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Techno-Economic Impact of Grid-Connected Rooftop Solar Photovoltaic System for Schools in Palestine: A Case Study of Three Schools

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ABSTRACT

The application of the On-grid photovoltaic (PV) power systems is currently experiencing significant increase and expanding vastly as an alternative source of energy provider for different buildings in Palestine. In the Palestinian territories most of the electricity is provided by the neighboring countries which imposes burden on the Palestinian economy due the insecurity of the electricity supply and fluctuation in its tariff especially in the last years. Palestine is very rich in the solar resources with an annual average of 5.4 peak sun shine hours and has a great potential for PV powered projects, this paper presents a 12-month-long performance evaluation of the 7.68 kWp grid-connected PV systems on the rooftop of each of the three schools in Palestine: Al-Razi Boys School, Almueh Boys School and Khawleh Bent Al Azwar Girls. The performance of implemented PV systems show that the average performance ratio (PR) was 78%, the average annual energy produces by each system equal 10.930 MWh/year. The results of economic analyses are encouraging to intensify the use of such PV school systems since the payback period of such a system is <5 years, the cost of kWh produced is around 0.1 US $, the internal rate of return around 20%. Besides these results, this paper presents also the impacts of PV school systems on the electric grid represented in decreasing the losses, and raising the voltage level, and the effect of PV systems on the environment.

Keywords: Photovoltaics, Grid-Connected Photovoltaics system, Economic Feasibility, School Buildings, Palestine
JEL Classification: Q24

1. INTRODUCTION

Palestine is a developing nation in great need of all types of energy for economic growth and human development. Most Palestinian people have access to electricity, but there are unusual constraints on energy development in the West Bank and Gaza. Palestine has no developed domestic energy resources, and relies heavily on imports from Israel (Juaidi et al., 2016).

Palestinian Authority ratified the "Palestinian Renewable Energy Strategy" which aims at producing 130 MW of electricity by year 2020, grid connected photovoltaic (PV) system is one of the PV technology where an electricity generating by solar panel is connected to the utility grid. Utilizing of grid connected PV systems on systems on ground or on the roofs of buildings started to spread in Palestine since 5 years due to decreasing the PV price and creation of governmental regulations supporting the use of renewable energy (Ibrik, 2008).

The rooftop solar PV systems for schools will provide several benefits for Palestinian economy, such projects will create significant savings in the cost of electricity bills for schools, it will cover part of the schools' expenses, also will creating awareness of green power in public schools and weaving sustainable energy practices into Palestine's teaching environment, also such projects will generate benefits for Palestinian electricity distribution companies and municipalities by making electricity available at lower costs than what is currently available from

Israel, in addition to reducing technical losses and at the national level, such systems will brings Palestine closer to energy independence and strengthens the country's commitment to renewable energy.

The Palestinian Ministry of Education and Higher Education developed a national program to deploy solar PV systems on the rooftops of public schools in Palestine as in Figure 1. The Schools Rooftop Program is covering around 500 public schools in a geographically diverse area across Palestine. Taken together, the rooftop program is having a total generation capacity of 35 MW (Palestine Investment Fund, 2018). The electricity produced from the program will cover the involved schools' electricity bills, based on a net metering scheme. The excess electricity will be sold to Palestine's electricity distribution companies at competitive rates. Projections for the program show that electricity prices from this program will be five percent less than current medium-voltage prices on the Israeli market.

For most schools, the decision to install PV systems is more about education and inspiration for their students than about cost savings. The students get a first-hand view of energy technologies. Integrating the data supplied by the PV systems into the school curriculum helps students learn about how solar electricity works and involves them in the study of the benefits of renewable energy and energy efficiency. The PV system also provides students with an opportunity to learn first-hand about employment opportunities in emerging renewable energy technology fields. (National energy Education Development, 2017).

The present analysis is aimed:

- To assess and define the solar resource potential at different cities in West Bank, Palestine.
- To predict the performance of 7.68 kWp grid-connected rooftop solar power plant using PV system software program.
- To compare the annual energy yield, PR and energy yield of the PV system from simulation results.

2. SYSTEM DESCRIPTION

The system proposed to install 7.68 kWp on the rooftop of each three schools in order to evaluate the feasibility of such installations in Palestinian schools. The PV cell material chosen is mono-crystalline because of the higher efficiency. The system is of fixed stand type and can sufficiently power a schools with required electrical energy.

