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Viability of a Utility-Scale Grid-Connected Photovoltaic Power Plant in the Middle East

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ABSTRACT

This study examines the technical and economic potential of a utility-scale grid-connected solar power plant in the Middle East. Furthermore it argues that, due to the recent decline in solar array prices, the cost of solar electricity can be competitive, compared to the conventional sources used in energy-poor states. Performance modeling and energy yield simulation for a 90 MWp plant was performed using the PVsyst software. Results show an annual performance of 82.6%; the specific power output of useful electricity is 1,939 kWh/kWp/year and the capacity factor is 22%. Findings show that the plant's electricity generation is 174,549 MWh per year, which is sufficient energy to power approximately 40,000 homes with clean, renewable energy. A simplified financial evaluation of the plant's capital, operation and maintenance costs using recent market prices show that the Levelized Cost of Electricity (LCOE) is between $0.05/kWh for the real cost scenario with no discount rate and $0.085/kWh with a 6% discount rate. In conclusion, the study shows that, in all cases and with no government incentives, the cost of solar electricity is lower than the current cost of $0.179/kWh that Jordan is paying for electricity generation using conventional sources.

Key words: Solar energy, PV, grid-connected, utility, levelized cost of electricity

INTRODUCTION

In the last six years, the cost of PV modules has decreased by 80%, making it one of the most promising technologies for electricity generation (International Energy Agency, 2014b). Making electricity generated from solar PV competitive especially with oil based generation in many parts of the world. Adaramola (2014) examined the feasibility of solar PV-grid tied energy system for electricity generation in northern Nigeria. Reichelstein and Yorston (2013) study of utility-scale PV projects found that the cost (LCOE) of electricity is 35-50% above the comparable cost of conventional power plants.

With a lack of conventional energy resources, Jordan is one of the few Middle Eastern states that depend profoundly on imports to fulfill its energy needs. In 2013, Jordan imported more that 97% of its energy needs at a cost equivalent to 17% of its GDP (Ministry of Energy and Mineral Resources, 2015).

The reliance on imports has raised energy-security concerns and motivated the search for indigenous resource utilization. In this study, we will assess the solar energy potential for electricity generation and its vital role in energy independence. In 2013, virtually all electricity generated in Jordan was from fossil fuels; in fact, less than 1% of the electricity generated was from non-fossil fuels, as shown in Fig. 1. According to National Electric Power Company (2014) the electricity sector consumed 3,598 thousand tons of oil equivalents (TOE) or 44% of the primary energy.

The recent study will evaluate the solar resources in Jordan utilizing long-term satellite-based solar irradiation data, the national electricity grid, a tariff and the site selection criteria.

The study proposes a utility scale photovoltaic solar plant and will argue that, in the Middle East, land based large PV plants are more feasible than the use of rooftops. This considers that roofs are usually occupied by water tanks,
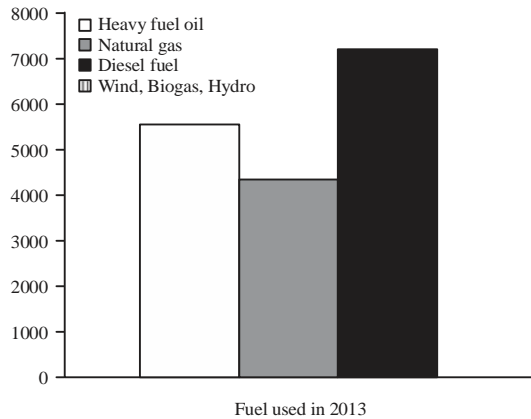
Fig. 1: Electrical energy produced (GWh) by fuel type in Jordan in the year 2013. Source: National electric power company (2014), http://www.nepco.com.jo/

satellite dishes and other home equipment, besides the fact that rooftop systems require gird upgrades and smart metering that might not be readily available in developing countries.

Using plant performance modeling and energy yield simulation, the proposed system will track the electricity injected into the grid on an hourly basis over the entire year. The technical evaluation includes system losses, energy yield prediction, capacity factor and power output.

A simplified financial evaluation of the plant's capital, operation and maintenance costs will demonstrate the plant's financial feasibility. Using recent market prices, we will show the cost of generating electricity and compare it to the cost of generation from current sources in energy poor Middle Eastern states.

This study examines the technical and economic potential of solar energy in the Middle East and argues that the cost of solar electricity can be lower than that of the current generation sources, even without government subsidies, using Jordan as a case study.

UTILITY SCALE POWER PLANT

Utility scale solar power plants are energy generating facilities capable of producing large amounts of electricity that can be fed into the electricity transmission grid; they range in size from 10 MW to over 200 MW.

The plant considered in this study is 90 MWp. Such a plant is small enough to make it technically and financially feasible in developing countries and large enough to supply sufficient energy to power approximately 40-100 thousand homes with clean, renewable energy.

