JJMIE

Volume 16, Number 4, September. 2022
ISSN 1995-6665
Pages 567 – 579

Jordan Journal of Mechanical and Industrial Engineering

Performance and Socioeconomics of 1st Wheeling PV Project Connected to Medium Grid in Jordan

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Received 10 Apr 2022 *Accepted 9 Jun 2022*

Abstract

The issue of energy security is becoming very important due to higher standards of living and being the engine for economic development. Hence, recently solar PV systems witnessed high popularity worldwide since it has facilitated the utilization of the untapped potential of solar energy. On-grid PV schemes have become the first option for power generation, among other renewable energy sources, due to low cost of generated power as compared with other systems and short construction time. This paper presents the real performance data of the first large size solar PV project, in Jordan, connected to the medium voltage grid on wheeling basis. The PV station was designed to be installed on south-north axis with an east-west solar tracking system to enhance electrical energy production. The technical specification and calculated design parameters, such as different losses and energy yield, using the commercial software, PVsyst, were reported and compared with real data from the field. The annual electricity yield, in 2019, was about 3954 MWh with an overall performance ratio of 95%, exceeding all expectations. Unfortunately, little attention has been paid by governmental institutions and/or distribution companies, to the general performance of such plants and variation in rates of production. It is deemed that this paper will answer some of critique questions and fill the gap of information related to the performance of PV power stations, connected to the medium voltage network, under local conditions. More work should be aimed to check influencing factors on the performance of other large PV and wind plants in the country.

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Keywords: PV modules, power generation, solar energy, performance, Jordan.

1. Background

Worldwide, all stakeholders including policymakers are keen to increase sustainability and reduce negative environmental impacts resulting from power generation through burning fossil fuels. Such trend could be accomplished by enhancing the utilization of clean, less costly systems such as using renewable energy (RE) sources in various applications. Jordan is considered unlucky, in terms of availability of conventional energy sources and security of supplies. Unfortunately, it suffers from the scarcity of conventional energy sources and being surrounded with all types of political conflicts and armed clashes in neighboring countries. On the other hand, it enjoys high solar radiation and good wind speeds in the western highlands that could be harnessed to generate electrical power, on commercial basis, Abu-Rumman*et al*. (2020). Equally important, being close to oil producing countries, mainly the Kingdom of Saudi Arabia and Iraq, Jordan was totally dependent on oil imports from these countries. Thus, the country was vulnerable to all types of shocks including regional political and armed conflicts, Jaber *et al*.(2015).

During the last decade with the aim of increasing energy security and local contribution of available energy sources, there was a clear shift towards renewable sources. The real of activities of harnessing renewable energy sources were started directly after the approval of the Renewable Energy and Energy Efficiency Law (REEE Law No. 13 for year 2012) in the 2nd half of 2012, Ministry of Energy and Mineral Resources (2012). This new law and its acts and directions aimed to (i) increasing the contribution of RE to the total energy mix in Jordan; (ii) promoting and exploiting RE for environmental protection and sustainable development purposes; and (iii) enhancing energy efficiency in all sectors of the economy. According to Article 10 of this law, rules and regulations to guide implementation of the REEL were issued by the Ministry of Energy and Mineral Resources and the Energy and Minerals Regulatory Commission. Such new legislation framework opened the doors for investors and developers to utilize RE sources and connect to the national and/or distribution grids. Consequently, long list of RE projects, in different regions of the country, are running now on commercial basis, and there are several large wind farm and PV projects are in the pipeline and expected to be

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completed and connected to the grid before 2024, National Electric Power Company (2020). Almost all these projects, upon completion, will be connected to the 132 kV national grid. However, the study in hand is dealing with a mega PV project but connected to the medium voltage (33 kV) distribution grid.

Historically, Jordan is a net energy importing country with nearly 97% of its energy needs supplied from abroad such as crude oil, refined products, and recently natural gas. Such energy scenario will continue in the future but with a small contribution, of around 10%, from renewable sources. In 2019, the total energy demand was around 9.05 million ton of oil equivalent (toe), compared with about 9.71 million toe in the previous year 2018 and 9.00 & 7.35 million toe in 2015 and 2010, respectively, Ministry of Energy, Annual Report (2020). The primary energy consumption dropped by about 7% in 2019 due to slow down of economic activities as a result of the general situation in the MENA region. The 2020 was not as any year, due to the COVID-19 virus. All sectors in the economy were under extreme pressure to mitigate the devastative impacts of the pandemic: further drop in energy consumption due to the general lockdown of most activities except health and some basic services. This situation is expected to continue during the next two or three years, until things settle-down and go back to normal life. Such situation is considered as historic opportunity to revive the economy, and cut down GHG emissions, considering part or all mitigation measures listed in the 3rd National Communication, Ministry of Environment (2014). However, without the highly needed technical and financial assistance from developed countries, donors and international organizations, the Government of Jordan (GoJ) alone will not be able to implement the proposed measures and projects.

