the help of these implications, the energy system transformation has also received much attention from people who are more focused on solar cells and biofuels [7, 8]. Sustainable and hybrid energy systems like biomass, geothermal, wind, and solar are viewed as crucial technologies in the renewable innovation phase [9, 10]. Between these energy resources, solar energy is a pollution-free generation of electricity without the emission of greenhouse gases (GHG) to the environment [11, 12]. The radiation of solar contains a high amount of energy in one minute that can be utilized as an excellent opportunity for pollution-free harvesting of energy [13]. Apart from being able to decrease the damage to the environment, the utilization of solar panels can save the cost of electrical energy constantly. Utilizing solar panels does not need regular maintenance, thus resulting in a more efficient method to save costs [14, 15]. PV grid-connected systems are one of the remarkable types of solar energy systems utilized widely because of the backup generators of solar panels. Lately, electricity prices have increased in Saudi Arabia due to the tariff consumption of electricity service providers in 2018. Hence, in 2018, the Electricity and Cogeneration Regulatory Authority accepted the utilization of a PV grid-connected system for houses and assisted in giving an advantage to lessen the bills of electricity loads faced in summer without any interruption. The government schools were affected after the notable increase in the electricity bills; most were charged higher than the houses since the tariffs were charged on them. Hence, public schools are classified as one of the finest places for installing PV systems because of the large spaces available on their roof that can be utilized to install these systems. The majority of the load is applied in the daytime due to the presence of staff and students; however, at night, there is no presence of load. Therefore, the surplus can be given to the electrical network during vacations or weekends. In addition, during winters, there is a dramatic drop in energy demand as a result of less air conditioning use. The main aim of this research study is to reduce the electricity bill of selected public schools annually to zero after employing a PV grid-connected system on the roof of the schools.

2. Literature Review

In recent years, a growing body of research has explored innovative approaches to enhance energy efficiency and sustainability, particularly in regions with high energy demands such as Saudi Arabia. Almasoud and Gandayh [16] review the utilization of PV systems to produce electricity in Saudi Arabia. The outcomes revealed that during peak hours, peak saving can be achieved by employing PV systems compared to traditional power generation systems. They also indicate that after estimating the total amount of health and environmental impacts compared to fossils. Another study examines the PV system's economic feasibility of installation on the consumer side. The study utilized a package of RET screens to simulate various installation of PV cases in Saudi Arabia among 5 cities (Dammam, Najran, Jeddah, Buraydah, and Tabuk) by including the latest price of components of PV systems, demand of energy, and every city meteorological property. The evaluation was performed based on the newly exchange tariff of energy and regulations, and the outcomes of the study revealed that if the PV system is developed to generate yearly energy demand for houses, the payback time will be less than ten years, and the LCOE will be less than 0.1 SAR/kWh. The research demonstrates that expanding PV system capacity higher than demanded annually will be economically infeasible due to the low rate of exported energy to the grid [17]. Rashwan et al. [18] conducted an environmental feasibility and cost-effective analysis of changing the power supply from electrical to Solar PV modules. A 12 kW PV system was calculated utilizing the worldwide PV Project Model. They determined that placing PV systems in areas that have high rates of electricity was feasible after examining 3 different scenarios. The off-grid PV system showed great results regarding issues related to the environment and reducing the emission of carbon dioxide.

A study was conducted on installing PV systems on the roofs of mosques and stated that this system would save a lot of money. They concluded that installing PV systems on mosques and residences in Saudi Arabia would be highly effective even without the assistance of the government. It was notable that when the net metering system was examined, the initial outcomes of the model recommended that about 250 kilowatts be installed to decrease the net present cost (NPC). Specifically, it was noted that the energy installation bill was zero practically, showing the exported and imported energy was equal virtually [19]. Flood et al. [20] examined PV systems on 130 houses that were environment-friendly in those areas where the building was insulated to take benefits of solar power. It has the power to produce a yearly income of about 4 to 8 thousand euros, which shows support for using solar power and the advantages of subsidies. Moreover, in 2014, it was noted that schools saved about 5 thousand dollars on electricity bills from the main grid as high power was exported between holidays and weekends [21]. The research was performed in Meknes, where two connected grid PV systems were examined. A difference between the results was made in the measurement and simulation of the systems, as they were technology-wise different and capacity-wise similar. The comparison based on measurement reported that a smaller number of differences was found due to similarities in the database and solar irradiance [22].

Johnson & Ogunseye [23] constructed and developed a PV grid-connected system in Nigeria on the government's building's roof. The research utilized PV*SOL 2016 software to examine the amount of electricity generated every day of the year. The outcomes showed that the continual PV system output was greater than the everyday energy consumption. A PV system in a school in Izmir, Turkey, was connected to the roof to examine for cooling, heating, and other electrical loads. The study proposed two cases; in the first case, 180 solar panels were placed, whereas in the second case, 265 solar panels were placed. In the second case, it covered schools at a rate of consumption which was 162 percent higher than in the first case. Moreover, extra profit was obtained in the second case for the school [24].