Solar resources: It is well known that the Middle East possesses one of the highest solar energy potentials in the world; the entire area is characterized by high solar irradiance, with an average annual solar energy at the horizontal plane of above 2,000 kWh m^{-2}.

Jordan is one of the Middle Eastern countries blessed with a rich and reliable supply of solar energy and with an average sunshine duration of more than 300 days per year. Figure 2 shows the solar map of Jordan, employing long-term satellite based solar irradiation data (SolarGIS, 2015 and German Ministry of Environment, Nature Conservation and Nuclear Safety, 2015).

Electricity grid: Jordan's electricity grid is the smallest among all of its neighbors, with a total installed capacity of 3,186 MW in 2015 (National Electric Power Company, 2015). Currently, the electrical power stations depend completely on imported oil and gas; in the year 2013, Jordan imported more than 97% of its energy needs (National Electric Power Company, 2014).

The national grid is connected through 400 and 132 kV lines (Fig. 3) that serve more than 99% of the total population through distribution networks. A 400 kV tie line connects the grid to neighboring Syria in the North and Egypt to the South (National Electric Power Company, 2014).

In the year 2013, the peak load was 2,975 MW and the total consumed energy was 14,564 GWh, resulting in an average annual consumption of 2,220 kWh per capita.

The domestic sector, which comprises 1,496,730 households, consumed 6,265 GWh, accounting for 43% of total electricity consumption for the same year (National Electric Power Company, 2014). Therefore, the average annual consumption per home was 4,185 kWh, making the proposed power plant capable of supplying sufficient energy to power more than 40,000 Jordanian homes with clean, sustainable energy.

Site selection: Although solar energy study results are site specific, it is the aim of this study to arrive at results that can be applied universally in various Middle Eastern locations, using the following selection criteria:

- It should be a typical Middle-Eastern location with average Middle-Eastern solar characteristics. Therefore, our results will not be limited to just one site but could apply to many locations in the Middle East
- It should be close to the national grid
- It should be close to populated centers and in an area where large parcels of low priced, vacant land are available

The site for the solar power plant was selected in Mafraq province in Northern Jordan at the boundary between the Hauran plateau and the Syrian Desert, about 80 km to the North from Amman. The selected site's geographical coordinates are latitude 32.4° N and longitude 36.4° E and its altitude is 746 masl.

Mafraq is a typical semiarid Middle Eastern area; it receives 150 mm of rainfall per year and has, on the average, 78% of sunny daylight hours per year. Long-term monthly
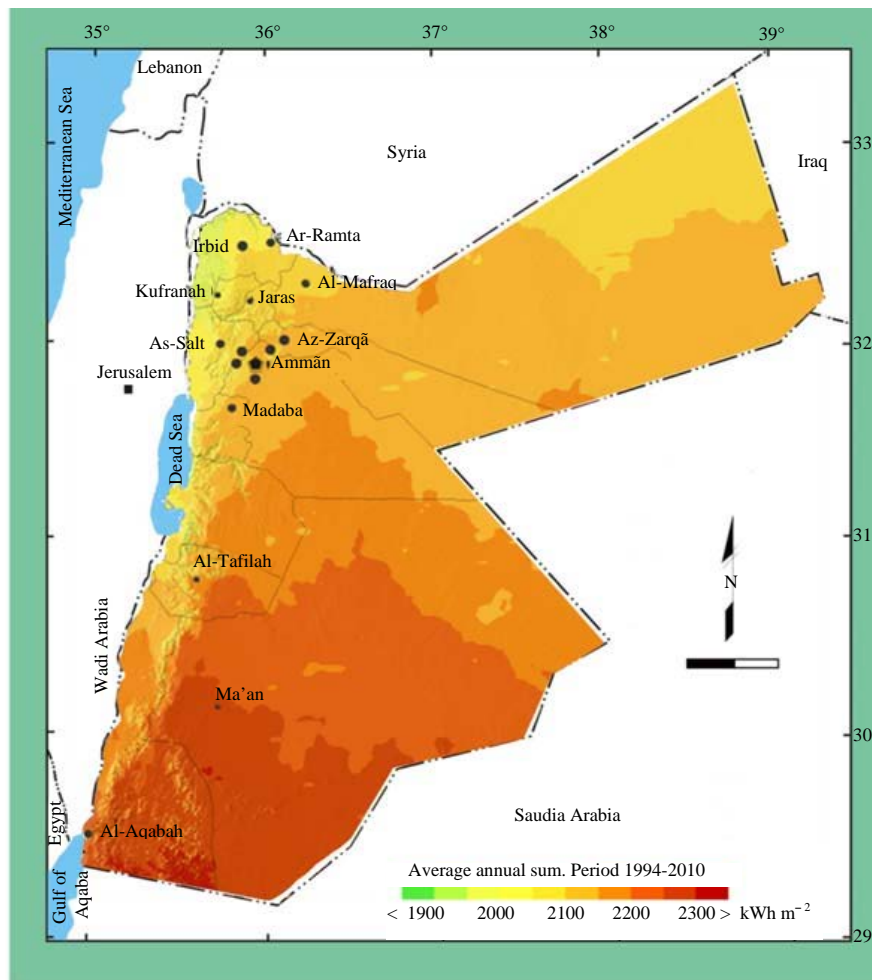
Fig. 2: A GHI solar map of Jordan employing long-term satellite-based solar irradiation data (modified after SolarGIS, 2015)