The grid connected PV system, consists of solar arrays to absorb and convert sunlight into electricity, a solar inverter to convert DC current to AC current, a mounting, cabling and other electrical accessories. Schematic of the grid connected PV system is shown in Figure 2. The main component for grid-connected solar PV power systems comprise of:

- Solar PV modules, connected in series and parallel, depending on the solar PV array size, to generate DC power directly from the sun's intercepted solar power.
- Grid-connected DC/AC inverter, making sure the generated and converted AC power is safely fed into the utility grid whenever the grid is available.
- Grid connection safety equipment like DC/AC breakers fuses etc., according to the local utility's rules and regulations.

2.1. Selected Pilot Cases for Installing PV on the Roof-Top of Three Schools

Al-Razi Boys School is located in Qalqilia – Palestine, with geographical coordination: Lat: 32°11'41.23"N, Long: 34°58'19.48"E, the school is not surrounded by high buildings from the south, so there is no object may cause shadow on system as shown in Figure 3.

Al-Umeh Boys School is located in Al-Ram – Palestine, with geographical coordination: Lat: 31°50'50.28"N, Long: 35°13'52.84"E, the school is not surrounded by high buildings from the south, so there is no object may cause shadow on system as shown in Figure 4.

Khawlah Bent Alazwar girls school is located in Albireh – Palestine, with geographical coordination: Lat: 31°54'14.63"N, Long: 35°12'52.05"E, the school is not surrounded by high buildings from the south, so there is no object may cause shadow on system as shown in Figure 5.

2.2. System Design

The main target is to design and install 7.68 KWp solar PV on the rooftop of each school, Components of the chosen system are illustrated in Table 1.

The specification of PV system effects on the operation of whole systems. The characteristics of the PV panel are summarized as in Table 2.

The PV array in each school connected to inverter through DC distribution board, the inverter specification as in Table 3 (Energy Research Centre-ERC, 2017).

For this on-grid system we used grid-tie inverter which will take the reference input (voltage, frequency and phase angle) from utility grid. The data is recorded and collected, then analyzed to evaluate the performance of PV system.

