Assessment of Photovoltaic Energy Production at Different Locations in Jordan

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Abstract- Jordan is considered one of the sun-belt countries, which possesses high solar radiation on its horizontal surface. This work presents the energy output of photovoltaic (PV) module for three sites in Jordan; these three sites are Irbid (32° N and 35° E) in the northern Jordan, Amman (32° N and 36° E) in the central Jordan, and Aqaba (29° N and 35° E) in southern Jordan. The paper analyses the solar radiation data and ambient temperature to compare the PV energy output at these sites. The analysis showed that the Aqaba is the optimum location in term of PV energy production compared to the selected study locations. It is found that the annual energy production for a module with 340 W capacities is 502 kWh.

Keywords Photovoltaic, Solar radiation, Energy output, sun-belt countries.

Abbreviations

FF	Fill factor
G	Solar irradiance (W/m^2)
$\mathbf{I_{pm}}$	Current at maximum power (A)
$\mathbf{I_{SG}}$	Short circuit current (A)
NOTC	Normal operating cell temperature (C)
$\mathbf{P_{max}}$	Power at maximum power point (W)
$\mathbf{T_a}$	Ambient temperature (C)
$\mathbf{T_c}$	Cell operating temperature (C)
$\mathbf{V_{ac}}$	Open circuit voltage (V)
$\mathbf{V_{pm}}$	Voltage at maximum power (V)

1. Introduction

Jordan relies on imported oil from neighboring countries, which causes a financial burden on the national economy [1, 2]. Domestic energy resources, including oil and gas, cover only 3–4% of the country's energy needs. Jordan spends more than 7.5% of its national income on the purchase of energy. The levels of energy and electricity consumption will probably double in 15 years. Jordan accounts an average of $15.85x10^3$ ton of emissions, of which CO_2 constitutes around 97%; fossil fuel combustion almost producing 85% by mass of the total GHG emissions [3].

Recently, photovoltaic (PV) systems are being widely used to generate electricity due to its positive features. These features and other advantages make photovoltaic technology as promising one over other generation systems. Examples of these features are PV systems converting the solar radiation into electricity through a simple solid-state device which has a low temperature, no moving parts in the PV systems, low maintenance cost, pollution free, long effective operation life, high reliability and easy to install and operate [4-11, 55-62]. Production power amount from a PV system depends on the available solar energy at the site and the performance of the PV panels. For that, electricity generation cost varies from one site to another site. Therefore, for more electricity generation and environmental profitable PV panels must be installed at sites where relatively higher solar irradiation intensities are available and pollution levels are also high.

The performance of PV systems at different sites around the world are studied by many researchers. Kim et al. [12] study the performance and present economic analysis for two installed photovoltaic systems in different locations in Korea. The performance of a grid- connected Photovoltaic is monitored and studied for a long time in order to improve the PV performance [13-18]. Ayompe et al. [19, 20] presented the measured performance of a 1.72 kW rooftop photovoltaic system in Dublin, Ireland. Many studies presented a solution of the high energy consumption of the world countries, PV can contribute significantly to the reduction of the primary, conventional energy supply, as well as to the reduction of the CO_2 emissions [21-28].

Several researchers [29-33] compared between the roof-mounted PV system and using a PV system within the boundary of the building site to generate electricity which is less favorable because the area outside the building's footprint could be shaded or developed in the future. Thus, it cannot be guaranteed to provide long-term generation.

The energy situation in Jordan presented and discussed the importance of the increasing role of renewable energy technologies in the energy mix in Jordan [34-41]. Badran [42] has studied different solar power technologies. He suggested that the Jordanian government needs to do more serious steps towards the utilization of industrial solar energy for power generation applications in arid regions.

The studies in the above have discussed the energy situation in Jordan and examined the potential of PV energy production at different locations. In this study, the PV energy output at three locations in Jordan is presented. The three locations (Irbid, Amman, and Aqaba) will be studied to estimate the annual energy output per PV module and the reduction in the amount of emitted greenhouse gases. In addition, these estimations are used to determine the best site of PV power plant in Jordan.

