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Muhammad Zubair,[a] Ahmed Bilal Awan, R. P. Praveen, and Muhammad Abdulbaseer

AFFILIATIONS

Electrical Engineering Department, College of Engineering, Majmaah University, Majmaah 11952, Kingdom of Saudi Arabia

[a]m.zubair@mu.edu.sa

ABSTRACT

High energy utilization per capita and the country's gross domestic product (GDP) dependence on oil exports are the major problems of the Kingdom of Saudi Arabia (KSA). Abundant solar energy resources available in the country can help KSA to diversify its GDP. In this work, the photovoltaic (PV) energy outputs of KSA are compared with the potential PV energy customer such as European Countries, China, India, and Pakistan based on the levelized cost of energy (LCOE) and the net present cost (NPC). The PV energy is analyzed by a 4 GW grid connected PV system placed in the capital of each country. The grid sale price of PV energy is taken as half of the grid purchase energy price for each respective country. The high voltage direct current (HVDC) transmission of solar energy generated by the 4 GW PV system in KSA exported to potential customers is analyzed based on the NPC, LCOE, and payback period. Gwadar (Pakistan), (Antalya) Turkey, Karachi (Pakistan), and Ahmedabad (India) are economically feasible options with an LCOE of 5.2 ¢/kWh, 5.5 ¢/kWh, 6.2 ¢/kWh, and 7.5 ¢/kWh, respectively. The European countries are infeasible for PV energy export from KSA based on their load curves and NPC. The megacity of Karachi can be the first customer of KSA solar energy transmitted by HVDC.

NOMENCLATURE

A	Annual worth, US$
AOI	Angle of incidence, degree
BUS$	Billion US$, US$
C_{AT}	Total annual cost, US$/year
CC	Capital cost, MUS$
CF	Capacity factor, %
CRF	Capital recovery factor, US$
DNI	Direct normal irradiance, W/m^2
$DR_{nominal}$	The nominal discount rate with inflation, %
DR_{real}	The nominal discount rate without inflation, %
E	Energy generated, kWh
E_{Con}	Energy consumed, kWh
EPC	Engineering, procurement, and construction, US$
GHI	Global horizontal irradiance, W/m^2
i	Interest rate, %
I_b	Direct normal irradiance by the angle of incidence, W/m^2
$I_{d,ground}$	Irradiance reflected from the ground, W/m^2
$I_{d,sky}$	Total sky diffused irradiance, W/m^2
I_{poa}	Irradiance plane-of-array, W/m^2
I_{tr}	The transmitted irradiance, W/m^2
IDC	Insurance during construction, US$
IF	Installed capacity, kW
LCOE	Levelized cost of energy, US$/ kWh
MUS$	Million US$, US$
N	Number of years, number
NPC	Net present cost, MUS$
O&M	Operation and maintenance cost, US$
P	Investment, US$
P_{dc0}	Nameplate DC rating of the PV module, W
P_{PV}	DC power of the PV module, W
PDC	Project development cost, US$
POA irradiance	Plane-of-array irradiance, W/m^2
Q_n	The electricity generated in a year, kWh
R_n	The revenue generated from electricity sales, US$
RR	The rate of return, %
T_{cell}	The cell temperature, °C
T_{ref}	The reference cell temperature, °C
TAC	Total annualized cost, US$/year
γ	Temperature coefficient, %/°C

ΔI The incremental investment cost, US$
ΔS The annual saving net of future annual costs, US$
¢ Cent US$, US$

I. INTRODUCTION

The Kingdom of Saudi Arabia (KSA) is the largest exporter of oil. A major share of the GDP of KSA consists of exports of fossil fuels.[1] The government had restricted the fuel and electricity prices until January 2018 for domestic use. The price of electricity in 2017 was 1.3 ¢/kWh which increased to 4.8 ¢/kWh of lower tier for household use.[2] The current price of electricity is still much lower than most European countries.[3] The cost of electricity in Germany and Denmark is 609% and 642% higher than KSA, respectively.[3]

These energy subsidies by KSA resulted in a high net energy per capita. KSA was using 3.6 times more energy per capita than the world and 1.8 times more energy per capita than Germany in 2014.[4] Germany is an industrial country with the highest GDP in Europe. These cheaper energy rates affected the country's agricultural paradigm and the design of buildings. The agricultural sector used cheaper energy to pump water from underground nonrenewable resources to achieve an economically viable harvest.[5,6] The buildings in KSA have poor insulation and use energy inefficient techniques to maintain indoor temperature.[7,8] The inhabitants of buildings are protected from the extreme heat of summer and extreme cold of winter by heat pumps operating inefficiently by cheaper electricity. KSA generates the required electricity (206 045 GWh in 2016)[4] from fossil fuels.