3. Method

3.1 Study design

In the current study, three schools in the city of Buraydah were selected i.e., Buraidah Secondary School, Prince Abdulelah Secondary School, and Anas bin Malik Primary School. All three schools contain the same climate conditions but they are different in regards to the requirement of energy and the area of the school's roof.

3.2 Ethical approval

Ethical approval was obtained from the Education Department in Buraydah City.

3.3 Study procedure

3.3.1 Meteorological data

Saudi Arabia receives abundant sunlight all year, so it was suggested that the PV system would work effectively at any site in the country. Per day, an average of 6.08 kWh/m^2 global horizontal irradiance (GHI) was found in the city. The meteorological data was collected with the help of K.A.CARE's Renewable Resource Monitoring and Mapping (RRMM) program. The collected data is shown in Table 1, which includes the recorded metrological data in addition to the sun irradiance calculated at both horizontal and tilted planes.

3.3.2 Measurement of load profile

The rate of consumption of energy at any time is measured. To evaluate the profile load, a bill of energy consumption was collected from the electrical energy providers between 2017 and 2019. Figure 1 illustrates the average consumption of electricity bills for the selected schools. Table 2 shows the difference between the annual consumption noted by monthly energy bills and the calculated consumption based on installed loads.

Table 1. Meteorological data of Buraidah City

Month	Ambient Temperature - C	Global Horizontal irradiance GHI - kWh/m2/d	Relative Humidity - %	Global radiation (Tilted) GTI* - kWh/m2/d	Atm. Pressure - MPa	Daily Diffuse Radiation - Horizontal - kWh/m2/d	Wind Speed - m/s
January	13.17	4.24	42.18	5.31	942	1.57	3.7
February	17.95	5.34	30.33	6.04	940	1.8	3.79
March	21.7	5.7	32.2	6.25	937	2.79	4.15
April	26.11	6.25	22.58	6.17	936	3.18	4.18
May	31.08	7.1	15.05	6.29	934	3.47	3.84
June	34.28	8.15	10.26	6.84	931	2.82	3.72
July	34.91	8.13	10.04	6.97	929	2.28	3.41
August	36.57	7.54	10.56	6.95	930	2.26	3.55
September	33.57	6.68	12.04	6.92	933	2.35	3.53
October	26.33	5.61	18.56	6.51	937	2.03	3.78
November	20.77	4.37	39.82	5.06	940	1.7	3.82
December	16.77	3.83	46.9	4.85	943	1.52	3.67
Average	26.10	6.08	24.21	6.18	936	2.31	3.76
*The tilt angle equals the latitude of the corresponding location-Buraidah City							

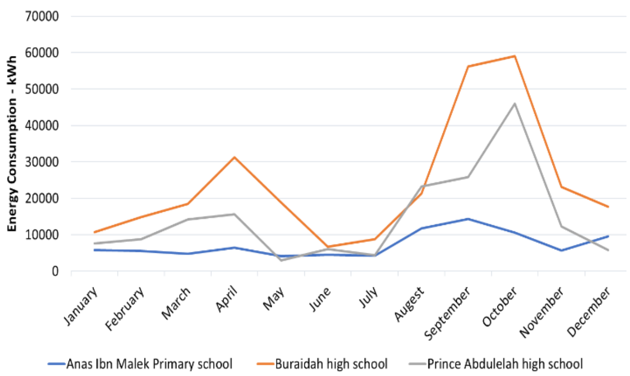

Figure 1. Monthly average consumed energy of schools under study

There was no big difference; therefore, the energy consumption annually extracted from monthly bills was utilized for calculation.

3.3.3 Selection of PV module

A PV module (HiKu6 Mono PERC, CS6 W-550MS) from the Canadian Solar Company was selected for evaluation in the current study for various reasons, such as availability in the local market, warranty, and performance. Table 3 shows the specification of the module for which it was selected in the study.

Table 2. Annual energy consumption (recorded and estimated)

	Recorded by bills (kWh)	Estimated using installed loads (kWh)
Anas Ibn Malek school	87100	84401.6
Buraidah high school	286730	277258.5
Prince Abdulelah school	172600	164602.6

Table 3. Specification of selected PV module at STC

Cell Type	Mono-Crystalline
Nominal Max. Power (P_{max})	550 W
Operating Voltage (V_{mp})	41.7 V
Operating Current (I_{mp})	13.2 A
Open Circuit Voltage (V_{oc})	49.6 V
Degradation Factor (%)	1st year 2%- Subsequent annual 0.55%
Short Circuit Current (I_{sc})	14 A
Module Efficiency (%)	21.5%
NOCT	42±3C°
Temperature Coefficient (%/C°)	0.34%
Dimensions (mm)	2261*1134*35 mm

Throughout the school's visit to fields, the building's area of the rooftop was estimated, and it was found that there were no walls or barriers that could lead to shading on the panels. Hence, the areas of rooftops of all 3 schools under evaluation were determined to be unrestricted. The selected modules of the PV system's maximum number were examined based on the roof area availability of selected schools.