2. Locations Data

The three locations in Jordan were investigated in this paper at the north (Irbid), the center of Jordan (Amman), and south (Aqaba) between (35° E and 36° E) latitude and (29° N and 32° N) Longitude and various elevations between 50 and 1120 m. The geographical locations of these stations are shown in Figure. 1. The global radiation which is a combination of direct, diffuse, and albedo radiation [43-46] for the three sites is listed in the table. 1 [47]; these data present the monthly average global radiation on a square meter per day. The data have been recorded for a period of more than 10 years. According to the data obtained from these sites, the summation of global solar radiation available over the year in Irbid, Amman and Aqaba is 1876, 1967 and 2151 kWh/m^{2}respectively. In addition, the monthly average ambient temperature in the daylight of the three sites is listed in the table. 1

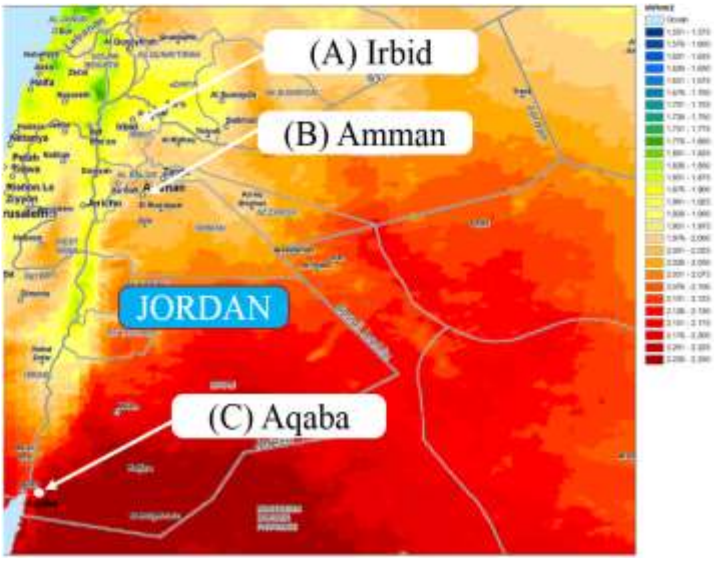


Fig. 1. Distribution of three locations, Pre-selected, over Jordan[48].

3. Estimation Energy Production

The PV system electricity generator is the PV module, which is consists of a number of solar cells and these cells are connected in different ways on a panel. The area of the solar cell is of the order of few square centimeters [49]. The efficiency of the PV module is the main parameter in the system which represents the ratio between the PV power output and the global solar radiation input. Nowadays, PV modules with 20 % efficiency are available in the market with reasonable cost [50-52].

In this work, a SUNIVA (OPT340-72-4-100) PV module with 72 cells is chosen which has a module efficiency of 17.43 %. This module has a maximum power output of about 340 W when the global radiation is 1000 W/m^2 and with an area about 2 m^2[53]. Table. 2 shows the manufacturing specifications of the PV module [53] which are under standard laboratory test conditions (air mass 1.5, irradiance = 1000 W/m^2, cell temperature = 25 °C).

Table. 1 Monthly average global radiation and ambient temperature

Month	Monthly average global radiation ($kWh/m^2/day$)			Average Daily Sunshine Hours			Monthly average ambient temperature (°C)		
	A	B	C	A	B	C	A	B	C
January	5.4	5.5	5.9	6	7	8	9	8	14
February	6.7	6.8	7.1	6	7	8	10	9	16
March	8.4	8.5	8.7	7	8	9	12	14	19
April	10	10	10	8	10	9	16	17	24
May	11	11	11	9	11	11	20	23	27
June	11.4	11.3	11.3	11	13	12	22	25	31
July	11.1	11.1	11.1	11	13	12	24	26	33
August	10.3	10.4	10.4	11	13	12	23	25	33
September	8.9	8.9	9.1	10	11	11	23	26	31
October	7.1	7.3	7.6	9	10	10	21	23	26
November	5.7	5.7	6.1	7	8	9	14	16	20
December	5	5.1	5.5	5	6	7	9	12	15

Table 2 Specifications of the PV module

Characteristics	Value	Units
Maximum power (P_{max})	340	W
Maximum power voltage (V_{pm})	37.8	V
Maximum power current (I_{pm})	8.99	A
Open circuit voltage (V_{oc})	46	V
Short circuit current (I_{sc})	9.78	A
Module Dimensions	1970 x 990	mm
Temperature coefficient of P_{max}	-0.420	%/°C
Temperature coefficient of V_{oc}	0.335	V/°C
Temperature coefficient of I_{sc}	-0.047	mA/°C
Operating Module Temperature	-40 To 85	°C

The maximum power output (P_{max}) of the PV module under the site weather conditions can be estimated by the following equation [54].

$$P_{max(G,Tc)} = Isc(G) \times Voc(Tc) \times FF \quad (1)$$

Where I_{sc} is short circuit current, V_{oc} is open circuit voltage, and FF is fill factor.