Figure 1: Solar photovoltaic system public school programme in palestine

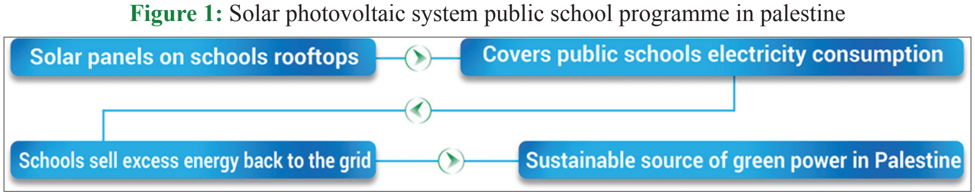


Figure 2: Elements of photovoltaic system for each selected school

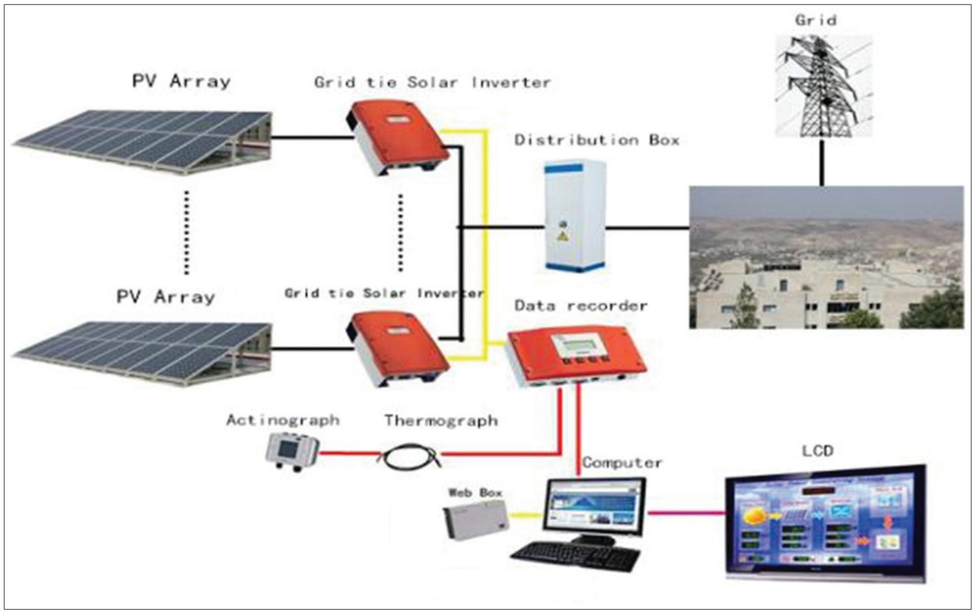


Figure 3: Al-Razi boys school top-roof building

Figure 4: Al-Umeh boys school top-roof building

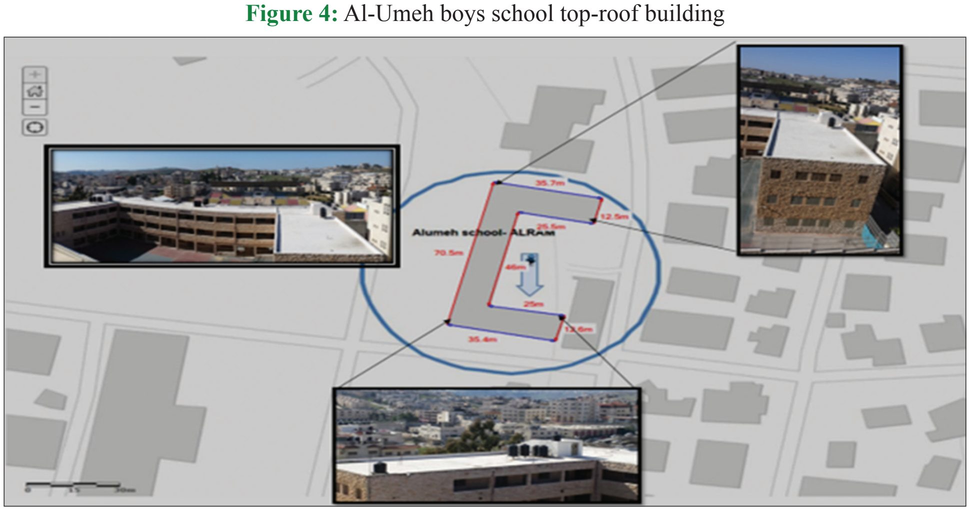


Figure 5: Khawlah Bent Alazwar girls school top-roof building

Table 1: The components of On-grid PV system on the roof of each school

Item#	Category	Description of item(as offer)	QTY
1	PV	PV modules 320 Wp-24 V	24
2	Inverter	Grid Interactive Inverter, single phase	3
3	Monitoring	Real time monitoring system (data logger) with on-line screen unit	1
4	Meter	Bi-directional three phase meter with time discrimination and indirect measure using current transformers	1
		Three phase electronic meter 400 V	1
5	Fire extinguisher	Fire extinguisher system	1
6	Surge protection	Surge protection device I max=15 KA, 400 V, including circuit breaker	1

PV: Photovoltaic

Table 2: Characteristics of the selected PV panel

PV array with tilt angle=32°	
Number of panel	24
PV brand	Amerisolar
Model no.	AS-6M 320
Wp/panel	320 Wp
Voltage at maximum power (Vmpp)	37.1
Current at maximum power (Impp)	8.63
Open circuit voltage (Voc)	45.7
Short Circuit Current (Isc)	9.0
Panel efficiency (%)	16.49
Cell type	Poly-crystalline
Panel dimension (m)	1.956×0.992×0.05m
Panel area (m^2)	1.94
Panel weight (Kg)	27

PV: Photovoltaic

Table 3: Characteristics of the selected inverter

Brand	Astronergy
Model no	CHPI 5KTL-M2-4.57 kw
Inverter type	Single phase
Number of independent MPP inputs/ string per MPP	2/2
Max DC power	5000 W
Max AC power/rated	4600 W
DC MPPT Range/Input voltage range	175-550 V
Max input current (DC)/string	15 A/15 A
Rated AC power (W)	10,200
AC voltage range	180-280
Max output current	23 A
Efficiency (%)	96.5%
Weight	24 kg
No. of inverter per project site	3

PV: Photovoltaic, AC: Alternating current, DC: Direct current, MPP: Maximal power point, MPPT: Maximum power point tracking

2.3. Simulation of PV Systems using PV System Software program

In order to evaluate the design and performance of grid-connected PV system, a simulation tool called PV system has been used in research (Shahhoseini and Abbasi, 2018). This software is generally considered to be a powerful and comprehensive program. This software is commonly used for design and simulation of solar power plants, including grid-connected systems. In addition, this simulation tool can prove useful to calculate economic and environmental indicators.

In the following, the intended systems has been analyzed in technical and economic terms and also, considering the location of the building, selecting the best direction for installing the panels in order to receive the highest amount of available solar energy. The expected simulated energy output are shown in Table.4 and Figure 6 (Shuqqo, 2017).

4. TECHNICAL IMPACT OF INSTALLING PV SYSTEMS ON THE ROOF-TOP OF SELECTED SCHOOLS

The PV system installed on the roof-top of each school, with capacity 7.68 kWp, covers area around 40 m^2 with expected energy produced 12 MWh/year, as shown in Figure 7.

4.1. Technical and Performance Evaluation

4.1.1. The energy output versus energy expected

For Al-Razi School, the output real energy versus the expected energy is as in Figure 8.