With this reference, 2 significant factors are generally reviewed to increase the installation of solar system efficiency. They are as shown:

- Orientation: It is not affected whether the installation is a portrait or landscape.
- Row spacing: It is also called the shading distance, which is the shortest distance between rows without the shading possibility.

Table 4 depicts the maximum number of PV modules that can be installed on the roof for each school utilizing the selected module.

Table 4. The maximum number of modules that can be installed

The Name of the School	Number of PV modules
Anas Ibn Malek	351
Buraidah	782
Prince Abdulelah	290

3.3.4 Sizing and optimization of the PV system

The array of PV systems will be sized utilizing the selected module of PV system to satisfy the demand for energy annually, taking into consideration the location's climatic characteristics. Hence, the impact of the change in the temperature of the PV cell on the efficiency of the PV array must be examined. Utilizing Equations (1) and (2), the efficiency of the PV system module can be estimated depending on the solar radiation and average ambient temperature at the site all over the year. Therefore, the PV array is differentiated by its new average efficiency (η_e), which is estimated by the average module cell temperature, T_c [25, 26]:

$$\eta_e = \eta_R[1 - \beta(T_C - T_R)] \quad (1)$$

$$T_C - T_a = \frac{NOCT-20}{800} * G_t \quad (2)$$

where η_R is the efficiency of the PV module at the reference temperature (T_R), and the temperature coefficient for the efficiency of the module (β) needs to be collected from the datasheet of the PV module to investigate the array average efficiency (η_e). As shown in the equation, Tc is the mean ambient temperature (Ta) function, and NOCT, which is the temperature of the nominal operating cell, the G_t constitutes the solar irradiance on the tilted surface denoted in W/m^2 [27]. The energy output of the PV array can be measured utilizing Equation (3) as shown:

$$E_A = \eta_e(No.of\ modules * A)G_t(1 - L_{PV})(1 - L_C) \quad (3)$$

Where E_A is the delivered energy by the PV array, A is the area of the PV module, G_t shows the irradiance of solar on the tilted plane denoted in (Wh/m^2/d), and L_c is power conditioning losses and L_m is miscellaneous PV array losses. To calculate the amount of energy fed into the grid, Equation (4) illustrates that the injected energy into the grid is equal to the produced energy by the PV array lowered by losses of the inverter:

$$E_{grid} = E_A * \eta_{inv} \quad (4)$$

Utilizing Equations (3) and (4), PV array size can be obtained.

3.4 Performance indicators

To calculate the performance indicators IEC 61836 (International Electrotechnical Commission) and IEC 61724 (International Electrotechnical Commission), three effective performance indicators were employed in the current study: the performance ratio, capacity factor, and yield factor. The results of these indicators allow us to find the long-term variance in the performance of the PV system.

3.4.1 Yield factor

The yield factor calculates the PV array productivity under specific conditions of weather is shown as follows [28]:

$$YF = \frac{E_{grid}\left(\frac{KWH}{year}\right)}{P_{array}(KW_{peak})} \quad (5)$$

3.4.2 Capacity factor

The capacity factor specifies the usability percentage and is defined as the fraction of the annual energy production ratio to the energy amount of the PV array [28]:

$$CF = \frac{YF}{8760} \quad (6)$$

3.4.3 Performance ratio

It is the PV energy quantity given to the grid for a specific period divided by the theoretically calculated amount depending on the data of the STC module. It is not impacted by size or location and gives the losses effect on the nominal power array caused by the inefficiency of the inverter, mismatch of wiring, and a few other losses when changing from DC to AC power, such as the temperature of PV module, irradiance insufficient utilization and component failures of components. The PR indicator is estimated as follows:

$$PR = \frac{YF * G_{STC}}{\sum G_t} \quad (7)$$

where ΣG_t is the accumulative irradiance, and G_{STC} is the amount of irradiance at STC.

3.5 Economic analysis

Economic indicators are essential for the feasibility of PV systems. The present study utilizes several parameters, such as the LCOE and payback time. The specifications and pricing of the PV system components were recorded from the local market.