The renewable energy systems can help in achieving sustainability and diversification of the GDP of KSA.[2,9–12] Renewable resources are intermittent in nature and location dependent. In renewable resources, solar and wind are the most prominent sources.[9] The most prominent renewable resources of KSA are solar resources.[9] KSA has laid a plan of Vision 2030 to incorporate the renewable energy system into the national grid.[13–15] Initially, KSA announced 41 GW (Ref. 16) of renewable energy installed capacity of renewable energy by 2030 but later on, it was changed to 9.5 GW with 3.45 GW of renewable energy to be installed by 2020. KSA granted a contract of a 300 MW solar power plant to a private company in February 2018.[17] KSA has also signed a memorandum with Soft Bank Corp for a 200 GW solar plant with a cost of 200 Billion US$.[18]

Renewable energy systems have a large capital cost and a low maintenance cost. The costs of renewable energy systems such as solar and wind are decreasing day by day, which is making them economically more feasible.[19] Huge investment has been made in renewable energy systems with 157 GW of renewable energy projects being commissioned in 2017, of which 45% systems are in China by 126.6 Billion US$ to fight the air pollution and environmental effects caused by huge industrial progress.[20] The levelized cost of a unit generated by solar photovoltaic (PV) systems of a utility-scale project dropped to 0.086 US$/kWh which is 15% less than the previous year.[20] This reduction is caused by the lower capital cost. The cost of solar PV modules has been reduced by 80% in the last decade.[21] The installed capacity of wind turbines has reached 467 GW in 2017. The price of wind turbines has fluctuated during the last 20 years; nevertheless, the prices of wind turbines are at the lowest in the last 20 years at an average of 750–1000 US$ per kilowatt.[21]

KSA can export solar energy to other countries and reduce the dependence on the export of fossil fuel. Two main solar energy export megaprojects have been discussed in the literature which are solar energy exports from Gobi desert, Mongolia[22–25] to China, Korea, and Japan and solar energy export from the Middle East (ME) and North African (NA) (MENA) countries to Europe.[26–30] The researchers of solar energy export from MENA to Europe have failed to consider the load curves of the customer's countries with the PV energy generation time in ME. North Africa and Middle Eastern countries are analyzed together while these countries have a difference of 3 h in their local time. In this research, the largest country of ME, KSA is analyzed for not only European countries but also for the eastern countries of Pakistan, India, and China based on their respective load curves, levelized cost of energy (LCOE), and net present cost (NPC). The solar energy generated in KSA can be exported to energy-hungry countries using high voltage direct current (HVDC) transmission.

HVDC transmission is economically more feasible than high voltage alternating current (HVAC) for longer distances.[31] The cost of towers and conductors in HVDC is lower than HVAC but the cost of conversion station in HVDC is much higher than a conventional AC step-up/step-down transformer station.[32,33] HVDC has active power control and does not have problems like reactive losses while it also has less Corona discharge losses and no skin effect. The main disadvantages of HVDC are the induction of harmonic voltages and currents on both sides, consumption of reactive power by converters, and more expensive DC breakers.[34] Electrical energy generated by PV in KSA can be transmitted to Europe, India, Pakistan, and China using HVDC transmission.

The PV energy analysis is performed for KSA and the potential customers which are European countries, China, India, and Pakistan. The resources are explored based on the area, solar irradiance, temperature, and household energy prices. The PV energy output of KSA is compared with potential customers by simulating a 4 GW grid connected PV system in the capital of each country. The grid sale price is selected as the half of the grid purchase price of that country. The export of large-scale PV plant generated energy via HVDC transmission to European and Eastern Countries has been explored for the first time, based on the hours of solar energy generation and load curves of customer countries. The feasibility of HVDC transmission of solar energy generated by PV panels is analyzed based on the NPC, LCOE, and payback period.

II. METHODOLOGY

The objective of this work is to compare the PV energy potential of KSA with potential future customers like various European countries, China, India, and Pakistan. The GHI of KSA and potential customers are shown in Fig. 1. KSA is in the solar belt and has abundant solar resources. The European Countries are in the West of KSA and their distance form KSA is longer than the distance to Pakistan, Turkey, and India. The solar resources, available area based on the forest and agricultural land and the price of electrical energy for household customers is shown in Table I.