The total yearly output energy in 2018 was 9940 kWh.

For Al-Umeh School, the output real energy versus the expected energy is as in Figure 9.

Figure 6: The expected output energy from the photovoltaic (PV) systems - PV system software

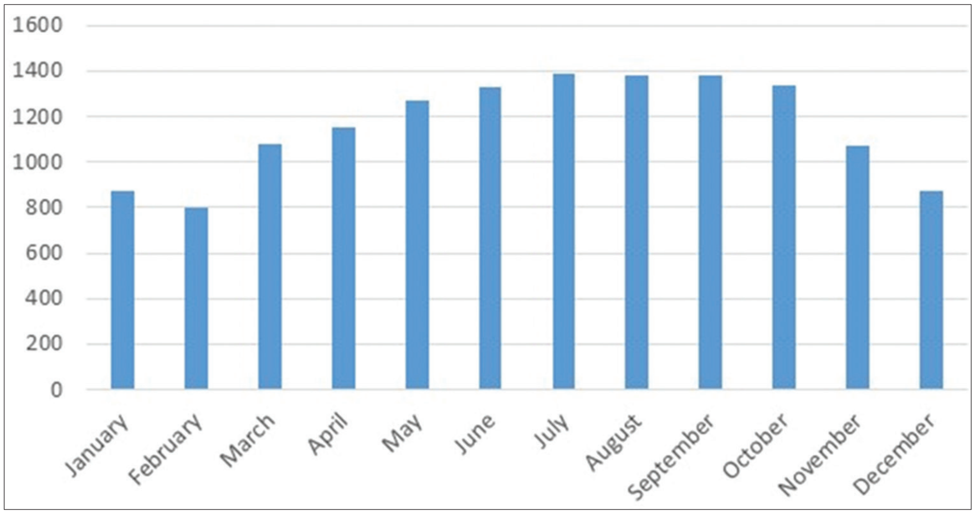
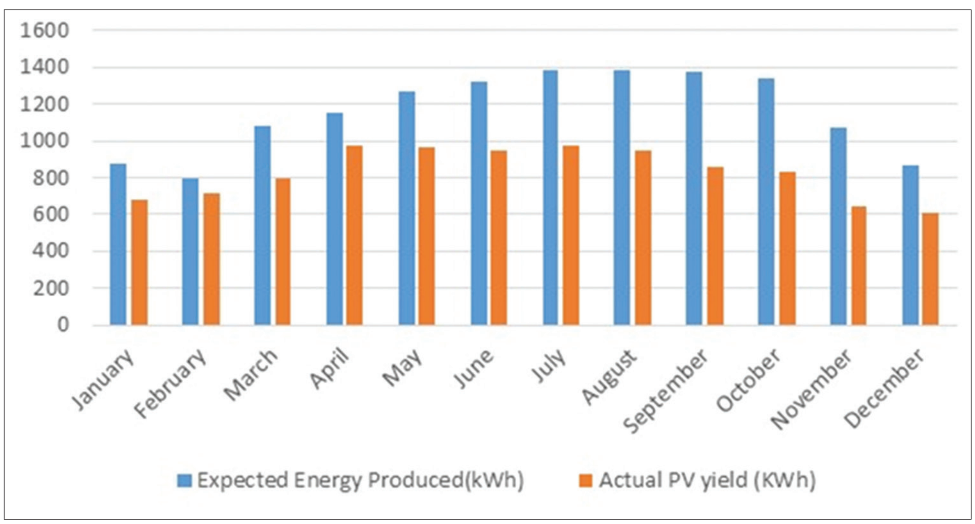


Figure 7: Grid-connected power plants – (a) Alrazi, (b) Khawla Bent ALazwar, (c) Alumeh school

Figure 8: Al-Razi School expected output energy versus actual photovoltaic output in 2018



The total yearly output energy in 2018 was 11270 kWh.

For Khawla Bint Alzwar school, the output real energy versus the expected energy is as in Figure 10.

The output energy generated from the PV system in 2018 was 11584 kWh.

4.1.2. PR of installed schools systems

PR indicates the overall effect of losses on the rated output due to PV module temperature, inverter inefficiency, wiring mismatch, soiling or component failure. It is a dimensionless quantity.