averages of solar radiation, temperature and wind speed (German Ministry of Environment, Nature Conservation and Nuclear Safety, 2015) for the selected site are listed in Table 1.

The module's total area was calculated to occupy 589,248 m^2; consequently, the total plant size is assumed to be 1,200,000 m^2, which is twice the array's area, thus allowing for service roads and other facility structures.

Electricity tariff: The electricity sector in Jordan is deeply regulated, where all power generation companies sell their output to the government-owned National Electric Power Company (NEPCO) which, in turn, sells to one of three distribution companies before it is sold to the consumer.

In 2013, the cost of electricity purchased by NEPCO was $0.179/kWh (National Electric Power Company, 2014), making it one of the most expensive sources of electricity generated by fossil fuels, not only in the Middle East but worldwide.

The Ministry of Energy and Mineral Resources (MEMR) announced in 2014 that it had set a tariff ceiling for electricity generated from PV plants of $0.140/kWh (Ministry of Energy and Mineral Resources, 2014). The tariff does not necessarily represent the final Power Purchase Agreement (PPA) price which is estimated to be as low as $0.100/kWh, depending on renewable energy utility negotiations with MEMR and NEPCO. According to MEMR, the tariff for electricity from photovoltaic power plants is a flat rate fixed for a 20-year term agreement, with no indexation to foreign or local inflation indicators (Ministry of Energy and Mineral Resources, 2014).

PV PLANT DESIGN

The proposed solar power plant is 90 MWp but is unlike conventional and nuclear power plants where the plant nameplate power indicates the electrical output after efficiency and other losses. The PV solar plant nameplate power reflects the theoretical maximum (peak) power of the plant.
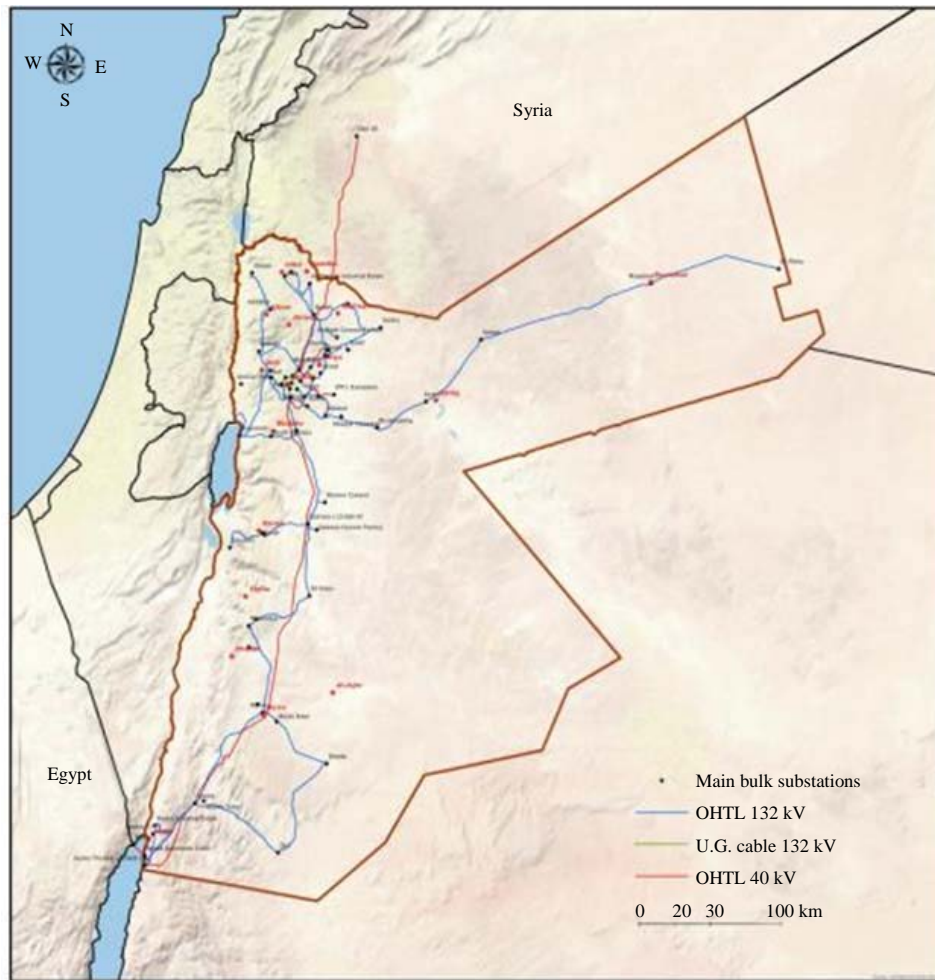
Fig. 3: National electricity grid interconnect 400 and 132 kV lines in Jordan (National Electric Power Company, 2014)