1.1. Energy Problem in Jordan

The indigenous energy sources covered only a small fraction, i.e. Jordan produced 0.136 million toe of natural gas and less than $0.12x10^{-2}$ million toe of crude oil. Thus, it is heavily dependent on imported fossil fuels (oil products and natural gas) to fulfill its domestic energy needs in industry, domestic heating, transport and power generation. The latter is considered the main driver for local energy demand, in addition to the transport sector, since these are chief fuel consumers. In 2019, transportation and power generation consumed about 35% and 30% of the total fuel consumption in the country, respectively. Main power stations are owned and operated by local generation companies, as IPPs, industrial self-generation for on-site consumption and a state company, i.e. Asamra. Maximum demand in 2019 was 3380 MW, while the contracted generation capacity was 4332 MW, i.e. 128% of the max demand, and the total installed capacity 5727 MW. Of which 2740 MW (48%) combined cycle plants, followed by renewable energy stations (i.e. 1100 MW solar PV plants, 370 MW wind and only 12 MW hydropower) which represents 26% of the installed capacity. The remaining, 26%, consists of steam (605 MW) and gas (83 MW) turbines as well as Diesel engine (814 MW) power plants (National Electric Power Company (2020), Ministry of Energy and Mineral (2020), Jaber *et al*. 2019). Fig. 1 shows the fuel-mix used to generate electrical power during 2008-2019, with natural gas being the prime fuel. The mix of power plants is based on firing natural gas (80%) as primary fuel and diesel oil or heavy fuel oil (HFO) as secondary fuel, followed by renewables (13%). This year, 2021, it is expected that the newly installed oil shale direct combustion power plant (2x235 MW) in the central part of the country will be commissioned and connected to the national grid. Currently, it is under testing and trial or non-commercial operation. Thereby, avoiding an additional fraction of the current oil and gas imports to the country. As can be seen in Fig. 1, the total generated power, in 2019, exceeded 20955 GWh, of which about 3000 GWh (14.3%) from renewable energy sources dominated by Solar PV (2086 GWh) and wind (892 GWh). While the generated electrical energy from hydropower sources was almost negligible: only 18.5 GWh. The major fraction (85.1%) of electricity generated by firing fossil fuels: 3338, 15.1 and 1.8 thousand toe of natural gas, heavy fuel oil and diesel, respectively, Ministry of Water and Irrigation 2020. It is worth mentioning that 99.8% of the population is served and have access to the electrical grid, even the Syrian refugee camps, Ministry of Energy and Mineral Resources (2020). It is true that, during the past decade, there was a growing interest in developing RE projects, especially those focused to meet self-consumption in various sectors. Either as net-metering system or wheeling basis. Consequently, the GoJ recently revised the regulatory framework to allow aggregation by groups of customers. However, still there are several obstacles that should be eliminated to open the door fully for developers and the private enterprises to invest in utilizing RE schemes for different applications. Currently, the most important barriers are distorted existing electricity tariff due to cross-subsidy, the ultimate authority given to electricity distribution companies regarding renewable energy systems without real monitoring or follow up by the Energy and Minerals Commission, and the imposed limitation on the capacity of wheeling project of 1 MW, Jaber *et al*. (2019). More importantly, is that none of the distribution companies nor the transmission company, i.e. National Electric Power Company (NEPCO), has invested in developing and improving the existing electrical grids to be smart and able to absorb the generated green electricity. Unfortunately, the latter sees renewable energy as a threat to its revenues.

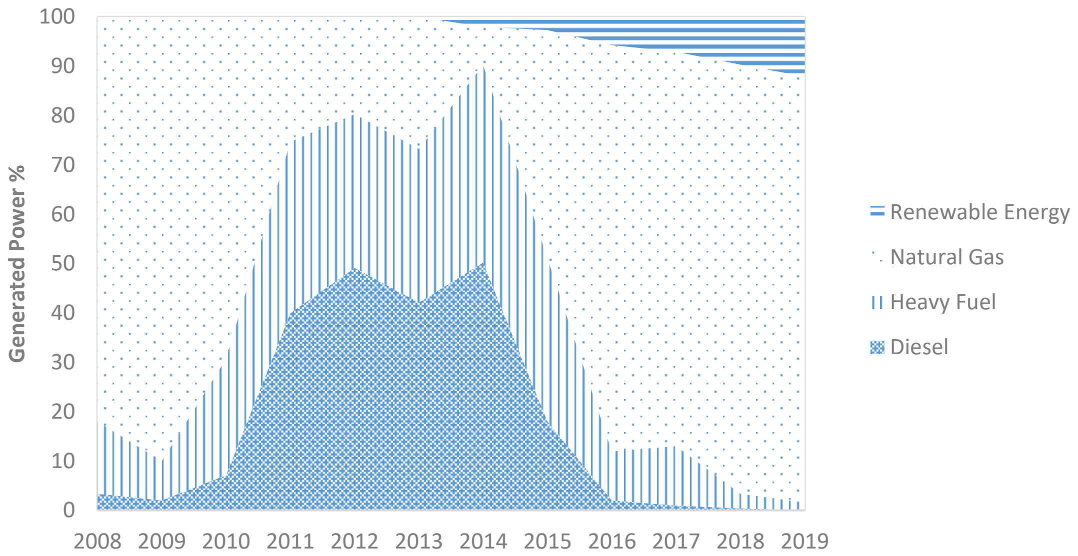

Figure 1. Fuel-mix used in power generation (National Electric Power Company (2020), Ministry of Energy and Mineral (2020), Jaber *et al*. 2019)

2. Introduction

As discussed previously that Jordan used to import all its energy needs as oil, from Iraq and Kingdom of Saudi Arabia (KSA), and natural gas and sometimes electricity, from Egypt, until 2015. Currently, around 14% comes from domestic renewable sources and the country is building more wind and solar power plants. It is planned to produce about 20% of expected electricity consumption in 2025, Ministry of Energy and Mineral Resources (2020-2025). The renewable energy sub-sector in Jordan is deemed to be a driver for job creation on temporary and permanent basis, especially for young technical and non-technical staff. In addition to economic benefits, the environmental advantages are numerous, but mainly the avoidance of burning fossil fuels. Thereby, the direct reduction of GHGs and other emissions. It should be mentioned here that common environmental difficulties and disasters, e.g. desertification and changes in rainfall patterns, have not received enough attention by concerned governmental institutions as well as from different categories of the society. Unfortunately, this is a very serious situation, and it may lead to more of environmental difficulties that would threaten the existence of our lives, such as the depletion of freshwater resources, and the continuous loss of biodiversity, bearing in mind that Jordan is considered the 2nd poorest country in the world in terms of available water resources, Ministry of Water and Irrigation (2020).