Normally PR varies depending on the location, solar irradiance and climatic conditions. It does not represents the amount of energy produced because a system with low PR in high solar irradiation

Figure 9: Al-Umeh School expected output energy versus actual photovoltaic output in 2018

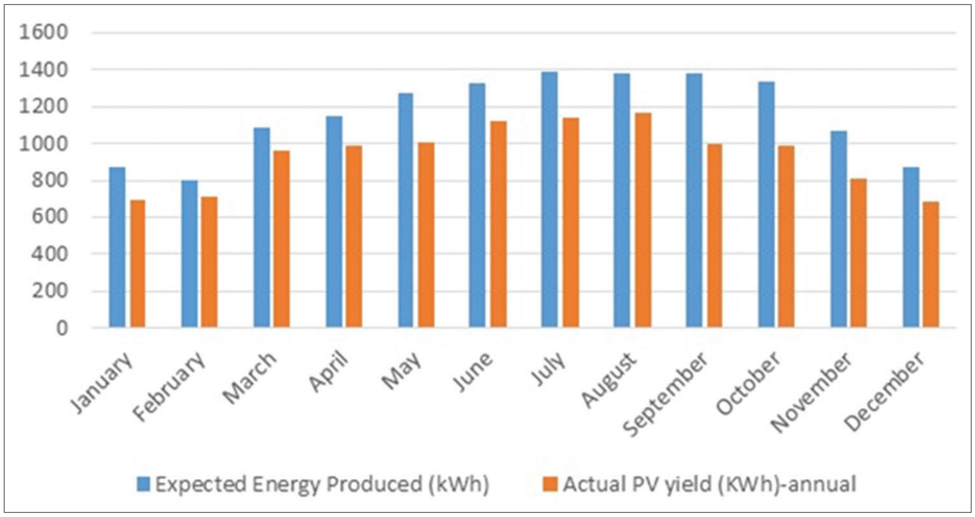


Figure 10: Khawla Bint Alzwar school expected output energy versus actual photovoltaic output

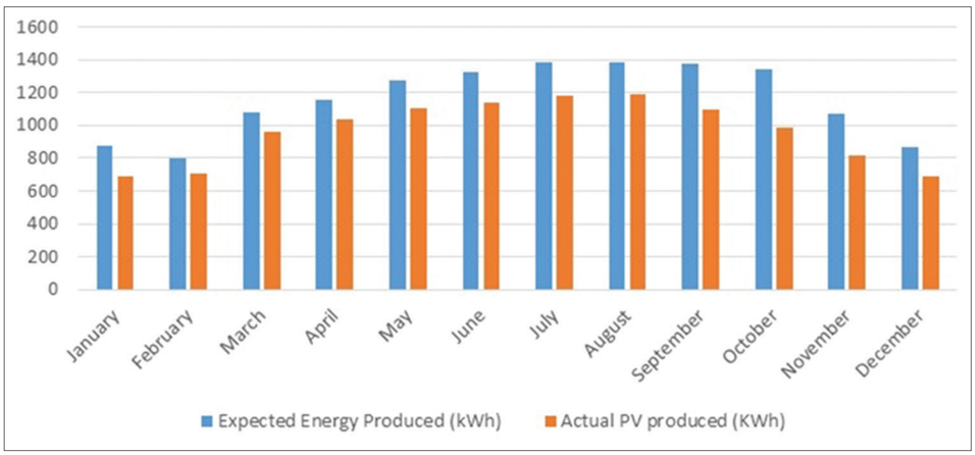


Table 4: PV expected monthly outputs energy-PV system simulation

Month	System expected monthly output (KWh)
January	872
February	800
March	1082
April	1152
May	1272
June	1326
July	1388
August	1381
September	1378
October	1340
November	1072
December	869
Total	13932

PV: Photovoltaic

area may produce more energy than a system with high PR in a low solar irradiation location (Meredith, 2017).

The PR can be calculated by using the following eq (1):

$$PR = \frac{\text{Actual energy generated by PV system (kWh)}}{\text{Energy produced by system at STC (kWh)}} \quad (1)$$

To get accurate evaluation, the data was evaluated yearly for the targeted sites, and PR was different according to variation of radiance, system losses.etc.

The PR of selected three scholls are illustrated in Figure 11.

Average yearly PR for: Al-Razi: 0.72, Al-Umeh: 0.81, Khawla: 0.83.

4.1.3. Capacity utilization factor (CUF)

The CUF is defined as the ratio of actual annual energy generated by the PV system (Ea) to the amount of energy the PV system would generate if it is operated at full rated power for 24 h per day for a year.

$$CUF = Ea/PVrated*24*365\times100 \quad (2)$$

Where Ea is the annual AC energy output (kWh), PV rated is the rated pf PV system.

The capacity factor for a grid connected PV system is also represented by CUF = (Peak sun hours/day)/24 h/day.

The CUF for three selected schools summarizing in Table.5.

4.1.4. Monthly average electricity generation versus energy consumption

For Al-Razi School, the real energy output for the system vs. load consumption of the building was as in Figure 12.