The simulation is performed by the System Advisory Model (SAM) by the National Renewable Energy Lab, USA (NREL). The energy generation by PV panels is directly proportional to the plane of array (POA) irradiance, which is a function of the direct irradiance, its angle of incidence on the module surface, and the diffuse irradiance,

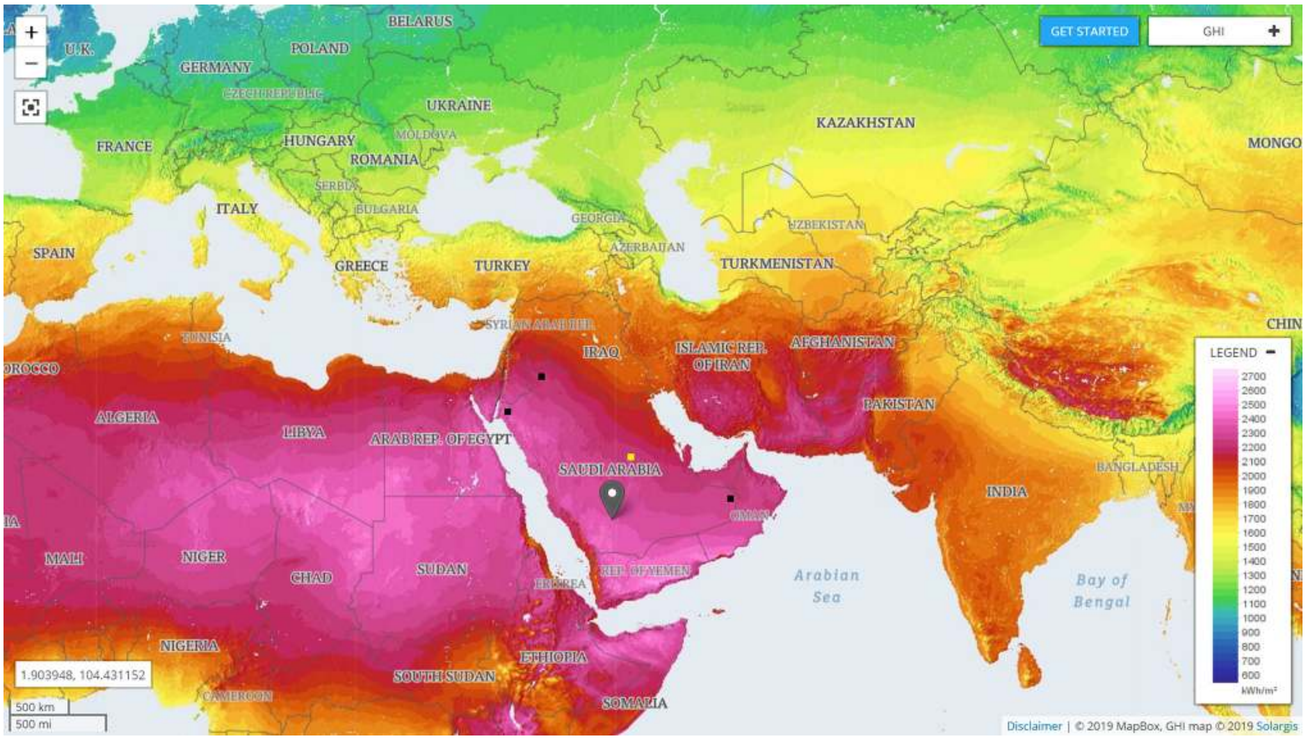

FIG. 1. GHI of KSA and its potential customers for PV energy exports.[35] The black squares present the three locations (Tabuk, Al Ahsa, and Al) for large PV plants for energy export using HVDC. The yellow square shows the location of Riyadh. Solar resource data obtained from the Global Solar Atlas, owned by the World Bank Group and provided by Solargis.[35]

and is calculated by using an empirical model proposed by Perez *et al.*,[37]

$$I_{poa} = I_b + I_{d,sky} + I_{d,ground}, \tag{1}$$

where[37]

$$I_b = DNI \times \cos(AOI). \tag{2}$$

The PV energy output degrades with the rise of temperature as shown in equation[9]

$$P_{PV} = \frac{I_{tr} P_{dc0}}{1000}[1 + \gamma(T_{cell} - T_{ref})]. \tag{3}$$

The PV panels used in this work are Jinko Solar365JKM. These PV panels are 72 cell monocrystalline flat plate panels with a rated capacity of 365 W with an efficiency of 17.4% and their temperature coefficient γ is $-0.41/°C$. These panels are placed on single axis tracking.

