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# Impact and Recommendations for AHU 2MW PV Plant

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**Abstract**

This study examines constructing a photovoltaic solar system station with 2 MW electricity generation capacities; to supply Al-Hussein Bin Talal University's premises (AHU); which located in the southern part of Jordan. The study examines different proposed design installations and discusses the potential economic impact resulting from this project. Monthly and annual irradiation estimates has been used to calculate approximately the expected energy production in kilowatts hours, other parameters such as size, electric cost, tilt angle, and azimuth angle were also examined. The study is extended to show the economic impact (energy savings, payback period, and return on investment) a solar installation of a 2 MW system size will benefit an institution in the southern region of Jordan (AHU).

## Introduction

Domestic energy resources in Jordan (oil and gas) cover only 3–4% of the energy needs. Today about 97% of consumed energy is still from fossil resources (oil or gas), which costs Jordan about 20% of its Gross Domestic Product (GDP), while no more than 2% of the consumed energy is depending on renewable sources. [1]

Over the 80-90s of last century, Jordan imported most of the country's oil needs from Iraq in preferential prices. After 2003, the political situation has been dramatically changed in the Middle East. Consequently, oil prices risen on international markets and thus, Jordan faced crucial energy difficulties. This situation put further pressure on the Jordanian Government to set up a series of initiatives to remedy the dilemma, and make the country less vulnerable. Based on these records, Jordan's energy master plan is seeking to increase the share of renewable energies to 7% in 2015 and 10% in 2020. [1] [2] [3] [4]

In the same vein, Jordan has an outstanding potential for constructing solar power stations, especially in the southern parts of the country. These parts have an annual direct irradiation of around 2300 kWh/m²/year, and represented by regions of Ma'an and Aqaba (29–30.5vN, 35–38vE). [5]

In order to develop a solar energy station, it is crucial to determine the amount of reduction in the incoming solar irradiance due to the atmosphere. It has been reported that in clear sky conditions, there are various reasons for direct solar irradiance reduction such as: atmospheric scattering cause (9%), surface reflection (6%) and other gases, smoke, dust etc. 3%. [6]

To quantify the economic impact of this project and the expected payback period it is important to explain Jordan's new Renewable Energy Law (REL). According to the new laws issued in 2012, it states that the distributor (National Grid) will make a monthly compromise between the amount of energy (kW/h) that the costumer export and imported from the distributor. If the imported amount is greater than the exported amount, the customer will have to pay the difference between consumption and production for that specific month. While if the exported amount is greater, the distributer will consider the difference as a credit that will be added to the following month and so on till the end of the year. By Dec. 31$^{st}$ in the event that the generated energy exceeded the consumption the National Grid will be obligated to buy the excess for a tariff of 0.12 JD/kWh. [7]

It could be stated that AHU is the largest among all governmental as well as private entities in Ma'an governorate, this is evidenced by a number of indicators, include: total number of employees; total annual budget; total area of constructions and premises; accumulated number of students; and the institutional resources available. Based on these indicators, it could be argued that AHU is a promising area for constructing a solar power station. In this context, opportunities of success in constructing the solar power station at AHU are enhanced by the following facts:

- The location of Jordan in the Sun Belt country, and specifically Ma'an area;
- The availability of plain and continuous land which reduces the foundation cost, (this includes a topography sketch for the University that shows the areas of unoccupied land);
- The orientation of the project's area which implies that the proposed land of the station have a clear south facing without any obstruction in Southern hemisphere;

- University campus and other surrounding premises do not have any polluting industries in the neighborhood that resulting in radiation reduction; and
- Providing opportunities of research and development (R&D) platform for the university's scholars and students, mainly long term activities in the solar system technology.

**Methodology**

For the purpose of the current proposal, data of electricity consumption were collected for all the university's premises, this data were taken from the university computer center. Table 1 illustrates the electricity consumption in kWh for the University during 2011 - 2013.