Yearly actual PV yield = 9940.55 kWh

Yearly building energy consumption = 14196 kWh

The PV system covered about 70% of total energy consumption of school building.

For Al-Umeh School, the real energy output for the system versus load consumption of the building was as in Figure 13.

Table 5: CUF for schools

School	CUF %
Al-Razi	14.7
Al-Umeh	16.7
Khawla Bint Alazwar	17.2

CUF: Capacity utilization factor

Yearly actual PV yield = 11269.9024 kWh

Yearly building energy consumption = 13866.58 kWh

The PV system covered around 81% of total energy consumption of school building.

For Khawla Bint Alazwar School, the real energy output for the system versus load consumption of the building was as in Figure 14.

Yearly actual PV yield = 11583.936 kWh

Yearly building energy consumption = 16010.31847 kWh

The PV system covered about 72% of total energy consumption of school building

4.1.5. Penetration factor for PV systems

The penetration factor of three installed PV systems analyzed each month and the results illustrated in Table.5.

Figure 11: Performance ratio for three selected schools

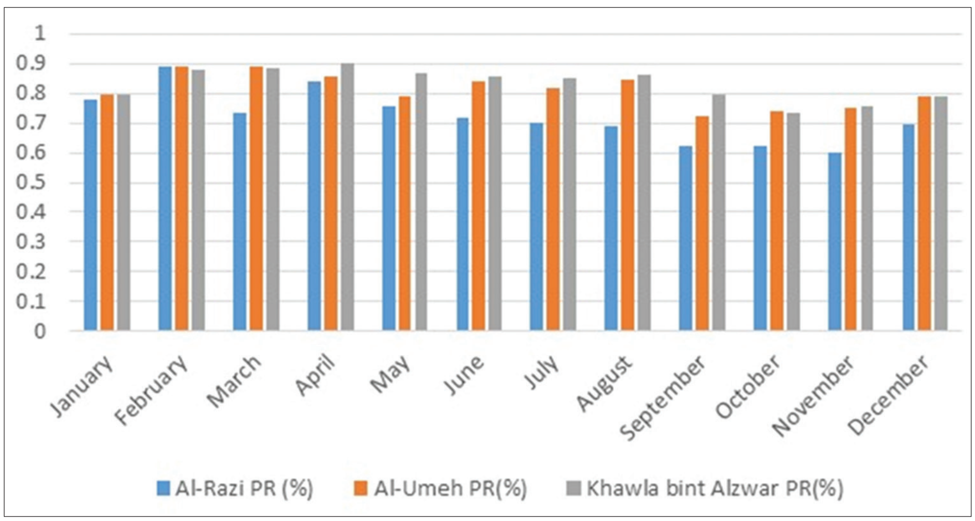


Figure 12: Al-Razi school photovoltaic energy produced versus energy consumption

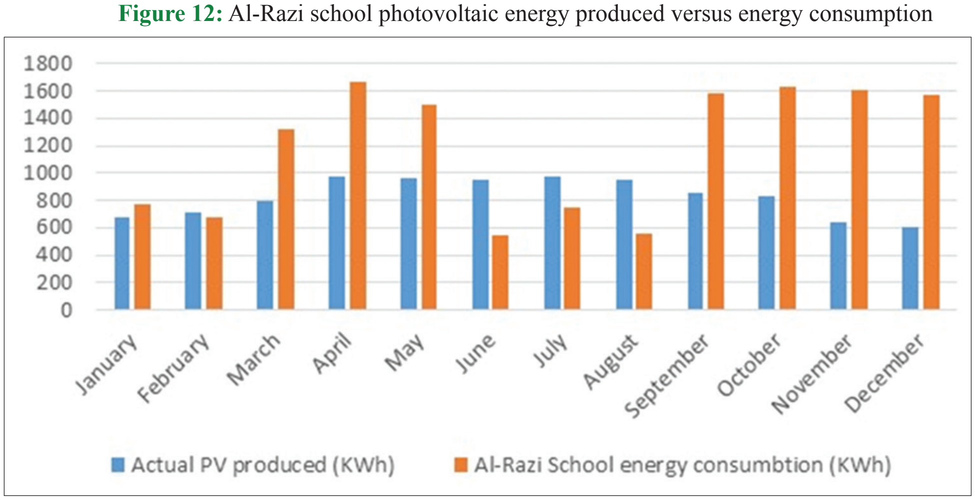