PV energy analysis is performed for all the capitals of all the selected countries with a 4 GW grid-connected PV system. The grid sale price is selected as half of the grid purchase price of each country. The weather file containing solar irradiance and temperature of locations is taken from the photovoltaic geographical information system (PVGIS).[38] The economic parameters of these projects are shown in Table II.[19,39–41] The capital cost is kept constant for all countries ignoring the difference in various customs duties and taxes.

The results are analyzed based on the energy performance parameters of the capacity factor and energy yield. The capacity factor is the ratio of total energy generated by the maximum energy that can be produced by the system in a specific time period which are presented as[44]

$$CF = \frac{E}{365 \times 24 \times IC}. \tag{4}$$

The energy yield is a ratio between the total energy generated and installed capacity which is shown as[45]

$$EY = \frac{E}{IC}. \tag{5}$$

The economic analysis is performed on based on the financial performance parameters of NPC, LCOE, and payback period where the NPC is the current sum of all future cash flows of the project and is calculated by[44]

$$NPC = \frac{TAC}{CRF}, \tag{6}$$

where TAC is the total annualized cost and CRF is the capital recovery factor which is calculated as[44]

$$CRF = \frac{A}{P} = \frac{i(1+i)^N}{(1+i)^N - 1}. \tag{7}$$

The LCOE is the lifecycle cost by lifetime energy production. Normalized and real LCOE of the renewable energy project are calculated by[44,46]

TABLE I. Energy parameters and PV energy resources of the potential customers of KSA.[4,36]

Country	Fossil fuel energy use %	Total area km^2	Forest and farmland %	Household electricity price ¢/kWh	GHI kWh m^2 day	Temperature °C
KSA	100	31 521 000	0.6	4.8	6.2	21.6
China	88	9 596 961	23.9	8	4.7	6.9
Pakistan	62	881 913	4.4	13	5.5	25.9
India	74	3 287 263	28.2	8	5.3	27.5
Austria	65	83 858	47.7	22	3.2	9.1
Belgium	73	30 510	23.3	31	2.8	10.5
Denmark	68	44 493	14.7	36	2.9	8.7
Finland	42	338 145	80.7	18	2.7	4.7
France	46	25 713	42.9	20	3.8	7.3
Germany	80	2428	40.1	34	4.6	18.6
Greece	86	357 386	24.8	21	3.4	11.3
Italy	79	70 273	74.0	24	3.7	9.4
Netherlands	91	41 198	12.3	19	3.0	10.7
Norway	58	385 178	36.2	20	2.7	4.9
Poland	90	312 685	32.1	16	2.9	8.3
Portugal	73	91 568	42.9	26	4.9	17.2
Spain	72	498 468	46.2	27	4.4	12.9
Sweden	30	450 295	75.7	22	2.9	6.9
Turkey	90	23 507	19.5	10	4.4	10.5
Ukraine	75	603 628	18.2	5	3.1	8.2
United Kingdom	83	248 532	13.2	21	2.7	10.7

$$\text{nominal LCOE} = \frac{\sum_{n=1}^{N} \frac{R_n}{(1+DR_{nominal})^n}}{\sum_{n=1}^{N} \frac{Q_n}{(1+DR_{nominal})^n}}, \tag{8}$$

$$\text{real LCOE} = \frac{\sum_{n=1}^{N} \frac{R_n}{(1+DR_{nominal})^n}}{\sum_{n=1}^{N} \frac{Q_n}{(1+DR_{real})^n}}. \tag{9}$$

The discounted payback period is the minimum number of years required for the discounted sum of annual net savings to equal the discounted incremental investment costs calculated by the equation

$$\sum_n \frac{\Delta I_n}{(1+DR_{nominal})^n} \le \sum_n \frac{\Delta S_n}{(1+DR_{nominal})^n}. \tag{10}$$

The export analysis for the potential customers of solar PV energy export from KSA to energy-hungry countries is explored based on the load factor. The load factor is defined as[47]

$$\text{load factor} = \frac{\text{average load}}{\text{maximum demand}}. \tag{11}$$

The timing of PV energy production in KSA to the load curve of these countries is used to analyze the load factor of potential customers.