Table 1: Long-term monthly averages of solar radiation, temperature and wind speed for the power plant's selected site in Mafraq

Months	GHI (kWh m^{-2})	DHI (kWh m^{-2})	T Amb. (°C)	Wind Vel. (m sec^{-1})	IGI (kWh m^{-2})	SDI (kWh m^{-2})
January	95.1	30.86	7.92	2.3	144.5	37.77
February	106.5	41.47	8.73	2.5	141.5	47.14
March	161.5	49.25	12.02	2.9	191.2	54.06
April	196.2	58.71	16.34	2.9	204.5	60.84
May	237.8	62.17	21.35	2.9	224.1	61.94
June	256.1	42.48	23.6	2.8	227.3	41.57
July	260.9	40.91	25.91	3	237.2	40.72
August	236.2	44.28	25.31	2.7	236.6	46.54
September	196.1	35.38	23.2	2.3	225.5	40.3
October	155.5	35.87	19.77	1.7	207	43.66
November	111.4	30.61	14.16	1.6	167.1	38.54
December	89.8	30.48	9.75	1.8	141.9	38.45
Year	2,103.2	502.46	17.39	2.5	2,348.3	551.53

GHI: Average monthly sum of global horizontal irradiation, DHI: Average monthly sum horizontal diffuse irradiation, T Amb: Average ambient air temperature, Wind Vel: Wind velocity, IGI: Incident global irradiation in the collector plane, SDI: Sky diffuse incident in the collector plane

A commercial solar power plant design involves the design and selection of several systems, as well as equipment and components. The two primary ones are the solar arrays and the inverters.

The power plant employs stationary ground mounted arrays with a maximum rated power (P_{max}) of 250 Wp, hence requiring 360,000 modules. The array modules are installed on a ground-based mounting steel support structure, with a tilting angle of 30°.

The plant's lifetime is assumed to be equal to the lifetime of the solar arrays, 25 years, based on the manufacturer's warranty as stated by Xihe Solar Co., 2015. Design assumption parameters and technical specifications are shown in Table 2.

The two systems that will determine the plant's characteristics and technical performance are the solar arrays and the inverters. The photovoltaic array selected is the poly-crystalline silicon model XH250P with 60 cells in a series in each array.

The array is made by the XiHe Solar Company in China, which has a proven record in the design and installation of large PV systems in China.

The array has a 12 year warranty at 90% power output and 25 year warranty at 80% power output as stated by Xihe Solar Co., Ltd. Thus, in our calculations, we assumed a 1% annual reduction of power output over the plant's life. The technical specifications of the solar panel at Standard Test Condition (STC) are in Table 3.

The PV grid-connected inverter model SG500KTL made by Sungrow Power Company was selected for this study.

The inverter is designed without a transformer for photovoltaic grid-connected systems with a maximum

efficiency of 98.7% as stated by Sungrow Power Company, 2015. Design calculations resulted in the need for 156 inverters for the plant.

TECHNICAL EVALUATION AND RESULTS

Solar power plant performance modeling and energy yield simulation depends heavily on the input variables. To ensure more accurate results of the energy yield, the analysis was carried out by using area specific resource data, with allowance for undermining factors.

The plant's technical analysis was performed by using commercial PV system design software, PVsyst Version 6. The solar simulation software PVsyst has been developed by the University of Geneva since 1994 and has been validated in the evaluation of PV plants around the world (Mermoud, 2012).

Plant performance modeling: The system quality factor that measures the quality of a photovoltaic plant independent of location is the performance ratio. It is the percentage ratio of the actual energy exported to the grid to the theoretical energy outputs of the PV plant. Thus, it is an indicator of the plant's efficiency and reliability.

A detailed simulation of the plant's performance was performed using the PVsyst version 6 computer code as shown in Fig. 4, resulting in an annual performance projection of 82.6%:

Energy yield prediction: An energy yield prediction provides the basis for calculating project revenue. The aim is to predict the average annual energy output for the lifetime of the proposed power plant.

The annual electrical energy injected into the grid and available for sale is estimated at 174,549 MWh in our analysis. The global incident irradiation in the collector plane is 2,348.3 kWh m^{-2} per year and the effective energy output of the array is 177,423 MWh per year.