The fill factor is the ratio of the maximum actual power output to the theoretical maximum power output. The fill factor is given as:

$$FF = P_{max} / I_{sc} . V_{oc} = (I_{pm}.V_{pm} / I_{sc}.V_{oc}) \times Л r^2 \quad (2)$$

where I_{pm} is current at maximum power and V_{pm} is voltage at maximum power.

It is clear from the Eq. 1 that the short circuit current is proportional to the irradiance (G) and the open circuit voltage is proportional to the cell temperature (Tc). The practical short circuit current and practical open circuit voltage at the site are given as [18]:

$$I_{sc}(G) = I_{sc} \text{ (when } 1kW/m^2) \times G \text{ (in } kW/m^2) \quad (3)$$

$$V_{oc}(Tc) = V_{oc} – 0.0023 \times \text{Number of cells} \times (Tc – 25) \quad (4)$$

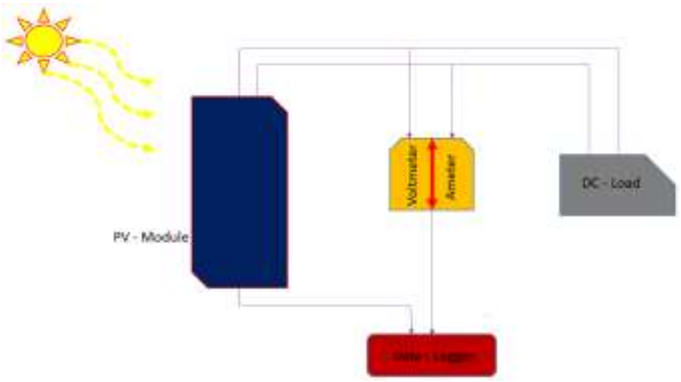
The cell temperature (Tc) is determined by:

$$Tc = Ta + (NOCT -20) /0.8\ G\ (kW/m^2) \quad (5)$$

where NOCT is normal operating cell temperature (usually between 42 and 46 ℃), and Ta is ambient temperature [18].

The PV power output measurement system layout is shown schematically in Figure. 2.

Fig. 2. Measurement system layout



The system consists of PV module connected to digital voltmeter/ammeter device and DC load. The voltmeter/ ammeter device is used to measure the open circuit voltage and the short circuit current. The power of DC load must be equal or greater than the maximum PV power capacity to ensure consumption of all the PV electricity transferred to the grid. The digital weather station is used to measure the ambient temperature and solar radiation at the site. The thermocouples are mounted on the top and bottom surfaces of PV module and inserted between the glasses and the solar cell the PV surface to measure the PV cell temperature and taking the average value of these temperatures. The data of voltmeter, ammeter, thermocouples, and weather station are collected by the data logger and stored in the computer over the year.

4. Results

4.1 PV Energy Output

PV module energy output depends on the available solar radiation at the selected location, ambient temperature at the selected location and the efficiency of PV module. In this investigation, the same PV module is used for the three locations. The main measurement parameters of the PV output are the short-circuit current and the open circuit voltage, the short circuit current is evaluated by Eq. 3 which is proportional to the available solar radiation at the site.

Figure.3 presents the average short circuit current for the three locations during the year, the maximum average short circuit current of Irbid, Amman, and Aqaba are 4.65, 4.28 and 5.51 A respectively, while the minimum average short circuit current are2.03, 2.17 and 2.69 A respectively. The maximum value of average short circuit current for the three locations occurs in June, and the minimum was in December.

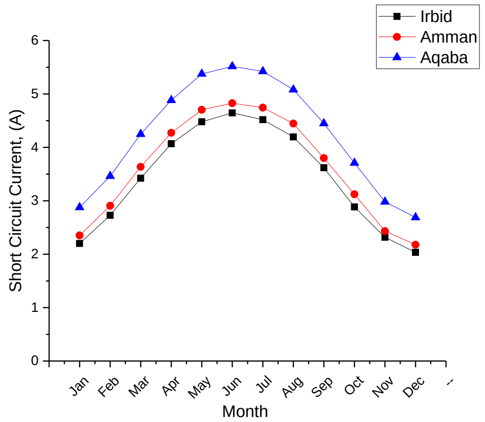


Fig. 3. PV module average short circuit current for the three locations.

Equation. 4 is used to calculate the open circuit voltage. It is clear from the Eq. 4 that the open circuit voltage is affected by the cell temperature at the site, so it should first calculate the cell temperature than calculating the open circuit voltage. To calculate the cell temperatures using the Eq. 5, it is clear from the Eq. 5 that the cell temperature is affected directly by ambient temperature, which is presented in Table. 1 for the three locations.