Jordan's ability to ensure less polluting, reliable, and low-cost energy sources for its growing economy and population, will require avoiding burning fossil fuels. Furthermore, the country should follow strong policies including technological jumps, in some sectors, such as transport, and more investment in clean energy and energy efficiency. In previously published papers, the role of renewable energy in the 21st century in Jordan was discussed, Jaber *et al*. (2004), and barriers facing utilization of renewable sources, Jaber *et al*. (2015)and energy education in schools of engineering, (Alawin *et al.* (2016), Jaber *et al*. (2017)) as well as knowledge and skill of fresh graduated engineers, Jaber *et al*. (2020). As in other developing countries, the interest was in using solar and wind energy, in particular PV modules, to generate electrical power in various sectors of the economy. Researchers, owners and operators of PV systems have focused their efforts and work on the simulation and direct effect of dust and birds' guano on the performance and the generated revenues Jaber *et al*. (2003) have investigated the integration of PV modules and gas turbine engine to meet max demand. PV system for water desalination Mohsen *et al*. (2001), and PV as sources of energy for residential space heating applications were studied under Jordan conditions, Jaber *et al*. (2008). The integration of PV modules with oil shale industry in central Jordan was investigated by Sladekand Jaber (2016). Repowering old thermal power plants, using steam turbines through employing a concentrated solar system was evaluated, and it was concluded that the payback period is relatively long, Abbas *et al*. (2016). Based on these papers and other reports, it was concluded that the GoJ should concentrate its efforts to help investors and developers working in RE to have access to easy financing long term plans regarding the unit prices of electricity generated via renewable energy sources and the gradual removal of all existing obstacles. Many Jordanian researchers studied the effect of climatic conditions, such as temperature, wind speed, and dust on the performance of PV modules. Since the accumulation of dust coupled with the lack of rain, in the MENA region, especially during the long summer season will reduce the generated electrical power. Saidan *et al.* (2016), have studied the rate of efficiency degradation of the of solar modules and found that the average drop in the productivity due to dust accumulation may reach approximately 6.24%, 11.8% and 18.74% for exposure periods of one day, one week and one month, respectively. Hammad *et al*. (2018), examined the cleaning frequency of PV modules, under local conditions, and reported that the optimal cleaning period is around two weeks during the summer season. Also, Al-Addoss *et al.*, Al-Addous *et al.* (2019), studied the optimization of PV cleaning schedules for the best return-on-investment according to the average dust accumulation on models in PV power plants. They stated that average energy loss could hit 10% easily in semi-arid areas if cleaning schedules are not followed, Al-Kouz *et al*. (2019), predicted the conversion efficiency of a roof-top PV system as a function of dust accumulation and arrived at almost similar results: PV cleaning is recommended on bi-weekly basis. Obeidat *et al*. (2020), conducted a field survey and sensitivity analysis for five methods of cleaning PV modules. They concluded that manual cleaning on bi-weekly basis is the preferred option by experts in this field. Thus, cleaning of PV modules and its frequency are key features for a PV system, especially in semi-arid regions with frequent dust storms, as eastern and southern parts of Jordan. Other researchers studied the construction of a large central solar power plant, with thermal storage, in southern Jordan and reported that the cost of unit electricity produced is still higher than that generated by PV modules or conventional power stations, Al-Kouz *et al*. (2020). However, none of the researchers assessed the performance ratio and monthly or annual yield of large PV power plants in the country. Therefore, the paper in hand will try to answer these points and fill part of the gap in information regarding the performance ratio of mega-size PV stations connected to the medium-voltage grid. The prime aim of this field study is limited to assess the technical performance, losses and annual energy yield of the 1st PV power station connected, on wheeling basis, on 33 kV distribution network in the country.

On the international level, the green economy is gaining more momentum, and many governments in different parts of the world support and try hard to fight the global warming which is recognized as a threat to humanity. Thus, renewable projects, especially PV modules, are gaining extra thrust forward. This have activated scientist to pave the way for the development of research in renewable energy with some focus on solar energy (Goura, (2015), International Renewable Energy Agency (2021), International Renewable Energy Agency (2021), International Renewable Energy Agency (2021)). Cervone *et al*. (2015), discussed the impacts of regulatory rules on the economic performance of PV power plants, and developed a software instrument to analyze energy production of a PV power plant from the economic point of view with reference to prevailing regulatory rules. Daha *et al*. (2018), studied the impact of tropical desert maritime climate on the performance of a PV grid-connected power plant, in Djibouti, and reported the seasonal variation and energy loss due to soiling and weather conditions. Honrubia-Escribano *et al.* (2018), reviewed the influence of solar technologies on the economic performance of PV power plants in Europe. Oh *et al*. (2020), evaluated the performance and failure of PV system in 10 years field-aged 1 MW PV power plant and reported that output loss was mainly due inverter(s) failure and annual degradation in PV strings. Jed *et al*. (2020), evaluated the performance of a 954,809 kWp photovoltaic array made up of micro-amorphous silicon situated in Nouakchott (capital of Mauritania) based on measurements of one year of operation from September 2014 to August 2015 according to the IEC 61724 and concluded that the energy generated by the PV array and the energy fed to the utility grid are affected by solar insolation and the module temperature. Boretti and Castelletto (2021) reported the cost and performance of concentrated solar plants (CSP) and PV power stations in USA and concluded that combination of CSP and PV systems could provide a comparable performance at an acceptable cost. Şevik and Aktaş (2022) efficiency-enhancing and improvement activities such as manual and natural cleaning, thermal monitoring, and snow load removal in a 600 kW grid-connected photovoltaic (PV) power plant and found that up to 5.66% power reduction can occur for PV modules that have been dirty for close to one year. It was determined that the dust removal effect of the rain was up to 0.94%.

As in other countries around the world, there was a strong interest, during the last decade in Jordan, to use PV systems since it receives high solar radiation, all around the year of not less than 3000 hr. This is considered a tremendous amount of solar energy: the average daily solar radiation is about 5-7 kWh/m^2 day, Jaber *et al*. (2015). According to the Updated National Energy Strategy, the GoJ through the Ministry of Energy and Mineral Resources, has an ambitious plan to continue the construction of large grid connected power plants in close cooperation with private investors. There are about new 1500 MW of solar and wind are connected to the national and/or distribution grids and almost 1000 MW are in the pipeline and will be connected between 2021 and 2024, (National Electric Power Company (2020), Ministry of Energy and Mineral Resources (2020), Ministry of Energy and Mineral Resources (2020-2025)). These projects could substantially reduce Jordan's energy dependency and create significant fiscal benefits. On the other hand, other renewable sources, such as biomass and hydropower, are limited in Jordan due to the lack of surface water resources and the long dry summer season. The existing capacity, of only 12 MW of hydropower represents the current potential. In addition to few new small hydropower systems that has a good potential in selected sites in the western mountains and opportunity to construct pumped storage schemes powered by RE sources, Jaber (2012). However, at present there is no official interest in such projects. The planned Red-Dead Sea Water Conveyance project, which as very high potential to produce drinking water and generate electricity, was cancelled recently. The World Bank has confirmed that this project will no longer be among the projects intended to be implemented due to the lack of Jordanian governmental agreement on the parameters of the project, World Bank, Press release statement on Jordan's Red-Dead sea project (2021).