**Table 1: AHU Energy Consumption**

| Year | 2011 | | 2012 | | 2013 | |
|---|---|---|---|---|---|---|
| **Month** | **kWh** | **JD** | **kWh** | **JD** | **kWh** | **JD** |
| **January** | 270,000 | 23,377 | 277,000 | 36,407 | 238,000 | 42,130 |
| **February** | 240,000 | 20,782 | 286,000 | 37,590 | 236,000 | 41,776 |
| **March** | 270,000 | 23,377 | 272,000 | 35,749 | 254,000 | 44,966 |
| **April** | 239,000 | 20,696 | 247,000 | 32,462 | 242,000 | 42,839 |
| **May** | 375,000 | 32,475 | 260,000 | 34,171 | 224,000 | 39,649 |
| **June** | 286,000 | 24,761 | 333,000 | 53,576 | 275,000 | 48,688 |
| **July** | 376,000 | 46,049 | 359,000 | 63,577 | 356,000 | 63,046 |
| **August** | 292,000 | 38,379 | 258,000 | 45,675 | 251,000 | 49,987 |
| **September** | 318,000 | 41,798 | 353,000 | 62,514 | 279,000 | 69,101 |
| **October** | 322,000 | 42,324 | 342,000 | 60,564 | 234,000 | 57,941 |
| **November** | 260,000 | 34,171 | 251,000 | 44,434 | 235,000 | 58,189 |
| **December** | 299,000 | 39,300 | 272,000 | 48,157 | 265,000 | 65,629 |
| **Total** | **3649,000** | **396,303** | **3510,000** | **554,881** | **3089,000** | **623,944** |
| **Monthly average** | 304,083 | 33,025 | 292,500 | 46,240 | 257,417 | 51,995 |
| **Daily average** | 13821 | 1501 | 13295 | 2101 | 11700 | 2363 |
| **Hourly average** | 1727 | 187 | 1661 | 262 | 1462 | 295 |

The irradiance data used in this study were collected from NASA Surface meteorology and Solar Energy. NASA, through its' Earth science research program has long supported satellite systems and research providing data important to the study of climate and climate processes. These data include long-term estimates of meteorological quantities and surface solar energy fluxes. These satellite and model-based products have also been shown to be accurate enough to provide reliable solar and meteorological resource data over regions where surface measurements are sparse or non-existent. The data collected is global, and reflect a 22 year monthly and annual averages for air temperatures at 10 m above the surface of the earth and insulation incident on a horizontal surface. [8] The outcome from this data has been fed to a solar energy estimator to produce relevant estimates to the amount of energy expected at AHU. [9]

For the purpose of this study, the energy estimates for different orientations and tilt angels for the project location was computed. An overall DC to AC derate factor of 0.77 was used to reflect the expected conditions for that location. shows the assumptions used to reach that derate factor, it is worth mentioning that given the current deserted location of AHU an expect 10% reduction due to soiling is recommended.

**Table 2: Overall DC to AC derate factor**

| Component Derate Factors | Component Derate Values |
|---|---|
| PV module nameplate DC rating | 0.96 |
| Inverter and Transformer | 0.96 |
| Mismatch | 0.98 |
| Diodes and connections | 0.995 |
| DC wiring | 0.98 |
| AC wiring | 0.99 |
| Soiling | 0.9 |
| System availability | 0.98 |
| Overall Derate factor | 0.769 |

A standard 315 Watts DC PV solar panel was used for the purpose of this simulation. The expected lifetime for the panels is 25 year. [10] The average, minimum, and maximum expected energy generation per panel were computed for different azimuth orientations and tilt angels. The system that was chosen for this study is the grid-tied micro-inverters.

Grid-tied inverters are presented in three categories; string, multi-string and micro-inverters (also called AC modules). [11] String inverters are large in nature with high power levels. String inverters introduces many challenges; the high DC voltage presents safety concerns, which require special protection measures, in addition, one weak panel can limit the power output of the whole string since the string inverter optimizes for the weakest link. As much as 50% of the power output can be lost if only one of the solar panels is covered in shading or dirt. On the other hand, multi-string inverters offer partial solutions to string inverter problems, yet they still have similar issues of losing the energy from a number of strings. Moreover, Micro-inverter systems are able to push more power out of a solar system than string inverters. [9] With micro-inverters each panel is optimized to its maximum ppt (power point tracking), and given their current mass production, the prices went down, and the advantages that they bring to the whole installation justifies the minimal expense. It is also worth mentioning here that with micro-inverters, each panel + inverter act as a solar plan of their own, and they can be portable, so in the event were the university needed the space for future projects, the solar system can be redistributed to other regions, without affecting the profitability it brings to the project.

**Results and Analysis**

Figure 1 shows only the average expected monthly generation (where 1 represent January and 12 represent December) for five different combinations, azimuth of 180º and tilt of 30º, 35º, and 25º respectively, azimuth of 190 º and tilt of 30º, and last azimuth of 170º and a tilt of 30º.

These orientations are aligned with the energy consumption of AHU represented in Table 1. The other studied orientations were proved to be out of bound, as the monthly expected energy productions were off, and does not align with the peak demand that AHU needs.