Figure. 4presents the results of the average cell temperature through the year. The maximum cell temperature of Irbid, Amman, and Aqaba are 60.6, 63.54 and 70.53°C, respectively. Figure.5 shows the open circuit voltage for the three locations through the year. The maximum average open circuit voltages of Irbid, Amman, and Aqaba are 45.93, 45.65 and 45.28 V, respectively, and the minimum are 43, 42.8 and 42.2 V respectively. The maximum value of average open circuit voltage is for the three locations occurring in January because the ambient temperature is minimum, and the minimum value of average open circuit voltage for the three sites occurs in July because the ambient temperature is maximum.

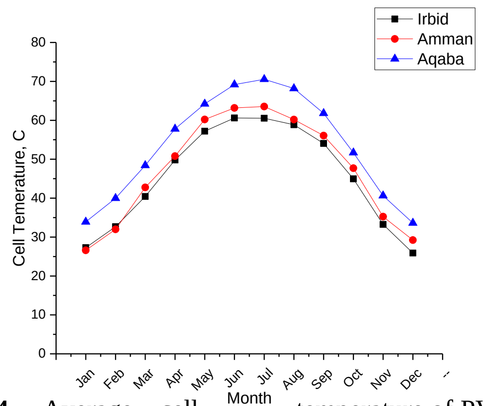


Fig. 4. Average cell temperature of PV module for the three locations

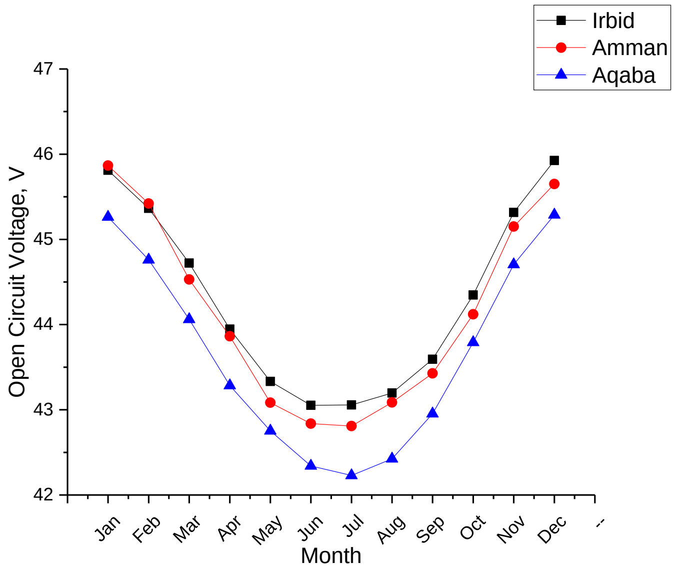


Fig. 5. Average open circuit voltage of PV module for the three locations.

PV module power output under the real site weather conditions can be estimated by Eq. 1. Figure.6 shows the result of power of the PV. It is found that the maximum power for Irbid, Amman and Aqaba can be reached at 151, 153.33 and 175.16 W respectively.

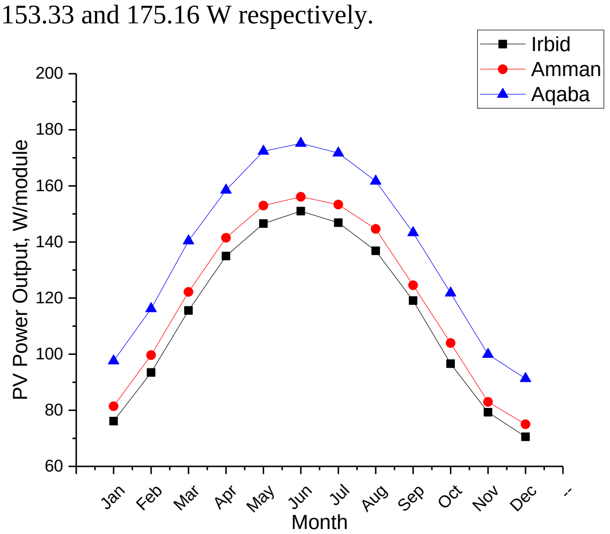


Fig. 6. PV module power output for the three locations

The average daily and monthly PV energy outputs per one module and over the year are estimated and presented in Figures. 7 and 8, respectively. DC that the maximum average daily PV energy outputs of Irbid, Amman, and Aqaba are 1.66, 2.02 and 2.10 kWh respectively, and the minimum are 0.35, 0.45 and 0.63 kWh respectively. Figure 8 shows the monthly PV energy output over a year. The maximum monthly PV energy outputs of Irbid, Amman and Aqaba are 49.83, 60.88 and 63.06 kWh respectively, and the minimum are 10.58, 13.50 and 19.17 kWh respectively.