The annual average energy-output efficiency (η) of the solar array per area is found to be 12.82% and the annual

Table 2: Plant design assumption parameters and technical specifications

Meteorological data	Solar Mediterranean atlas
Collector plane orientation	Tilt 30 degrees
	Azimuth 0 degrees
Horizon	Free horizon
Near shadings	No shadings
PV module	Silicide polycrystalline
	Model XH250P
Total number of PV modules	360,000 modules
Number of PV modules	In series 20 modules
	In parallel 20,000 strings
Module area	589, 248 m^2
Array global power at STC conditions	90 Mwp

Sources: Xihe Solar Co., Ltd (2015), http://www.xihesolar.cn/ accessed February 3, 2015

Table 3: Technical specifications of the solar panel at standard test condition of 1,000 wm^{-2}, Am 1.5, cell temperature 25°C

Manufacturer	Xihe solar Co.
PV module type	Si Polycrystalline
Cell efficiency	16.8%
Rated power (P_{max})	250 Wp
Voltage at P_{max}	30 V
Current at P_{max} (Im)	8.17 A
Short circuit current	8.72 A
Open circuit current	37.1 V
Module dimension (mm)	1650×992×40 mm

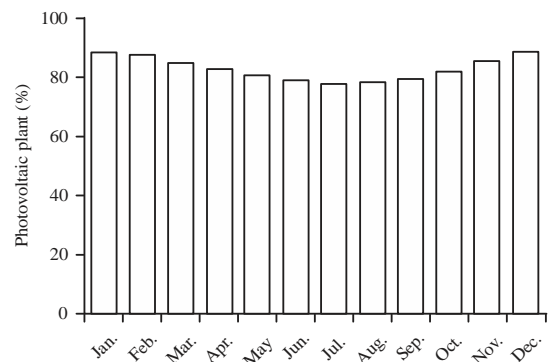Sungrow Power Company (2015), http://sungrowpower.com accessed February 3, 2015

Fig. 4: Photovoltaic plant performance ratio

Table 4: System simulation main results

Months	EffG(kWh m^{-2})	E-Ar (MWh)	E-Gr (MWh)	Array η (%)	Sys. η (%)
January	136.8	11,772	11,585	13.83	13.61
February	133.7	11,443	11,263	13.72	13.51
March	180.8	14,940	14,696	13.26	13.05
April	192.9	15,603	15,346	12.95	12.73
May	210.9	16,625	16,357	12.59	12.39
June	213.7	16,512	16,238	12.33	12.12
July	223.1	16,941	16,661	12.12	11.92
August	223.2	16,992	16,713	12.19	11.99
September	213.6	16,423	16,151	12.36	12.16
October	196.2	15,556	15,310	12.75	12.55
November	158.4	13,096	12,889	13.3	13.09
December	134.3	11,519	11,340	13.78	13.56
Year total	2217.6	177,423	174,549	12.82	12.61

EffG: Global irradiation effectively reaching the PV-cell surface corrected for IAM and shadings simultaneously, E-Ar: Effective energy (DC) at the output of the array (Mwh), E-Gr: Electrical energy (AC) injected into the grid (Mwh), Array η: Efficiency of the array defined as the energy output of the array divided by the rough area of the modules, Sys. η: Efficiency of the system defined as the energy output of the inventor divided by the rough area of the modules
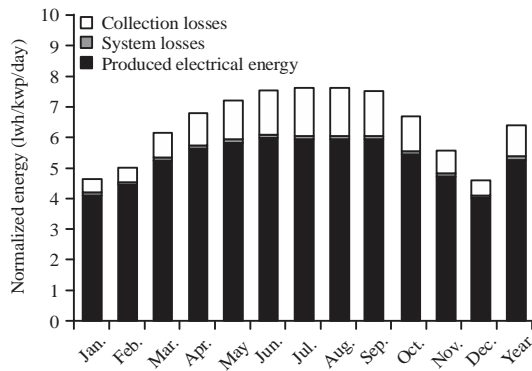

Fig. 5: Normalized electricity production and loss factors per installed kWp

average energy output efficiency (η) of the entire system per area is found to be 12.61%. The simulation's main results on a monthly basis are summarized in Table 4.

Specific power output: The specific energy yield of PV systems is an essential indicator that relates the installed capacity of photovoltaic systems to the amount of PV generated electricity. It is a practical way to calculate the amount of generated electricity based on the installed capacity, especially if a standard indicator is established for a country or a region. Such a universal number can also be used as a rule of thumb to give a preliminary indication of the efficiency and feasibility of a PV system or to compare two systems or sites.

The PV system's calculated annual average daily final yield is 5.31 kWh/kWp/day. This is more than twice the numbers reported in Germany, Poland, Spain, Italy, the Netherlands and Northern Ireland (Kost *et al.*, 2013).