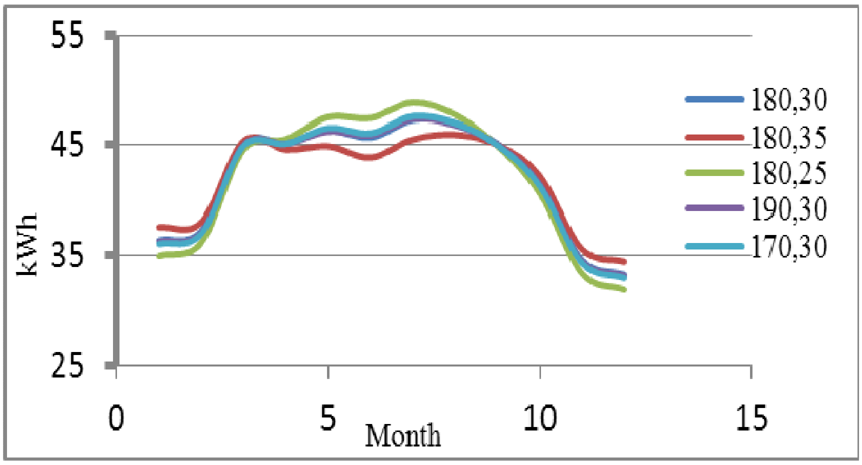
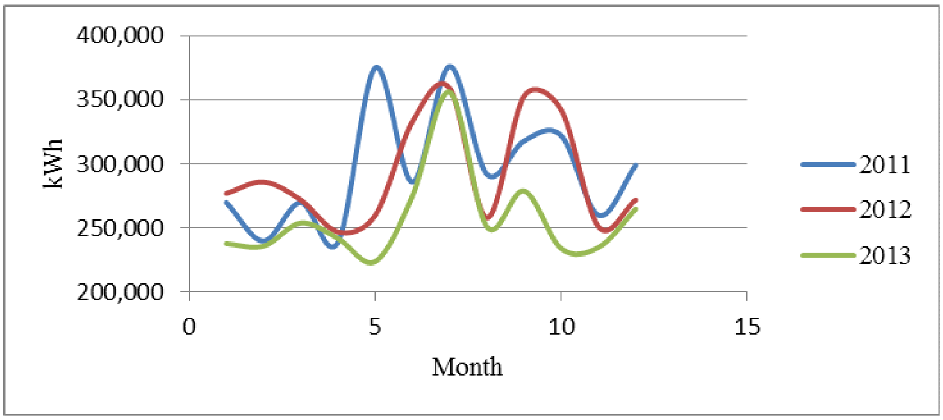
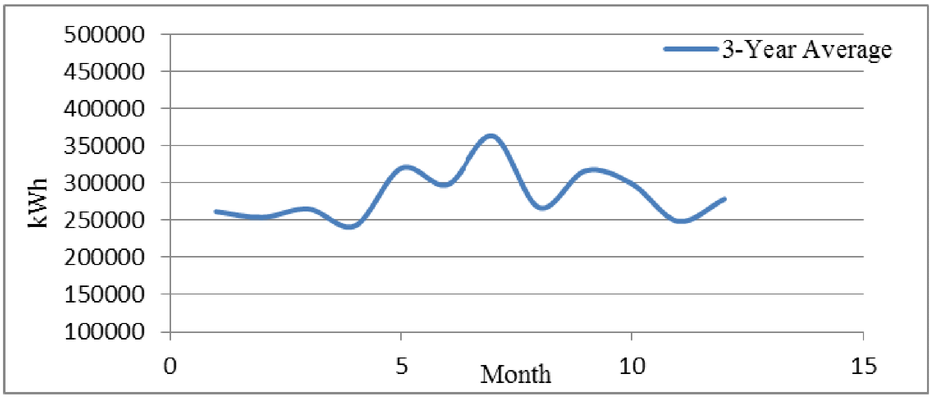



Figure 1: Average monthly expected energy generation

Figure 2 below illustrate the energy consumption for AHU for the three years (part a) and the average over the three years (part b).




(a)




(b)

Figure 2: AHU consumption a) per year b) averaged over the 3 years

Figure 3 below shows the electric bill cost for the years from 2011 to 2013. Looking at the data in Figure 2 and 3, it is clear that the amount of consumption was decreased in 2013 in comparison to the consumption in 2011 and 2012. The degradation is regarded to some procedures the university followed for this purpose, such as replacing most of old light bulbs to electric saving counter parts by the end of 2013.