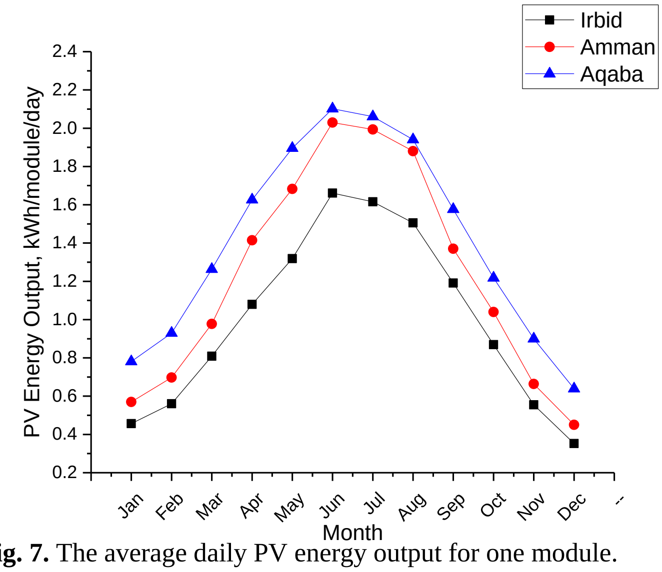


Fig. 7. The average daily PV energy output for one module.

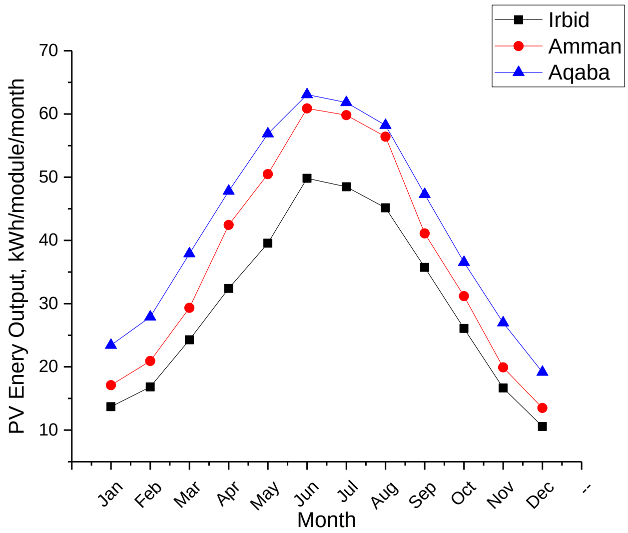


Fig. 8. The monthly PV energy output for one module

In order to determine the best energy output location, one has to determine the cumulative energy output during the year. Figure 9 shows the total cumulative energy output over the year for the three considered locations. The total energy outputs per module for Irbid, Amman and Aqaba are 359.26, 443.11 and 501.97 kWh respectively.

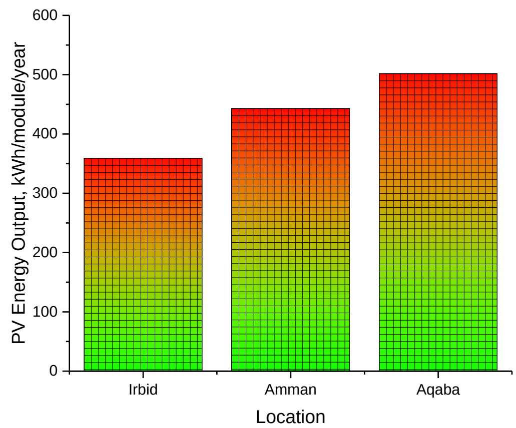


Fig. 9. The annual PV energy output for one module

5. Conclusions

In this work, the performance of a PV module is investigated under three location conditions in Jordan. According to these locations data, the annual global solar radiation available in Irbid, Amman and Aqaba is 1876, 1967 and 2151 kWh/m^2 respectively. The generated electricity per one PV module during the year in Irbid, Amman and Aqaba is 359.3, 443.1 and 502.0 kWh respectively.

It can be concluded that the location with the highest global solar radiation has the best capacity of electrical power generation. On other hand, the location with highest global solar radiation is the best in reducing the amount of greenhouse gases and it is found to be the Aqaba location among the considered three locations in Jordan. For the future studies, it is recommended to investigate all the sites in Jordan in order to figure the best location for such investments as well to make the selection of the system components easier.

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