The normalized electricity production per installed kWp is illustrated in Fig. 5. The annual specific power output of useful electricity is 1,939 kWh/kWp/year.

Hourly tracking of power output: Hourly tracking of the PV plant's supply of electrical energy shows that the system is capable of supplying the grid with electricity for 13 h a day from 5:00 am until 6:00 pm., where the peak electricity supply is at noon with an annual grid injection of 22,795 MWh from 12:00-1:00 pm.

The amount of electricity expected to be injected into the grid per hour is an important factor for grid management and electricity distribution companies. The PV solar plant, as an electricity supplier (energy generation company), is required to predict the amount of energy it will supply to the grid with a fair degree of accuracy. An hourly sum of electricity supplied to the grid each month is listed in Table 5.

System losses: In a photovoltaic system, solar energy is converted into electricity through several steps utilizing subsystems and components; a fraction of the energy is lost at every step of the way depending on the efficiency. Losses are lumped into three major stages.

The first stage is converting the available solar energy (GHI) into effective irradiance on collectors; here, the incoming sunlight is attenuated by shading, dirt and reflection before it reaches the photovoltaic cell. The global incident irradiance as received by the tilted plane (2,348 kWh m^{-2}) losses 5.6% to become (2218 kWh m^{-2}), resulting in a total of 1307235 MWh of solar energy received by the PV cells.

In the second stage, the sunlight is converted into an electric current; this is done at an efficiency of 15.58%. Overall losses in this stage (temperature, module, quality, mismatch and resistant) are 12.9%, resulting in a net total of 177,756 MWh of DC electrical energy at the output of the array.

The third stage, the DC electrical energy is converted into useful AC electrical energy through inverters and transformers. System losses in the electrical components at this stage are 1.8%, resulting in a net total of 174,549 MWh of AC electrical energy available at the output of the inverter.

Table 5: Hourly sum of electricity supplied to the grid

Months	Hourly sum of electricity (Mwh)												
	5 h	6 h	7 h	8 h	9 h	10 h	11 h	12 h	13 h	14 h	15 h	16 h	17 h
January	0	0	500	1024	1314	1566	1692	1731	1618	1266	735	138	0
February	0	39	533	960	1213	1364	1532	1519	1560	1262	905	374	0
March	0	266	861	1389	1731	1921	1990	1954	1718	1419	980	437	30
April	47	450	1027	1495	1821	1956	1943	1899	1724	1439	1014	478	54
May	84	545	1111	1563	1873	2051	2064	2009	1835	1520	1078	536	88
June	86	507	1069	1532	1846	2003	2052	1990	1823	1540	1109	574	108
July	82	463	1050	1538	1872	2056	2097	2049	1905	1615	1182	631	120
August	56	435	1046	1567	1915	2096	2130	2079	1926	1624	1166	595	77
September	24	457	1077	1579	1910	2082	2111	2038	1858	1527	1030	435	23
October	0	420	1074	1580	1886	2083	2094	1999	1759	1379	832	204	0
November	0	203	875	1336	1654	1836	1887	1769	1566	1132	621	8	0
December	0	4	573	1026	1407	1648	1705	1758	1459	1130	629	1	0
Year	379	3789	10798	16590	20441	22662	23297	22795	20753	16852	11282	4411	500

Capacity factor: The capacity factor is the ratio of actual energy produced in a year to the maximum theoretical potential energy output over the same period. For solar power plants, the capacity factor is calculated by dividing the annual AC electricity generated (AC kWh) by the plant's nameplate power (DC kW) and then dividing this figure by the total hours in one year (8,760 h) as shown in Eq. 1. This universally used definition for an electrical power plant capacity factor is a disadvantage when used to compare the performance of solar power plants to fossil or nuclear power plants since the solar plant day is only 12 h. Since the average time that the fuel (Sun) of the solar plant is available during the year is 12 and not 24 h every day, one can argue that there is a need for a more meaningful definition for the capacity factor for solar plants. The capacity factor for a solar power plant is calculated using Eq. 1:

$$\text{Capacity factor} = \frac{\text{Electricity produced (MWh per year) in AC}}{(\text{h/year}) \times (\text{PV power (MW) in DC})}$$
(1)

$$\text{Capacity factor} = \frac{174549 \text{ MWh}}{8760 \text{ h} \times 90 \text{ MW}} = 22\%$$

ECONOMIC ANALYSIS

Capital cost: Worldwide, the capital cost (CAPEX) of photovoltaic systems has been decreasing significantly over the past five years; module prices, which make up the majority of the cost, have decreased by 80% and system prices have decreased by 65% (International Renewable Energy Agency, 2015; International Energy Agency, 2014b). In 2013, the capital cost of a large-scale utility system could fall below 1.50 W^{-1}.