Based on the International Standard (IEC 61724), which defines classes of photovoltaic (PV) performance monitoring systems and serves as guidance for various monitoring system choices, the purposes of a performance monitoring system are diverse, IEC TS 61724-2 (2016-2017). These include (i) identification of performance trends in an individual PV system; (ii) localization of potential faults in a PV system; (iii) comparison of PV system performance to design expectations and guarantees; (iv) comparison of PV systems of different configurations; and (v) comparison of PV systems at different locations. Such wide concern drivers will lead to a diverse set of requirements, including sensors and/or analysis methods depending on the specific objective. Unfortunately, local regulations contain nothing regarding monitoring, performance and evaluation of PV power stations. Hence, the performance of PV plants, as a reliable future energy source, is not examined and weighed annually. This paper is the first of its kind in the country and, may be in the MENA region, and could be used as a reference to evaluate similar PV projects, connected to the national or distribution networks, in Jordan and the neighboring Arab countries. It has the main following objectives:

- assess the technical performance and annual energy yield,
- compare actual performance data, from the field, with the original design and simulation by the PVsyst.
- analyze the seasonal variation of the plant output and the performance ratio.

PV modules, which are semiconductors that have no moving parts, allow the conversion of solar insulation into DC electrical current. The latter can be converted to AC current by using special inverters. Such system is considered reliable, safe, environmentally sound method for power generation under different climatic conditions and almost maintenance free except cleaning and other minor jobs. It should be stressed here that it is not the aim of this investigation neither to discuss principles of design of PV plants nor to address the existing legal framework. Rather it is deemed to serve as a reference for monitoring large PV power plants and provide recommendations on how to maintain high performance ratio based on related international standards. The following section presents a short description about the studied PV plant, location and its layout. Followed by the technical specification of main components and then description of the adopted methodology. Finally, results and discussion of measured variables all year round, performance ratio and socio-economic impacts are presented.

3. Plant Description

3.1. Location

The solar PV plant is located south of Amman, about 30 km south-west of Queen Alia International Airport, in Umm Rassas (Lahoon) town. This is an old historical site, built during the Roman presence, in the country, more than 2000 years ago. The old town contains an old castle, churches, theater, and water collection system and currently it is a destination for foreign tourists. However, the PV power station is far from the historic town and inhabited area. It is owned and operated by the Islamic Charity Center Society (ICCS) and the generated electrical power used to supply the Islamic Hospital, in Amman, based on the Wheeling Directive, Energy and Minerals Regulatory Commission (2014).The project covers an area of 50,000 m^2, including the main sub-station which connects the project to the medium voltage (MV) 33 kV distribution grid, which belongs to Jordan Electrical Power Company (JEPCO) as shown in Fig. 2. The site topography is nearly flat; but contains a storm water drainage system to ensure that no water accumulation inside the project area.

The project included all needed infrastructure such as a ring service road, control room and special storage area, guard room, security lighting, cameras and monitoring system and as well as the security fence around the project area.

3.2. Project Capacity and Main Equipment

The original design of the plant was based on 6707 (Jinko Eagle-72) PV modules, which were planned to be fixed north-south on 33 trackers, i.e. moving galvanized steel-structure, with a single axis tracking (east-west). These were arranged to form 353 stings and each of these connected to the central inverter via combiner boxes and DC cables. All used equipment and components were specified and selected from well-known manufacturers, from Europe except PV modules, as shown in Table 1. Some minor stuff such as bolts, washers, earthing rods, cable ties and insulation materials were purchased from the local market, taking into account that specification should comply with the original desired technical specification.

3.3. Project Design

The PVsyst package, PVsyst (2015), is a simulation software developed specially to predict the overall performance of a PV solar system under specific conditions.

It is designed to be used by engineers and researchers as a very useful educative tool. The software includes a detailed contextual Help Menu that explains the procedures and models that are used, and offers a user-friendly approach with a guide to develop a project. The PVsyst has the ability to import metrological data as well as other technical and non-technical details from many different sources. By using this software, the designer or developer will be able to estimate with high degree of accuracy the performance of stand-alone or grid-connected PV system, based on the specification of selected modules, inverter, etc., using hourly simulation data. The obtained results of the PVsyst are used in the techno-economic feasibility study of a PV system regardless of its size, i.e. roof-top or central station. The results of the simulation were used to select main equipment and devices as summarized in Table 1.

The original design of the Solar PV power plant was modified to allow for the distribution company, JEPCO, to have an area of about 1050 m^2 of the original land to house the main switches and to be the connecting point to the MV grid. Moreover, JEPCO forced ICCS to construct a special building, of about 160 m^2, on this piece of land according to their reference specification, just to enclose energy meters and connection switches to the 33 kV grid. Unfortunately, the cost of this building exceeded US$125 thousand. The new design of the PV plant was based on having 353 strings, instead of 340 in the original design, and 19 panel per string that set up North-South and allowing sun tracking from East to West. The strings are connected in parallel to the central inverters. The converted AC 380 V power from the four central inverters is fed to two step-up medium voltage transformers, 2x1500 kVA in parallel, to raise voltage up to 33 kV as shown in Fig. 3. The total installed capacity is 2,146.24 kWp.

The four 500 kVA central inverters, two medium voltage transformers and the delivery and control unit are located nearly in the central area of the project to allow for minimal losses. The generated electrical power is pumped to JEPCO 33 kV grid via 3x95 mm^2 underground medium voltage copper cables. The main reason behind such design is to maximize efficiency by reducing electrical losses and to have smooth operation without any shading on the PV modules. The plant is designed to take back the needed power from the grid after the sunset until sunrise next morning, and during up normal conditions, to supply security lighting and control room appliances. This was based on JEPCO conditions to allow connection and operation of this project. It is important here to mention that related international and national codes were considered, especially the guidelines for renewable energy projects, Energy and Minerals Regulatory Commission (2012), and the local grid code, Energy and Minerals Regulatory Commission (2015), as well as instructions for RE project provided in the project approval letter. Such letter may include but not limited to fees to paid, connection point, connection agreement, electrical power supply to the site and other special conditions specified by the distribution company. It should be mentioned here that distribution companies have an ultimate authority to accept or reject a particular PV project or its proposed location. Moreover, the customer cannot argue nor re-submit another application claiming that network capacity, in that location, does not absorb the planned new PV plant capacity. Unfortunately, there is no real follow up by the Energy and Minerals Regulation Commission.