3.5.1 Levelized cost of energy (LCOE)

The LCOE is a generally utilized statistic that shows the present net value of the electricity unit cost throughout the lifetime of a specific technology related to the production of electricity. It can be utilized to guide renewable energy goal-setting and other policies that motivate the adoption of renewable energy. Moreover, these findings can facilitate producers of renewable energy in locating suitable places for validations and measurement resources. Calculating the LCOE, which represents the present net value of the electricity unit cost for the lifetime of a definite production system of electricity in \$/MWh is the first crucial step in examining the economic potential of a region shown as follows:

$$LCOE = \frac{LCC}{\sum_{n=1}^{N} Epv} \quad (8)$$

3.5.2 Payback time

The payback time is the time necessary for yearly solar savings to become positive and cumulative solar savings to reach zero. This time can be obtained with and without discounting the savings, as shown in Equations 9 and 10, respectively [29], as shown:

$$n_{payback} = \frac{ln\left(\frac{C_{initial} * i}{FLC} + 1\right)}{ln(1+i)} \quad (9)$$

$$n_{payback} = \frac{ln\left(\frac{C_{initial} * (i-d)}{FLC} + 1\right)}{ln\left(\frac{1+i}{1+d}\right)} \quad (10)$$

where F is the fraction of solar, L is the annual load (kWh/year), and C is the electricity cost (SAR or $ per kWh) from the utility grid.

4. Results and discussion

Table 5 demonstrates the maximum number of modules of the PV system and the PV array size allowed for selected schools based on the roof area availability. Depending on the PV array size, the output of energy throughout the year was estimated utilizing Equations 3 and 4 and compared with the energy measured, which is the consumed energy by the three schools, as depicted in Table 6. The energy produced by the array of PV systems annually mostly equals the measured energy annually, which means that the annual energy balance is satisfied (Exported Energy = Imported Energy).

Table 5. PV array size for the selected schools

School Name	Size of PV array	Max. No. of modules
Anas Ibn Malek	82	351
Buraidah	266	782
Prince Abdulelah	160	290

Table 6. Generated energy and energy demand comparison

School Name	Generated Energy (Calculated)	Consumed Energy (Measured)
Anas Ibn Malek	88526.73	87100
Buraidah	287172	286730
Prince Abdulelah	172735	172600

However, the annual energy balance does not satisfy the annual zero bill, which was the main objective of this study. This is due to the large difference in the energy exchange tariff, which is 0.05 SAR/kWh for exported energy and 0.32 SAR/kWh for imported energy. Therefore, to satisfy the annual zero bill, the amount of exported energy should increase until the price of exported energy equals the price of imported energy. To achieve this condition, the size of the PV array should increase gradually until satisfying this objective, taking into account the following two constraints:

- The size of the PV array should not exceed the maximum number of PV modules allowed for each school.
- The annual zero bill should be satisfied until the last year of the project lifecycle, which is due to normal degradation in the output power of PV modules as a result of PV module aging.

For the three schools, the size of the PV array increased, considering the previous constraints. Anas School satisfied the need for an annual zero bill at 132 modules, Buraydah School satisfied the need for a yearly zero bill at 516 modules, and the Abdulelah School reached the maximum allowed number of modules (290) but did not satisfy the need for an annual zero bill. Figures 2, Figure 3, and Figure 4 show comparisons of the annual generated energy (calculated) and annual energy demand (measured) for the three schools under study after increasing the size of the PV array.