Figure 13: Al-Umeh school photovoltaic energy produced versus energy consumption

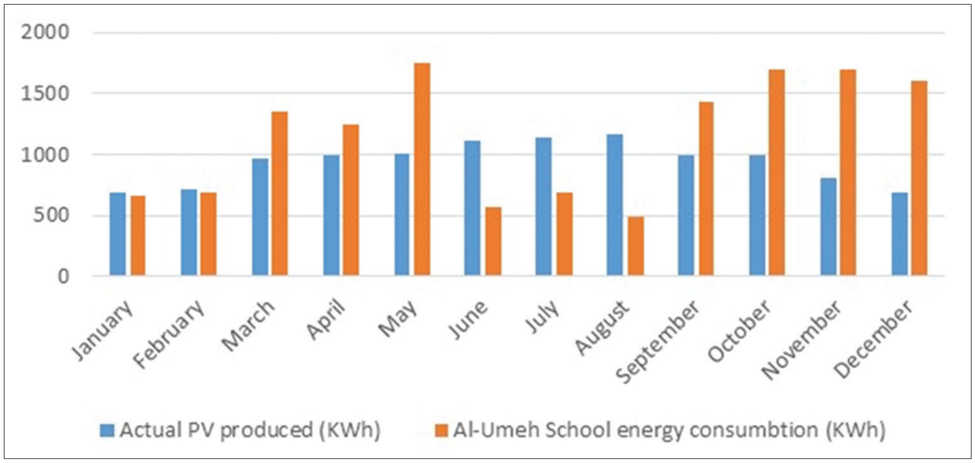


Figure 14: Khawla Bint Alazwar school photovoltaic energy produced versus energy consumption

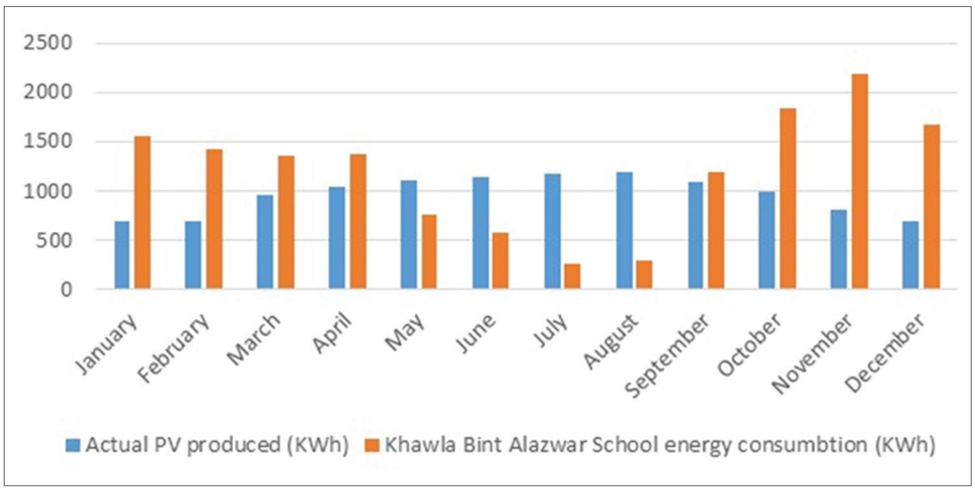
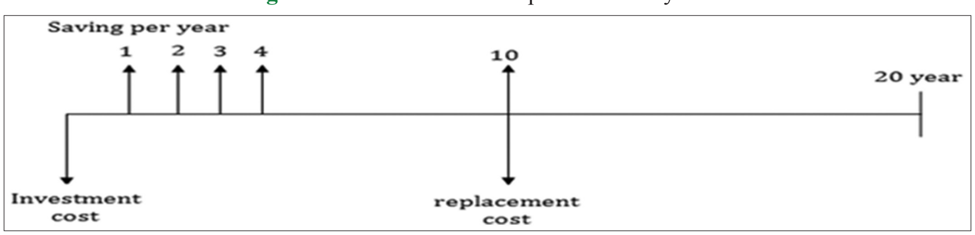


Figure 15: Cash flow for the photovoltaic systems



PV penetration = (Energy produced from PV system)/(Energy consumption) (3)

The penetration factor for the three schools are illustrated in Table 6.

5. PROCEDURE FOR ENVIRONMENTAL AND ECONOMIC ANALYSIS

5.1 Investigating Environmental Results

One of our main aims of establishing On-grid solar plants is to replace fossil fuels with solar energy. Therefore, an important issue to be considered in the discussion on PV systems is environmental impacts. Using solar energy systems contributes to saving non-renewable resources such as coal and reducing greenhouse effects (Augusto et al., 2017). Installation of the PV system in each school will saving an average 832.863 tons of CO_2 which can be of great help to environment improvement.

The CO_2 emission and electricity bills will be reduced according to how much energy producing from the PV solar system since the system operation, as shown in Table.7.