Even with controlled consumption the electric bill still increased, the reason behind this increase was due to the change in the electric tariffs. The tariffs changed in three main periods, before July 2011, it was 0.0866JD/kWh. From July 2011 to May 2012 it was 0.1314JD/kWh, while the last increment started in August 2013 were the tariff became 0.247 JD/kWh, this represent a total increase of ~ 185%. This increase was due to new governmental policies aiming at suspension of government subsidies for electricity being consumed by all types of entities. It is worth mentioning here that the government is still planning to introduce another increase in 2015.

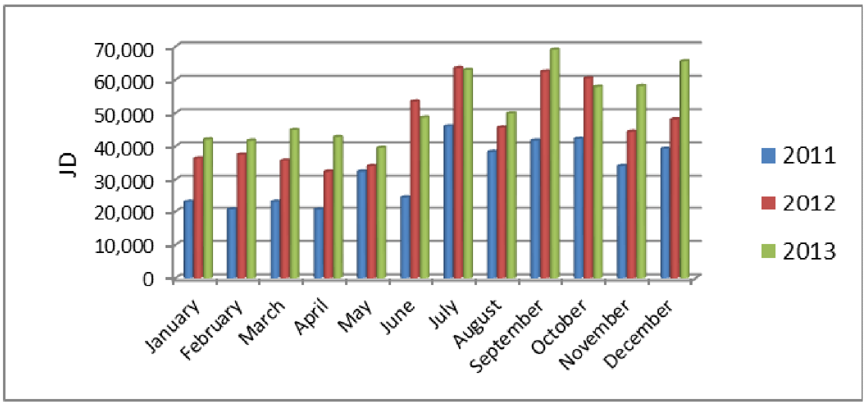



Figure 3: Electric Bill Cost for the years 2011-2013

Looking at Figure 1, it would be concluded that an azimuth of 180 ° and a tilt of 25° produce the most optimal energy production.

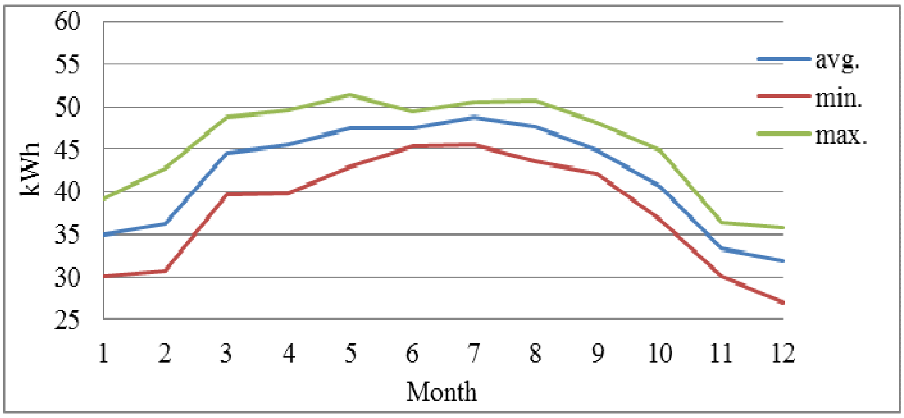



Figure 4: Average, Minimum, and Maximum expected energy production per panel at Azimuth 180 degrees, and tilt of 25 degrees

Figure 4 represent the average, minimum, and maximum energy expected for the combination of choice per panel.

**Project Feasibility**

In order to complete this project it is important to discuss the cost effective of the project. The project finances are based on the initial outlay for the system, where it is paid off over time by the reductions of the electric utility bill; based on the amount of electricity that the solar system generates.

The total cost of a PV system depends on many factors such as, the system size, geographic location, mounting structure, and type of PV module. The average cost for utility-scale ground-mounted systems.

The total numbers of PV panels required (N) for this station equals the total capacity of the station divided by the recommended panel capacity.

$$N = \frac{2MW}{315W} \cong 6349\, panels$$

The expected consumption for the station was founded via multiply the number of panels by the average expected monthly generation at azimuth of 180 ° and a tilt of 25°. The difference between the expected generation and the actual consumption for 2013 were calculated in Table 3. The negative sign indicate the shortage in the generation (which give the amount of kWh the University will buy from the national grid).While, the positive sign indicate an extra power generated.