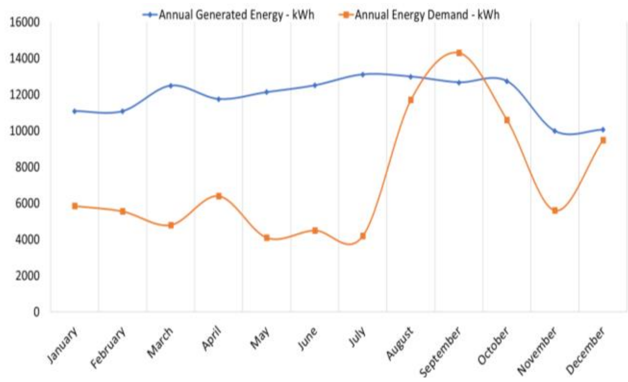

Figure 2. Comparison of generated energy and energy demand of Anas School

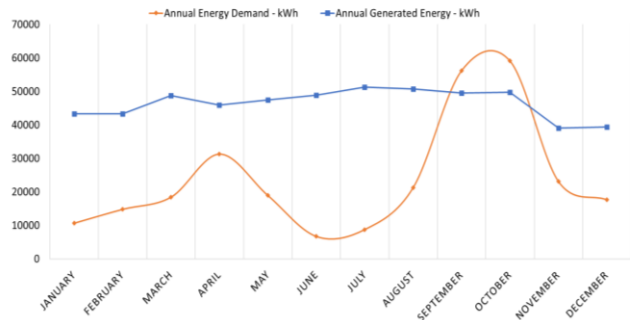

Figure 3. Comparison of generated energy and energy demand of Buraydah School

In Figures 2-4, the produced energy covers the energy requirement majority of the year, which reveals that the energy surplus will be exported to the grid except from September to November. Based on this, the yearly net bill and exchange rate of energy were estimated for the entire lifecycle of the project as shown in Table 7. Due to the exported energy is sold at 0.05 SAR/kWh, while the tariff for imported energy from the service provider is 0.32 SAR/kWh, the cash gain flows remain low. The difference values with a negative sign represent the amount of money to be paid to the service provider. As demonstrated in Figure 5, Figure 6, and Figure 7, the influence of the degradation coefficient on the output energy over the life of the PV system affects the amount of profit and loss and the difference between them. Furthermore, the findings have demonstrated that Anas Bin Malik School and Buraidah School could achieve an annual zero bill because the difference between profit and loss was found to be equal in the last year of the system's life, whereas Prince Abdulelah School did not achieve an annual zero bill because its losses began to increase in 8th year of the system's life as a result of high loads and the lack of sufficient roof space to install solar panels.

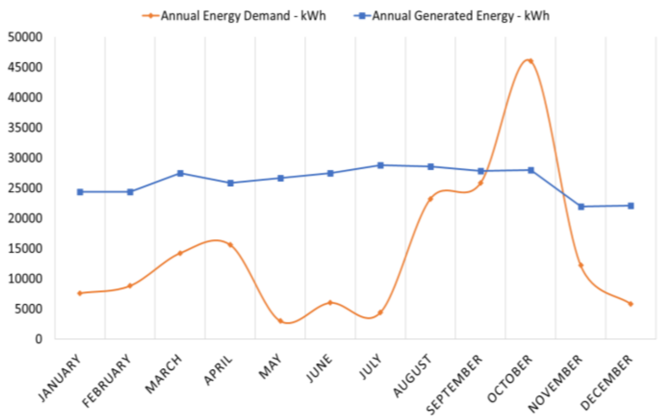

Figure 4. Comparison of generated energy and energy demand of Abdulelah School

Table 7. Yearly net bill over the lifecycle for the selected schools (SAR)

Year	Anas Ibn Malek Primary School	Buraidah High School	Prince Abdulelah High School
1	2026.38	7229.73	799.11
2	1966.27	6909.46	666.79
3	1906.49	6590.96	535.21
4	1847.04	6274.20	404.34
5	1787.92	5959.19	274.20
6	1729.12	5645.91	144.77
7	1670.65	5334.36	16.06
8	1606.39	5024.52	-111.95
9	1531.98	4716.38	-239.25
10	1457.97	4409.94	-365.85
11	1384.37	4105.18	-492.18
12	1311.18	3802.10	-662.51
13	1238.39	3500.69	-831.91
14	1166.00	3200.93	-1000.38
15	1094.01	2902.82	-1167.92
16	1022.41	2606.35	-1334.54
17	934.65	2311.52	-1500.24
18	843.47	2018.30	-1665.03
19	752.79	1726.70	-1828.92
20	662.61	1436.70	-1991.90
21	572.92	1148.29	-2153.99
22	483.73	861.47	-2315.19
23	395.03	576.23	-2475.50
24	306.81	292.56	-2634.93
25	219.08	10.45	-2793.48