In the USA, the installed prices for 98 utility-scale PV projects built between 2007 and 2013 have fallen from around $5.0 to $3.0/W (Energy Information Administration, 2013; Bolinger and Weaver, 2014). The lowest recorded price, as filed for regulatory approval in New Mexico, for a utility-scale

Table 6: Utility-scale PV system capital cost

Country	China	Germany	Italy	UK	Australia	France	Japan	US
PV capital cost ($ kWP)	1,400	1,400	1,500	1,900	2000	2,200	2900	3,000

plant to be built under turnkey construction contracts in 2015 is $1.6/W ($1.98/WAC) (Energy Information Administration, 2013).

The capital cost of a utility-scale photovoltaic plant in the year 2013 varied between 1,400-3,000/kWp according to the international energy agency (IEA). Typical utility-scale PV system prices in selected countries in $/kWp are shown in Table 6 (Feldman *et al.*, 2014; International Energy Agency, 2014a).

The capital cost of the solar plant in this study is estimated based on current market prices, a local contractor's quotation, materials, labor and land cost to be $131 million dollars or 1,456 $/kW.

Operation and Maintenance Cost: The cost of operation and maintenance (O and M) for large-scale PV plants is probably the lowest for any power generation source. Its simple technology of producing electricity without mechanical moving parts is a key factor in reducing this cost.

The National Renewable Energy Laboratory estimates the annual cost at $20.00/kW (Feldman *et al.*, 2014). The International Energy Agency's (IEA) World Energy Investment Outlook 2014 estimates the installation cost of a large-scale photovoltaic plant at $25/kW per year (International Energy Agency, 2014a). The U.S. Department of energy estimates that the average levelized O and M cost is $11.40/MWh for PV plants entering service in year 2019 (Energy Information Administration, 2014). The operation and maintenance cost of the proposed 90 MW power plant is calculated based on these estimates, resulting in an annual cost of $1,800,000, $2,250,000 and $1,989,859.

Since the operation and maintenance of a photovoltaic plant depend more on general labor (cleaning panel, site management) than on specialized technical and engineering

tasks and the labor cost in Jordan is much less than that in the US or Europe, we expect that the O and M cost will be 25-50% less than that reported in industrial nations. Thus, the estimated annual operation and maintenance cost is $1.5 million for the 90 MW utility-scale PV plant in this study or $16.67/kW.

Cost of electricity: The Levelized Cost of Electricity (LCOE) is a standard method used to define the cost of electricity generation (in $/MWh) over the life of a power plant, therefore enabling one to compare the electricity cost across a wide range of technologies (Ueckerdt *et al*., 2013 ; Branker *et al*., 2011; Reichelstein and Yorston, 2013). In this paper, we developed a simplified model based on Eq. 2 to calculate the cost of electricity:

$$LCOE = \frac{\sum_{t=0}^{T}(Capex_t + O_t + I_t) \times (1+r)^{-t}}{\sum_{t=0}^{T}(Elec_t) \times (1+r)^{-t}} \quad (2)$$

Where:
LCOE : Levelized Cost of Electricity ($/kWh)
t : The year from $t = 0$ the first year of operation to $t = T$ last year of operation
T : Plant life in years
$Capex_t$: Capital investment in year t
O_t : O and M expenditures in year t
I_t : Interest paid to service the debt in year t
r : Discount rate
$Elec_t$: Electricity produced in KWh during year t

In performing the calculations, we made the following assumptions. A capital cost of $131 million is invested in the first year ($t = 0$) and then, the total amount is financed for ten years, which is the payback period.

Considering that generated electricity will be sold to a government-owned company under a Power Purchase Agreement (PPA) backed by the government for the life of the plant, the interest rate is calculated as LIBOR+2%. The LIBOR rate over the past five years has averaged less than 1.0% (Macrotrends, 2015). Thus, the interest rate selected in this study is 3%.

Three scenarios of discount rate are used in the levelized cost of electricity calculations. The first is the real cost with a zero discount rate ($r = 0$), the second is at a discount rate equal to the interest rate ($r = 3\%$) and the third scenario is at a discount rate equal to twice the interest rate ($r = 6\%$). The operation and maintenance cost is fixed over the plant's life. Thus, inflation was not considered in our calculations.