**Table 3: The difference between the expected generation and the actual consumption for 2013**

| **Month** | **(A) Expected Generation (kWh)** | **(B) Electric Consumption in 2013 (kWh)** | **Diff. Between A and B** | **Accumulated Amount (kWh)** | **Monthly Cost (JD)** |
|---|---|---|---|---|---|
| **January** | 221,873 | 238,000 | -16,127 | -16,127 | 3983 |
| **February** | 229,746 | 236,000 | -6,254 | -22,381 | 1548 |
| **March** | 283,244 | 254,000 | 29,244 | 29,244 | 0 |
| **April** | 289,283 | 242,000 | 47,283 | 76,527 | 0 |
| **May** | 301,822 | 224,000 | 77,822 | 154,349 | 0 |
| **June** | 301,238 | 275,000 | 26,238 | 180,587 | 0 |
| **July** | 310,057 | 356,000 | -45,943 | 134,644 | 0 |
| **August** | 303,022 | 251,000 | 52,022 | 186,660 | 0 |
| **September** | 285,365 | 279,000 | 6,365 | 193,032 | 0 |
| **October** | 257,721 | 234,000 | 23,721 | 216,753 | 0 |
| **November** | 211,587 | 235,000 | -23,413 | 193,340 | 0 |
| **December** | 202,159 | 265,000 | -62,841 | 130,499 | 15660 |

According to Jordan's new REL, the final bill for the University will be calculated by taking the difference between the generated energy and the consumed. In January and February the University will be expected to pay a total amount of 5528JD, while for the rest of the year the expected generation will exceed the University needs. The total amount of accumulated energy the University will supply back to the grid will be 130,499kWh. Depending on the tariff determined in REL; the National Grid will buy this amount at 0.12 JD/kWh. Thus the National Grid will pay 15660JD for the University by the end of December. As a result, it is clear that the University will own an amount of 10,129 JD by end of the year.

Based on the average market price (within the national level), and the offers presented to AHU by different suppliers, the expected cost (Initial Investment) for this project is 2.5 million JD. In order to calculate the Payback Period (PBP) of the current project, data presented in Table (1) previously is used to illustrate the expected annual cash flow. In the same context, the current study assumes that the discount rate is 4.0%.[1] The following formula is utilized to calculate the Discounted Payback Period (DPP). [12]

$$DPP = \ln\left(\frac{1}{1-\frac{O1\times r}{CF}}\right) \div \ln(1+r)$$

Where:
$O1$ = Initial Investment (out flow)
r = Discount Rate
CF = Periodic Cash Flow

Therefore, the Payback Period for the project = 4.376 years[2]. Further to calculating PBP, it is essential to calculate how much ROI (Return on Investment) the project will bring by the end of the investment period. As indicated previously, the proposed system is expected to operate at least for 25 year. The following formula uses to calculate ROI: [12]

$$\text{ROI} = \left[\frac{E}{O1}\right]\times 100\%$$

Where:
E = Net Earnings (Net Return Amount per year)
$O1$ = Initial Investment (out flow)

ROI value equals 25.36% (annually). This result with conjunction of DPP (calculated above) would recommend that the system is highly feasible with the maturity of technology and other resources being available (including the financial resources).

**Conclusion**

Jordan is a rich country in its solar capacities and has a great potential for solar powered projects. This paper presents a study to evaluate the proposed PV power plant planned to offset AHU energy consumption. The energy estimates for different orientations and tilt angels for the project location were computed and as a result an azimuth angle of 180º and a tilt angle of 25º were chosen to produce the optimal energy production.

The payback period calculation confirms that, for lifetime of 25 year, it is feasible to invest in a PV system to offset a great portion of the University energy consumption.

Most universities undergo potential operational expansions, which lead to increased electricity demands. In this regard, it should be indicated that AHU is planning to initiate Phase 3 of its master plan that involves the establishment of new students' residential-halls. Therefore, it is expected that the level of electricity consumption will increase for the coming years, and this in return, implies an increased electricity bill. In this context, future construction plans must take into consideration the power needs, and further study the effect of harsh climate (intense heat, dust…etc) on the system's efficiency. The study presented in this paper only considered PV systems, while there are other solar technologies that need to be investigated for future studies such as concentrated solar power plants, or hybrid systems. Given the university's plans for expansion, it is expected that the power consumption profile will change, and to be able to insure that the university is building projects for the future, it needs to consider performing more studies on energy storage, and utilizing different renewable systems (such as wind energy, geothermal…etc) to offset its power consumption, especially for hours where solar energy is not harvested.

**Acknowledgment:**

[1]The discount rate used in this study (4%) is equivalent to the market interest rate (in average) given on deposits by the local commercial banks.
[2] The simple PBP could be also calculated (without considering the discount rate) as follow: *initial investment/expected cash flow per year* (= 3.95 year).

These data were obtained from the NASA Langley Research Center Atmospheric Science Data Center Surface meteorological and Solar Energy (SSE) web portal supported by the NASA LaRC POWER Project

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