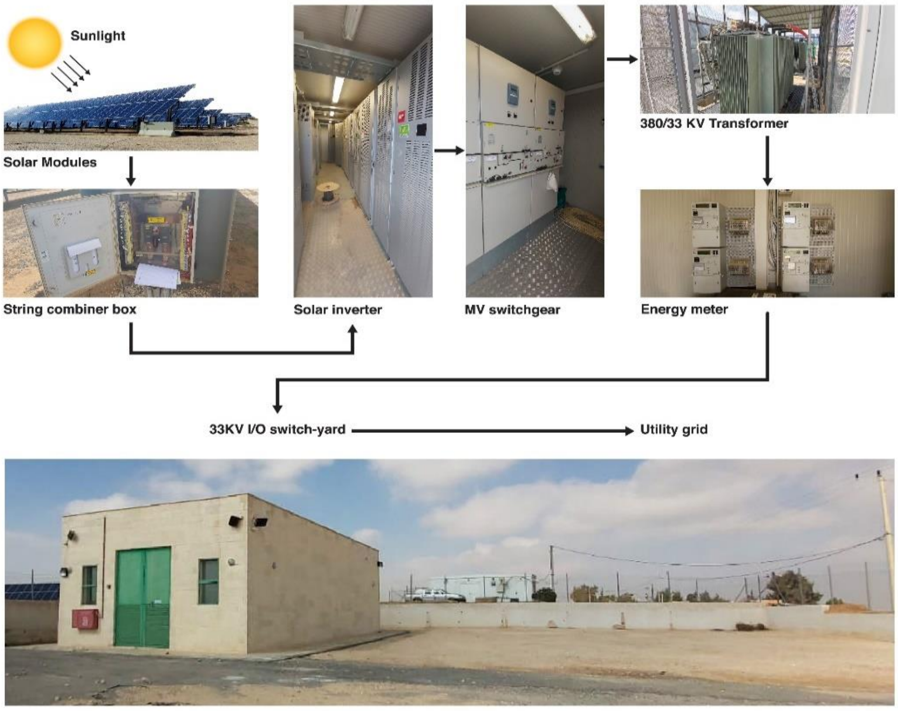

Figure 2. Um Rassas solar PV plant

Table 1. Specs of main equipment

No.	Item	Specification	Origin
1	PV modules	320 W Jinko, Type Eagle-72, Poly Crestline Module, Eff. 16% with a linear degradation rate over the lifetime of about 0.7% (2146.24kWp).	China
2	Inverters	FIMER, R6750TL, 4 Central Inverterswith active cooling (2484 kW), Eff. 98%.	Italy
3	Transformers	2x1500 kVA Step-up from 380 V to 33 kV, SEA and a small auxiliary transformer to supply internal consumption.	Italy
4	Delivery unit	Medium voltage (33 kV) switchgear and control unit, Siemens	Germany
5	DC and AC Cables	Solar cables (DC), low voltage (1000 V) and medium voltage (33 kV) cables (AC) as well as control and communication cables.	Grease
6	Conduits and Sleeves	High density polyethylene conduits and underground tubes.	Grease
7	Steel Structure	Mounting Systems, G235 Hot dip galvanized, steel structure with a single axis tracking system driven by 3-phase motor.	Germany
8	Tracking system	Single axis, screw-jack, Siemens SIMOGEAR Z59-LE90.	Germany
9	Closed Circuit Television (CCTV)	Cameras and recording system, remote zoom and focus (Full HD IR Bullet IP Camera) and weather station.	USA
10	Standby Generator	80 kVA Diesel generation set, Perkins, and Automatic Transfer System (ATS).	UK

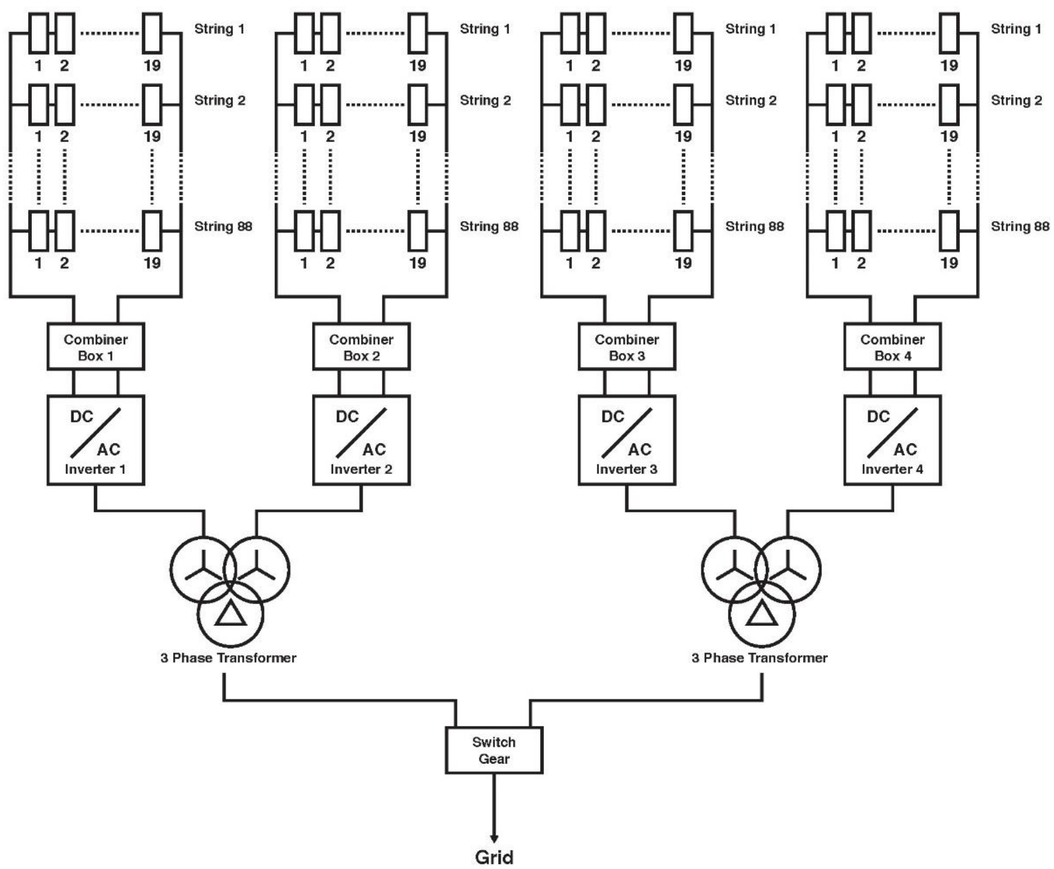

Figure 3. Main units and connection diagram of the solar PV plant

3.4. Annual Power Generation

As in other PV power plants, conversion efficiency and performance degradation over module's lifetime as well as PV cleaning are major factors affecting the generated electrical energy and its cost, (Kumar *et al*. (2015), Saidan *et al*. (2016), Hammad *et al*. (2018), Al-Addous *et al*. (2019), Al-Kouz *et al*. (2019), Obeidat *et al*. (2020)). The PV efficiency is defined as the conversion ratio of received solar intensity to electrical power and annual degradation of PV modules describes the decline in power production against time. A slight decline of these factors, in addition to PV cleaning frequency due to dust accumulation, may reduce the final output by 10-25%. Consequently, the cash flow and revenues of the PV project will be influenced significantly. Thus, such factors should be considered from early beginning and given high attention when designing a new PV power plant in order to reach and maintain high efficiency.