The PV energy generation by a 4 GW PV plant is analyzed in KSA. The financial parameters of this plant are the same as stated in Table II. This generated electrical energy is transmitted by HVDC transmission lines to the customers. The economic parameters of HVDC are stated in Table III. An HVDC transmission for a capacity of 4000 MW is designed for bipolar 660 kV with four conductors of 1250 mm^2. The HVDC system economic parameters are shown in Table III.[48]

The price of HVDC from KSA to Germany, UK, India, China, and Pakistan is evaluated. The political scenarios are evaluated for the safer route of HVDC cables for a 4 GW PV plant. Finally, the most prominent and financially feasible case of such a project is explored based on NPC and LCOE.

TABLE II. The economic parameter of the renewable energy systems.[2,11,19,39,42,43]

System type	Description	Value	Unit
PV system Jinko365M-72V[42]	EPC	1.05	MUS$/MW
	Cost of land	0.02	MUS$/MW
	PDC	0.04	MUS$/MW
	IDC	0.01	MUS$/MW
	Net initial cost	1.12	MUS$/MW
	O&M	1.78	¢/ kWh
	Insurance	0.73	¢/ kWh

III. ANALYSIS OF THE PV SOLAR ENERGY POTENTIAL

KSA has enormous scope for electrical energy generation by the PV system.[49] Table I[36,50] shows a comparison between the KSA and

TABLE III. Economic parameters of HVDC transmission of a 4 GW transmission line.

Cost type	Cost	Unit
Converters[48]	726	MUS$
Cable land overhead[48]	2.40	MUS$/km
Cable undersea[48]	4.12	MUS$/km
Return on equity	17	%
Discount rate	10	%
Operation and maintenance cost	58	MUS$
Energy sale price	10	¢/kWh
Copper resistivity	0.0172	$\Omega\cdot mm^2/m$

the potential customers of PV energy export based on parameters such as energy per capita, energy generation, use of fossil fuels in the energy mix, grid energy rates for household customers, GHI, and ambient temperature. Tabuk in west, Al Qurayyat in north, and Al Ahsa in the east are the locations in KSA from where PV energy export to European countries, Turkey and Eastern countries is possible based on their location. The PV energy analysis performed for these areas show that all these locations have good solar resources. Figure 2 shows the monthly and daily average PV energy output of the 4 GW plants at Riyadh, Tabuk, Al Ahsa, and Al Qurayyat. Tabuk has the highest capacity factor of 27.9% and Riyadh, the capital of KSA, has the least capacity factor of 23.9%.

PV energy analysis is performed for all the capitals of all the selected countries with a 4 GW grid-connected PV system with the energy price sold to the grid is selected as half of the household energy price.[36,50] The achieved CF, energy yield, LCOE, NPC cost, discounted payback period, and hour of operations of the project are shown in Table IV. The results show that all potential customers have on average 80% higher LCOE than KSA. The area is an important aspect in establishing very large-scale PV plants. Most of the European countries have large forests and farmlands which reduces their overall PV generation capabilities. The discounted payback period of KSA is 24.8 years which in comparison with European countries is high because the price of energy sale to the gird is selected as half of the household energy price which for KSA is just 2.4 ¢/kWh.

IV. ANALYSIS OF ENERGY EXPORT

The load curve of KSA has two peaks. The initial load peak is between 1200 and 1400 h and the latter between 1800 and 2000 h. The PV generation in KSA is between 0600 and 1800 h which coincides with the first load peak of KSA while for the second load peak, some other energy generation system must be used. Figure 3(a) shows the PV energy time duration in KSA according to the time zone of potential customer countries. The PV energy from KSA will be available for other countries at different times of the day. Now it is important to see the load curve[9,39,51–53] of potential customers of PV energy of KSA. The load curves of European and Asian countries are shown in Fig. 3(b). Figure 3 shows that European countries are not favorable customers based on their load curves as PV energy generation in KSA is only available in these countries during off-peak hours and this energy can only be used to reduce the base load of off-peak time which will decrease the load factor. The reduction of load factor will increase the net grid LCOE. This energy can only be used to store water in