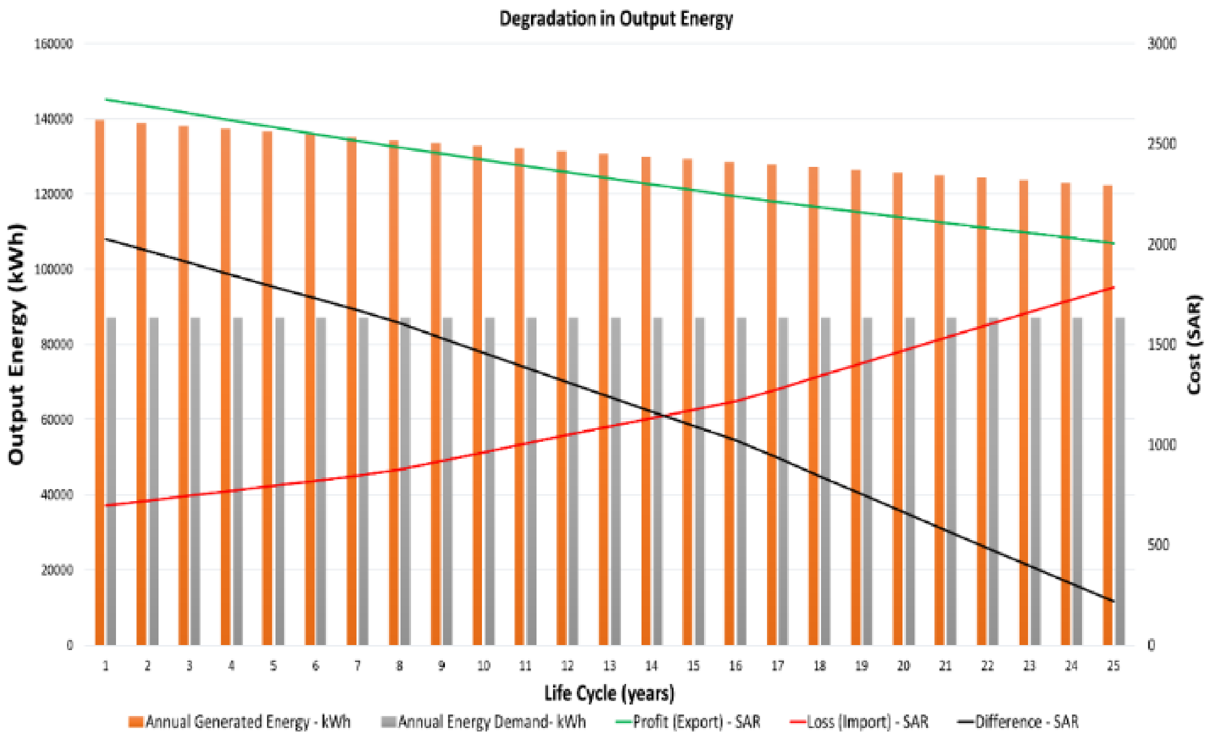

Figure 5. Variation of the annual net bill and the generated energy over the project lifecycle for Anas bin malik School

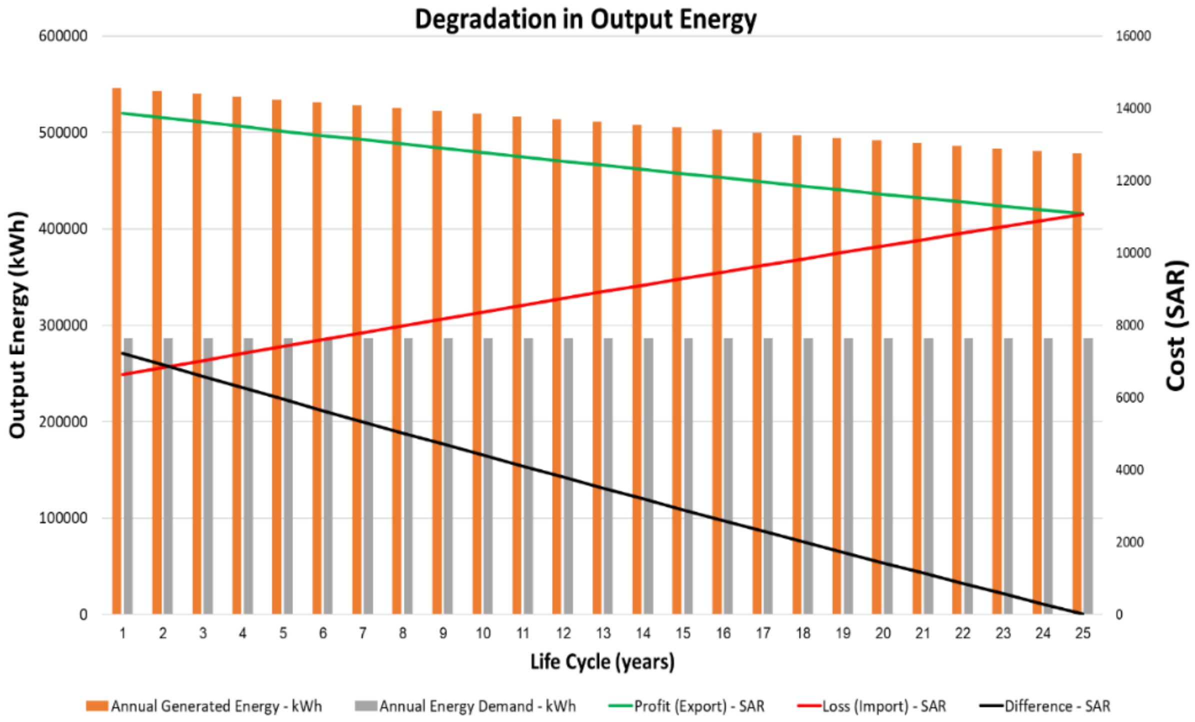

Figure 6. Variation of the annual net bill and the generated energy over the project lifecycle for Buraydah high School