Umm Rasas power plant is located at a longitude of 35.927 N, Latitude 31.493 E and an altitude of about 750 m above sea level. The site is an open area, bare land except some desert plants. However, not close to the PV power plant, there are some farming activities based on irrigation from underground water, i.e. deep wells. In general, the site is characterized by long, hot, dry summers and short (December to March) but cool winters with heavy storms occasionally. The climatic conditions are influenced by the eastern Mediterranean and the Arabian desert. The coldest month is January, with temperatures ranging between 5 °C and 10 °C, and may drop to sub-zero for few days during night time, and August is the hottest month with average temperatures between 30 °C and 35 °C, or even higher touching 40s for a couple of days that may extend to September due to hot waves coming from the Indian continent. The average annual sunny days exceeds 300 days or approximately 3000 hours, Dept. of Statistics, Annual Statistical Report (2020). Equally important is that the 33 kV overhead lines are passing the main gate, of this project, to the distribution and switches sub-station not far from the site: only 500 m from the PV power plant. Hence, the solar PV power plant is located in a good and suitable site, from both technical and socioeconomic points of view.

In this project the tilt angle of PV modules is zero, i.e. horizontal, since the design is based on a single axis tracking system to enhance the production of electrical energy during morning and evening times. This new single axis and single post system are driven by a torque tube connected to a single electric motor on both sides, and a customized software with a tilt range from -45° (east) to +45° (west). All members of the structure are made of self-healing zinc-aluminum-magnesium coated steel to provide high durability and good resistance to corrosive environment. The steel structure carrying PV modules are forced to adjust back to a stew position, i.e. zero inclination, when the wind speed exceeds 100 km/h (i.e. about 27 m/s) to minimize the lift and drag forces and protect the system from any possible damage. It is important to mention here that in 2016-2017, large scale and even small roof-top PV systems, close to Umm Rassas and in other cities in Jordan witnessed serious damage due to a very high speed of surface wind associated with heavy rainstorm. However, there was no destruction nor losses in this project and all components are functioning properly as of today. The frequent technical problems in this project are limited to failure of cooling fans used in the ventilation system for inverters due to relatively high temperatures during daytime around the year and complete collapse of some PV modules. The average number of failed PV modules was about 50, i.e. less than 0.8%, per annum. These are still under the manufacture, JINKO Co., product warranty of ten years and should be reported to the manufacturing company. The panels have a standard efficiency of 16.49% and open circuit voltage (VOC) of 46.4 V, short circuit current (ISC) of 9.05 A, and operating temperature range from -40°C to 85°C with a junction box rating of IP67. In order to keep high power production, it should be stressed here that operation and maintenance team must develop and enact a plan aiming to inspect and test PV modules, frequently. Faulty modules should be removed and replaced with new ones. In 2019, the annual energy production was 3954 MWh, without deducting the losses in the distribution network. This value was almost like that predicted, 4024 MWh, by using the PVsyst. The following section will discuss the performance of the PV power plant over one year.

4. Results and Discussion

4.1. Performance Analysis

Appropriate design of a PV system is possible when every aspect of the system is analyzed and selected properly. The performance analysis of the grid connected PV power plant was conducted in terms of final yield, conversion efficiency and the annual performance ratio. While the economic analysis was based on the generated electricity and its cost savings. This is in full agreement with the developed performance parameters, by the International Energy Agency, (Ayompe *et al*. (2011), Besarati *et al*. (2013)), for solar PV grid connected power plants. As in other PV power systems, the PVsyst simulation software was used in the early beginning to predict the performance of this power plant. While the real data were collected, on daily basis, from the field over one year via the SCADA system and weather station installed on site as well as electrical energy meters.

The Irradiance is defined as the measure of power density of sunlight received at a location on the earth and is measured in watt per meter square. Based on the actual measurements from the site, the average annual solar irradiance in Umm Rassas site is quite high, i.e. 6.5 kWh/m^2.day, while the irradiance's maximum and minimum exist in July and January, respectively, as shown in Fig.4. The measured values are in full agreement with reported data in Jordan, Bani-Younes (2017). But the high solar irradiance in Umm Rassas is expected due to its location not far from the sun built and clear sky most of the year, i.e. long sunny hours.

4.2. Final yield and Performance ratio

The final yield (kWh/kWp) is defined as the annual net energy output of the PV power plant divided by the peak power of the installed PV array at standard conditions, i.e. 1000 W/m^2 solar irradiance and 25°C cell temperature. Fig. 5 shows the average monthly yield during the year 2019, compared with original simulation results using PVsyst. Again, it is clear that during the period April-October, the yield is high due high irradiance and daily long sunny hours. Equally important is the continuous efforts in keeping PV modules clean: the cleaning schedule is based on wet-manual cleaning method bi-weekly. As can be seen in Fig. 5, that real production during summer season is slightly higher than simulation results. While during colder months, early and late in the year, energy production was almost similar to that obtained from the simulation program. Again, such results could be attributed to using a sun tracking system and the frequent PV modules cleaning as well close follow up by the operation and maintenance (O&M) team. However, it is worth mentioning that the actual annual electrical energy yield, 3954 MWh, in 2019 almost similar to that predicted by PVsyst, 4024 MWh. Thus, the slight deviation, during summer and winter, could be ignored.