Calculated results of the LCOE ranged between 0.05 and 0.085 $/kWh, which is comparable to reported results, such as in Germany (1,000-1,200 kWh m^{-2} GHI) where the lowest LCOE reached 0.085 $/kWh in the third quarter of 2013 (Kost *et al*., 2013; Philipps *et al*., 2014).
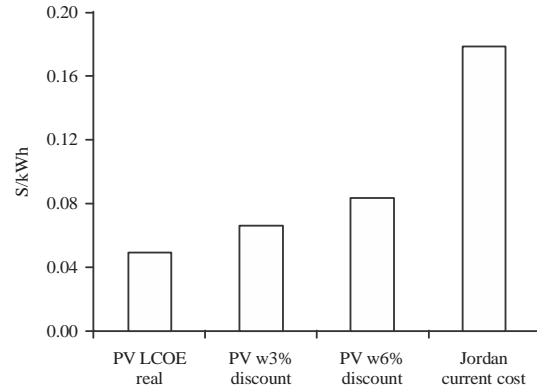

Fig. 6: Levelized cost of electricity (LCOE) of the utility-scale PV plant compared to the current cost of electricity using conventional power plants
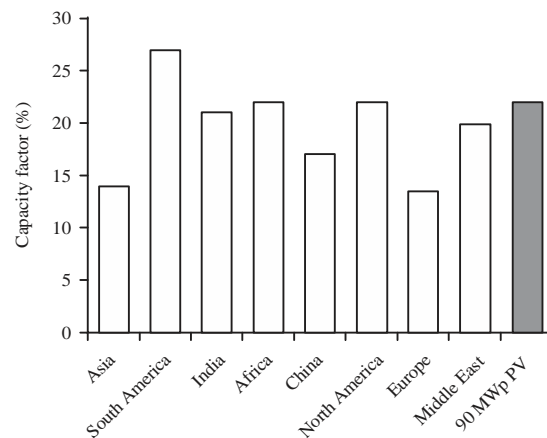

Fig. 7: Utility-scale PV plant average capacity factor in different regions of the world

The lowest cost was 0.05 $/kWh for the real cost scenario with no discount rate applied. In the second case scenario of a 3% discount rate, the cost was 0.066 $/kWh. In the third scenario of a 6% discount rate, the cost was 0.085 $/kWh as shown in Fig. 6.

In all three cases, the cost is much lower than the current cost of 0.179 $/kWh Jordan is paying for electricity generation using conventional power plants.

DISCUSSION

The capacity factor of 22% for the proposed power plant is in line with utility-scale average values of 14-27% worldwide. Utility-scale PV plants in Europe and Asia have the lowest average capacity factor of 14%, whereas PV plants in South America have the highest average capacity factor of 27% (International Renewable Energy Agency, 2015). The capacity factor of PV utility-scale projects in different regions of the world is shown in Fig. 7.

The calculated results of the levelized cost of electricity ranged between 0.05 and 0.085 $/kWh, which is comparable to reported results, such as in Germany where the lowest cost reached 0.085 $/kWh in the third quarter of 2013 (Kost *et al.*, 2013; Philipps *et al.*, 2014).

Compared with former studies, the levelized cost of electricity in this study is lower than most reported results. Adaramola (2014) reported a cost to $0.103/kWh for a small PV-grid tied energy system in Nigeria. According to Pickrell *et al.* (2013), the LCOE of solar PV system in California is between $0.15/kWh and $0.20/kWh. The first systemic study on the levelized cost of electricity of RE in China by Ouyang and Lin (2014) reported results between $0.12/kWh and $0.28/kWh for LCOE of solar PV. Another study by Mondal and Sadrul Islam (2011) of grid-connected solar PV system in Bangladesh, found that the electricity production cost varied between $0.17/kWh and $0.22/kWh.

CONCLUSION

This study examines the technical and economic potential of utility-scale PV electricity generation in the Middle East by proposing a 90 MWp plant in Jordan as a case study. The plant site was selected in Mafraq, a semiarid area with typical Middle Eastern meteorological characteristics and with 2,103 kWh m^{-2} of global horizontal irradiation, which is a type of solar radiation that is typical in the Middle East.

Solar power plant performance modeling and an energy yield simulation were performed using a PVsyst Version 6 computer code. The study found that the plant's annual performance is 82.6% and that the annual average yield of 5.31/kWh/kWp/day is more than twice the numbers reported in Germany, Poland, Spain, Italy, Netherlands and Northern Ireland.

The study found that annual electricity generation of the proposed solar PV plant is 174,549 MWh of useful AC electricity, sufficient energy to power approximately 40,000 Jordanian homes with clean, renewable energy.

Economically speaking, the study found that the LCOE ranged between 0.05 $/kWh for the real cost scenario without any discount rate applied and 0.085 $/kWh for the scenario of a 6% discount rate. In all cases, the cost of solar electricity is much lower than the current cost of 0.179 $/kWh that Jordan is paying for electricity generation.

We can finally conclude, based on our findings, that a utility-scale PV power plant is a viable option in Jordan and that it is capable of fulfilling a sizable portion of the country's energy needs at a competitive cost.

It can also be concluded that a utility-scale PV plant will reduce Jordan dependence on energy imports, which cost 17% of its GDP and will increase the country's energy security by utilizing indigenous resources.

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