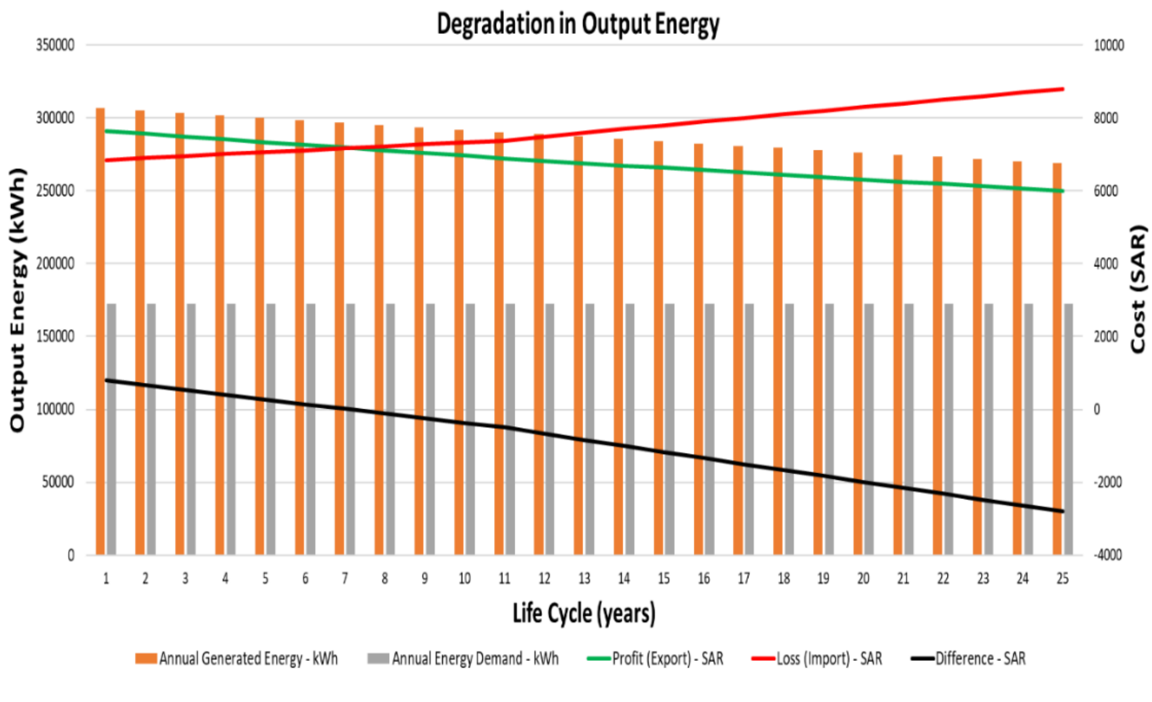

Figure 7. Variation of the annual net bill and the generated energy over the project lifecycle for prince Abdulelah School

Concerning the performance indicators of the solar system month-wise of selected schools, the yield factors are associated with the generation of energy by the capacity of the system and PV system. As shown in Figure 8, Figure 9, and Figure 10. The yield factors of all schools were between 137.45 and 180 kWh/kW over the whole year. Meanwhile, the capacity factor was between 18.62 percent and 24.25 percent. The outcomes of the performance ratio for the three systems were between 83 percent to 92 percent. In general, these indicators are reasonable and encourage the use of these three PV systems. The similarity in performance indicators between the three schools under study is because all the schools use the same PV module and have the same meteorological data; additionally, they differ in energy demand, which affects the size of the PV system but does not affect any of the performance indicators.