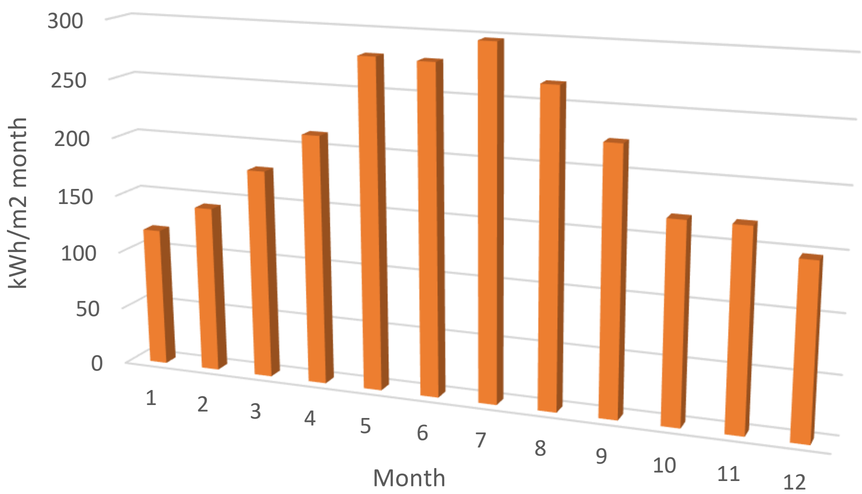

Figure 4. Monthly solar irradiance

The performance of PV modules under varying solar conditions will differ from the normal case. In particular, the intensity of solar radiation falling on a PV module changes in the time of day and varying in energy received by PV cells will affect its main parameters, such as I_{sc}, V_{oc}, power and conversion efficiency. The total energy generated by the PV plant and exported to the grid equals the daily monitored value of AC power output minus the losses in the system.

The performance ratio (PR) of the PV power plant is defined as the final yield of the plant divided by the reference yield. It is a comparison of the PV plant output to the output of the plant could be achieved by considering local solar irradiation, cell temperature, and other factors, such as grid availability, etc. According to the actual collected data during 2019, the actual calculated annual PR (0.950) is much higher than the simulated value (0.856) using the PVsyst package. The difference between the actual and simulated PR is due to the fact that the contracting company conducted the pre- and detailed-design, procurement and construction of this project. Moreover, the contractor provided a performance guarantee as part of the signed contract with the project owner. Fig. 6 illustrates the actual calculated PR over the average predicted PR. All values are high except in four months: January, February, November and December. This could be attributed to many factors, the most important is the high yield due to the efficient tracking system, continuous and daily monitoring and maintenance activities as well as cleaning the PV panels at least ten times a year during the summer season, i.e. twice a month. This is the only way to solve the problem of dust accumulation and consequently the drop in the generated power from the PV modules: cleaning is a key factor in maintaining the desired performance as well as plant economics. Several studies conducted to check the effect of dust accumulation on performance deterioration of solar cells, taking into account local conditions, and reported that appreciable losses incurred in the generated power due to the sun irradiance scattering effects on the surface of the solar panels (Kumar *et al*. (2015), Saidan*et al*. (2016), Hammad *et al*. (2018), Al-Addous *et al*. (2019), Al-Kouz *et al*. (2019), Obeidat *et al*. (2020)).

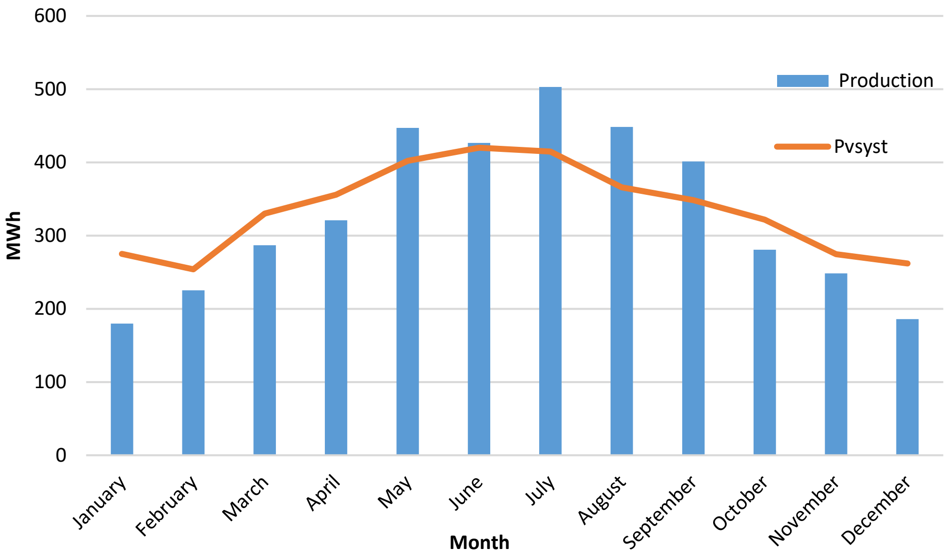

Figure 5. Average monthly energy yield

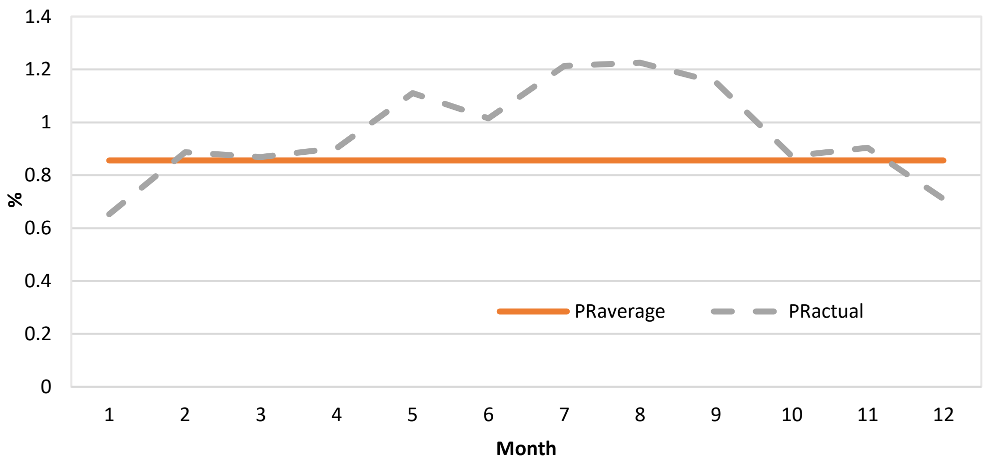

Figure 6. Actual and predicted average performance ratio

5. Socio-Economic Impacts

5.1. The economic impacts

This project contributed to economic and social development of Umm Rassas town and the final beneficiary of generated electric power, i.e. Islamic Hospital in Amman. During the construction of this project, more than 100 workers were involved in different jobs, including supervision and consultancy, engineers and technicians, guards and manual workers. Of them about 15-20 workers from Umm Rassas. On permanent basis there are 3 guards and two technicians to follow operation and maintenance issues on daily basis. PV modules cleaning is conducted by a special team, overnight, consisting of ten to twelve workers and large road water tank for about ten times a year.