5.2. Economic Impact of PV Installation

Economic analysis is an important part in PV project because it is an indicator for the project recovery and project profit. Several ways can be used to determine the profit of the PV projects. To determine the profitability of installation PV systems in schools,

Table 6: Yearly penetration factor for installed PV systems

Item	Al-Razi school	Al-Umeh school	Khawla Bint Alazwar school
Yearly energy produced	9940.55	11269.90	11583.94
Yearly energy consumption	14196	13866.58	16010.32
Penetration factor	0.70	0.81	0.72

PV: Photovoltaic

Table 7: Environmental result for installed PV systems

System	Energy output (Kwh/Year)	CO2 emission reduction (Kg.CO2) (76%)/Year	Capital cost–system cost ($)
Al-Razi school	9940.55	7,554.82	15730.5
Al-Umeh school	11269.9024	8,565.13	15730.5
Khawla Bint Alazwar school	11583.936	8,803.79	15730.5

PV: Photovoltaic

we preferred to use the payback period method and net present value or net cash flow (NCF) method.

5.2.1. The simple payback period method (SPBP)

The calculation of SPBP describes (in present value terms) how long it takes the project to recover its initial investment. This method depend on annual saving from electricity total bill and the capital cost of PV system, it can be calculated for each school as the following:

S.P.B.P = Investment or capital cost/saving cost per year (4)

Al-Razi School:

Annual AC energy production from installing 7.68 kW PV system was 9940.55 kWh/year and this amount of energy reduced the total bill of electricity with total yearly amount equal 1988 $.

The cost of PV system including the installation was 9730 $, therefore,

S.P.B.P = 9730/1988=4.89 Years

Al-Umeh School, the total yearly energy produced was equal 11269.9 kWh/year, with total saving equal 2254 $.

S.P.B.P = 9730/2254=4.31 Years

Khawla Bint Alazwar school, the total yearly energy production was 11584 kWh/year, with total saving 2317 $, therefore S.P.B.P = 9730/2317 = 4.19 Years.

5.2.2. NET Present Value NPV Method

The NPV value, obtained from an embedded formula from Excel, will tell how much profit the project will generate in present value. The function simply requires cash flow input (NCF) from all years of operation of the solar plant, and cash flow output including capital, maintenance and replacement cost as a negative amount. The discount rate (r) usually in Palestine it can be 8% for solar project (Wentao and Slameh, 2014).

NET Present Value/Cash flow calculation:

Calculation of NPV:

Al-Razi School

Investment cost = 9730 $

Saving-1/year = 1988$/year

Replacement cost (10th year) = 2850 $

i = 8 %, n = 20 years

NPV = Income cash flow–Outcome cash flow (5)

NPV = 1988 (P/A, 8%, 20)–[9730+2850 (P/F, 8%, 10)]

NPV = 1988×9.818–[9730+2850×0.4632]

NPV = 8468.064 (>0) “The project is feasible”

Al-Umeh School

Investment cost = 9730 $

Saving-2/year = 2254 $/year

Replacement cost (10th year) = 2850 $

i = 8 %, n = 20 years

NPV = Income cash flow – Outcome cash flow

NPV = 2254 (P/A, 8%, 20)–[9730+2850 (P/F, 8%, 10)]

NPV = 2254×9.818–[9730+2850×0.4632]

NPV = 11079.652 (> 0) “The project is feasible”

Khawla Bint Alazwar School

Investment cost = 9730 $

Saving-3/year = 2317 $/year

Replacement cost (10th year) = 2850 $

i = 8 %, n = 20 years

NPV = Income cash flow–Outcome cash flow

NPV = 2317 (P/A, 8%, 20)–[9730+2850 (P/F, 8%, 10)]

NPV = 2317×9.818–[9730+2850×0.4632]

NPV = 11698.186 (>0) “The project is feasible”

Roof top solar PV system in schools is feasible and can generate the consumption of schools by installing PV panels on the rooftop, usually these installations at the tail-end of the grid therefore they can enhance grid-stability and reduce power losses in grid “self-consumption”, savings in land requirement for solar installations, and savings in development of new distribution infrastructure because it will reduce the current flow in distribution network, its considered as a good example for distributed power generation sources.

6. CONCLUSION

The impact of implemented PV systems show that the average PR was 78 %, and the average annual energy produces by each system equal 10.930 MWh/year. The results of economic analyses are encouraging to intensify the use of such PV school systems since the payback period is <5 years, the cost of kWh produced is around 0.1 US $, and the internal rate of return around 20%.

It's clear that solar energy is the best option if it can be used in a cost effective manner. Moreover the technology is environmentally sound. So now it is high time for the ministry of higher education to install solar PV on the roof top of all schools to collect the solar energy as the alternative source of electricity for full or partial mitigate of schools demand.

7. ACKNOWLEDGMENT

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