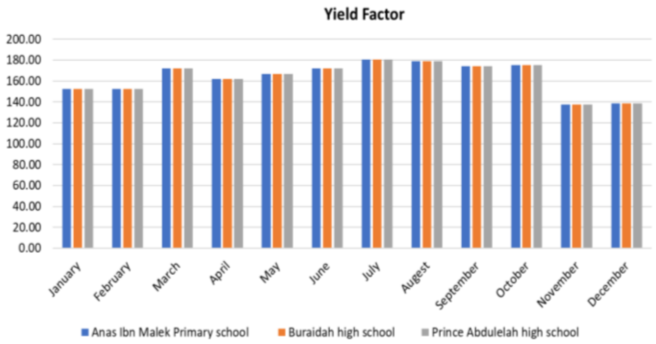

Figure 8. Variation of monthly YF for the schools under study

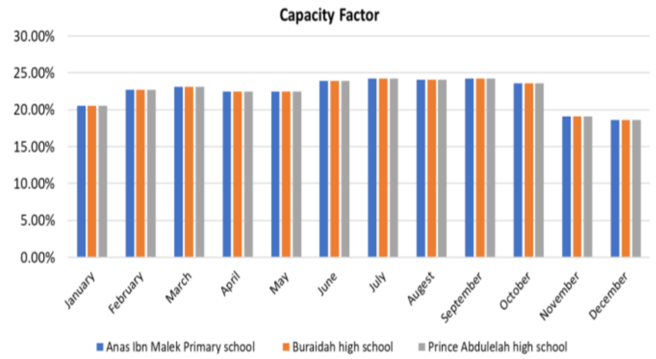

Figure 9. Variation of monthly CF for the schools under study

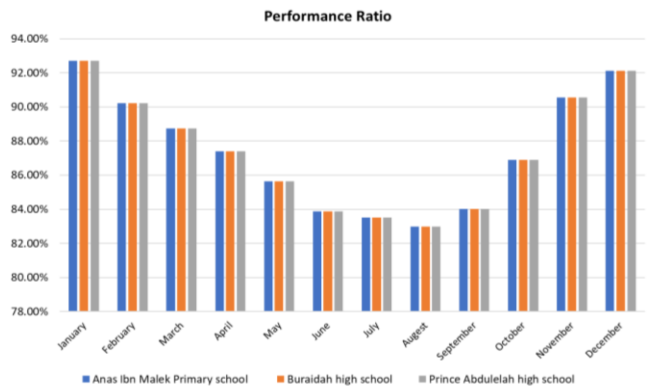

Figure 10. Variation of monthly PR for the schools under study

4.1 Economic analysis

Table 8 shows the total amounts utilized in these schools. There was a small difference among the schools considering the values of LCOE. These differences are a result of the PV system size in every school, which shows the system's lifecycle cost and the generation of energy during the lifecycle of the system. Hence, the LCOE is directly linked with the PV system's cost of lifecycle, and it is not directly linked with the PV system's overall efficiency. The payback time generally depends on investments that were made initially and savings annually because of the avoided bills of electricity of the provider of the services after employing the PV system.

Table 8. Economic indicators (all costs in SAR)

Indicator	Anas Ibn Malek	Buraidah High School	Prince Abdulelah
Total initial cost	258902.49	1012073.37	568800.93
Periodic Costs for Maintenance/Operation	18907.18	18907.18	18907.18
Periodic Costs for Inverter (once time)	12879.36	50346.58	28295.56
Salvage Value (30% of initial cost) after 25 Years	14002.22	54735.96	30762.46
Lifecycle cost (LCC)	276686.80	976592.74	582980.81
Levelized Cost of Energy (LCOE) - SAR/kWh	0.0846	0.0763	0.0811
Payback Time (undiscounted) - Year	8.40	9.78	9.21
Payback Time (discounted) - Year	13.47	17.46	15.68

Based on the preceding findings, we conclude that a grid-connected PV system is especially beneficial for government schools; in general, the use of such a system prevents excessive consumption during peak hours, helping to reduce the peak demand of the service provider and supply surplus energy to the grid. This thesis achieved a zero bill for the Anas and Buraydah Schools for the lifespan of the grid-connected solar energy system. However, Prince Abdulelah School did not reach the study target owing to excessive consumption and a lack of suitable space for the addition of solar panels. The consumption of buildings is rationalized by disseminating and developing knowledge of the significance of rationalizing consumption in an affordable manner and replacing electrical equipment with energy-efficient equipment, particularly air conditioning, which is highly effective. If these strategies are used, they will provide considerable and positive savings in terms of lowering consumption bills and the possibility of reducing the size of the solar energy system, thus lowering the cost bills of the components.

5. Conclusion

The study examines the utilization of the grid-connected PV system for public schools in Buraidah city to achieve an annual zero-bill. The research revealed that rooftops of schools are large and have sufficient space; hence, installing grid-connected PV systems will not just lower the bills of electricity and costs of government but also reduce the need for utilization of fossil fuel to power technologies. With the help of mathematical calculation, economic and performance indicators, which include yield factor, capacity factor, and performance ratio, were obtained. Based on the findings, the current study concluded that the PV system is significantly beneficial for public schools. The utilization of these systems avoids high energy consumption during peak hours, facilitating the reduction of the need for electrical energy from the service providers. The study achieved zero bills for Buraydah and Anas School for PV system lifespan. However, Prince Abdulelah School does not achieve the target of the study due to the lack of space for installing more solar panels. Deploying grid-connected PV systems in governmental schools in a wide range across the country will result in many benefits:

- Reducing the bill paid annually for energy as a result for the big reduction in energy demand of school, which will be reflected on the annual budget of education ministry.
- Deploying grid connected PV systems in schools may be considered as small distributed generation units which will provide some benefits to the utility grid, including: reduction in the power losses due to the energy is generated near the place of consumption, increasing the power supply security due to the variety of energy sources, enhancing the grid resilience.
- Also, it can potentially shave off the peaks in the energy demand, especially in the summer period due to air conditioning loads; this will remove the need to build a new peaker power plant.
- From a financial point of view, deploying grid-connected PV systems in schools will result in delaying major investment in building new power plants, upgrading a substation, or building new transmission lines.
- From an environmental point of view, deploying grid connected PV systems in schools will leads to significant reduction of greenhouse gas emissions especially Carbone dioxide due to burning fossil fuels.

The results of economic and performance analysis revealed the professionality of installing grid-connected PV systems in government schools.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically concerning authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere in any language.

Data availability statement

The manuscript contains all the data. However, more data will be available upon request from the authors.

Conflict of interest

The authors declare no potential conflict of interest.

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