According to the Wheeling Directive, Energy and Minerals Regulatory Commission (2014), the project owner should pay the wheeling fees, i.e. 0.007 JD/kWh, to the distribution company as well as bear the losses in the grid, i.e. 6% of the generated and transmitted electricity, regardless of the project location or how far from the load. Based on the prevailing electricity tariff and the specified category for hospitals, and after deducting energy losses in the distribution grid as well as distribution wheeling fees, the average annual savings exceeded 900 thousand JD, i.e. 1.25 million US$/year, at least. Such savings enabled the hospital management to keep the visit and prescription fees for all outside clinics fixed without any increase. This would help poor families and orphans having needed medical treatment at low and affordable cost. It is considered a unique and indirect impact of this project.

5.2. The social and environmental impacts

One of the aims of this project is to assess the sustainability of PV power plants, in Jordan, and their contribution in the national energy strategy and creation of jobs as well as poverty reduction. It is well known that appropriate feedback from the field will help in tuning and adjusting regional and national renewable energy policies and strategies, especially when it comes to socioeconomics of decentralized PV projects, Almasri *et al*. (2019). As in all power generation renewable energy projects, the impacts of the PV plant are grouped into the following categories according to the prevailed local regulation, Ministry of Environment (2020): environmental impacts (air, water and land), and social and economic dimensions. The first step was obtaining the environmental permit, after submitting the required EIA document to the Ministry of Environment. According to the Environmental Impacts By-Law, the Central Licensing Committee will review the submitted EIA and after approving the report including the environmental management plan, the permit could be issued to develop the project within certain time interval. This is a compulsory action for all development projects classified under list A. However, based on past field experience in large PV projects, it could be said that the relationship between a PV power plant and the local society and environment is always positive by all means. This is due to the fact that most of workers during the construction and testing phases are from nearby areas and no serious accidents or problems caused by such a new development. Bearing in mind that such projects are labor intensive during the construction phase and the value created in this phase arises mainly from labor-intensive works including civil engineering activities. Equally important is the technology transfer through foreign investment in such projects, which could lead to create new business relations such as manufacturing and/or assembly of certain parts locally under guidance and supervision of the mother company. At the end of the day, it is deemed that such project would strengthen local capabilities in engineering design, business development, and manufacturing and production.

Later on, during the commercial operation of this PV power station, three guards and two technicians are employed to look after the project. Technicians are highly skilled personal and responsible for integrating the PV solar power plant with the grid, facilitating the connection and looking after the PV plant. In this particular project, the major negative impact here is the reduction of grazing area according to cattle keepers and local residents. Thus, the positive socioeconomics of renewable energy projects is considered a key driver behind the development of such project in Jordan and other countries, Timilsina *et al*. (2011). Another possible but an important driver is the local content requirement which can support the expansion of related local industries and create new job opportunities. A special study, funded by the United States International Aid Agency (USAID) and conducted under Jordan Competitiveness Program (JCP) in 2015, showed that the introduction and enforcement of a rolling local contribution ratio, on renewable energy projects, starting from a low ratio would have a net positive impact on the economy, (El-Karmi *et al*. (2014), Interdisciplinary Research Consultants (2015)). However, the GoJ is still hesitating to introduce such a key incentive, especially for large power generation projects. This could be attributed to the low or absent official efforts in assessing the impact of renewable energy systems on value creation, which considered very critical for making informed policy decisions. Bearing in mind that such developments having a cross-sectoral nature and the analysis should look at various segments starting from job creation, added value to the economy, to welfare and responsibility towards local communities. Equally important is the absence of well-trained engineers and highly skillful workers in field of renewable energy in the local market, Jaber *et al.* (2020). Thus, the introduction of renewable energy courses and integrate vocational and technical as well as high education programs within the national renewable energy action plan is an essential step to promote renewable energy development in the country, Alawin *et al*. (2016).

The local applied research and development in renewable energy, and in particular, solar applications are still prowling due to lack of funding and inadequate study and training curricula related to RE sources and technologies. Thus, the value added through the created knowledge, that can lead to technological development, systems' improvement, reduce costs and better services at local conditions, is around zero. Without the development and adoption of a local RE plan, including serious funding to attract and bring together researchers and related industries to create applied research projects aimed to solve problems in the field, the innovation situation will remain stagnant with no real contribution.

The net positive environmental impact resulting from operating this PV power plant is emission reductions, mainly GHGs. Based on the annually generated power and the calculated rate of emission for 2019, the net reduction of GHGs is equivalent to approximately 1800 ton of CO_2, Jaber *et al*. (2019). It is too early to discuss the impacts of decommissioning phase of a PV power plant, in Jordan, at the end of its operational lifetime. But according to the submitted EIA reports, decommissioning of such plant will include recycling and final disposal of various components. The main issue is the disposal of PV modules since these are classified as an electronic waste and should be disposed-off in specified sites and following strict procedures, Ministry of Environment (2021). Thence, the importance of this phase will increase as the PV power plant reaches the end of its lifetime, i.e., within next two decades.

6. Conclusions

Jordan is highly susceptible to external energy sector shocks which impact its economy. However, it enjoys excellent conditions for the exploitation of solar energy due to its location close to the sun belt. Harnessing such resource would increase the green energy mix and lead the country to be more sustainable and energy secure. Given the importance of utilizing renewable energy sources, on the national and international levels, it is essential to have consistent and reliable information on renewable energy projects. Such info includes environmental and socio-economic viability, technological feasibility and technical details, etc. This paper tries to provide a project-based resource assessment which will help similar project developers and/or operators to monitor and evaluate their projects as well as investors and financiers to understand the performance and levels of revenues and possible risks. It contributes to the literature by reviewing the key performance indicators of mega PV projects, under local conditions, which has not been done in previous studies. Here the performance of 1st wheeling large scale PV, in Jordan, was analyzed and discussed based on real data obtained from the field. It was found that energy yield and performance ratio were high and reached expected values. This was not possible without frequent cleaning of PV modules on bi-weekly basis during summer season and continuous monitoring and O&M operations. Finally, such project and similar other ones, would enhance the diversification and reduction of energy imports, as well as the increase reliance on domestic energy resources. But this would require addressing and removing existing conflicts between stakeholders by adopting a more participatory approach to reform and improve energy sector governance.

Acknowledgment

Authors would like to thank the Islamic Charity Center Society (ICCS), Amman – Jordan, for providing the needed information to start this research work.

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