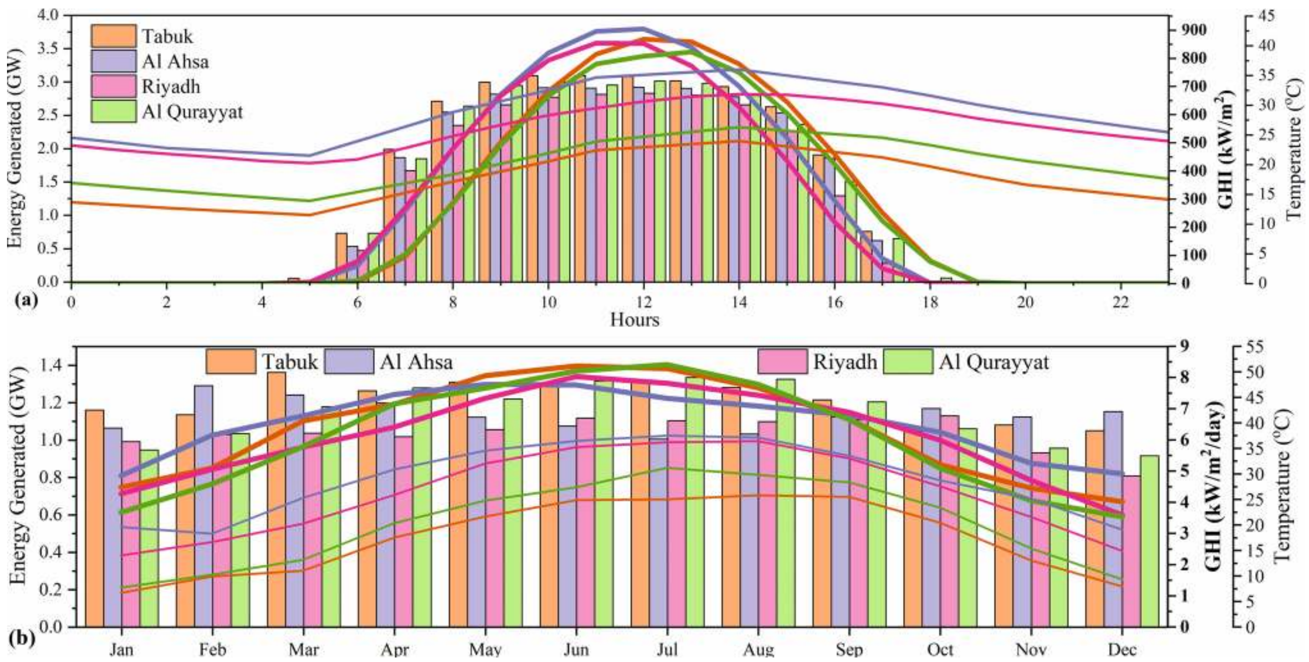

FIG. 2. Average PV energy output in Tabuk, Al Ahsa, Riyadh, and Al Qurayyat shown as bars and the respective inputs of GHI shown in bold lines and Temperature shown by thin lines. (a) Average hourly PV energy and (b) average monthly PV energy.

TABLE IV. The solar energy capabilities of potential customers of KSA and their respective economic analysis.

Country	Energy sold to the grid price ¢/kWh	Capacity factor %	Energy yield kWh/kW	LCOE (real) ¢/kWh	NPC BUS$	Discounted payback period Years
KSA (Riyadh)	2.4	23.9	2091	3.7	1.0	24.8
KSA (Tabuk)	2.4	27.9	2445	3.2	1.0	18.5
KSA (Najran)	2.4	26.4	2313	3.4	0.9	19.8
KSA (Al Ahsa)	2.4	26.2	2294	3.4	0.8	20.3
KSA (Al Qurayyat)	2.4	26.5	2321	3.4	0.8	20.4
China (Tibet)	4.0	21.3	1870	4.2	2.2	12.8
Pakistan	6.5	21.8	1912	4.1	6.2	6.3
India	4.0	21.3	1867	4.2	2.4	12.2
Austria	11.0	14.6	1281	6.1	7.5	5.4
Belgium	15.5	13.9	1217	6.4	11.6	3.8
Denmark	18.0	13.8	1213	6.4	13.8	3.3
Finland	9.0	13.3	1163	6.7	4.6	7.9
France	10.0	14.6	1275	6.1	6.6	6.0
Germany	17.0	13.6	1192	6.5	12.9	3.4
Greece	10.5	19.5	1707	4.6	10.3	4.2
Italy	12.0	18.8	1646	4.7	11.6	3.8
Netherlands	9.5	13.7	1201	6.5	5.5	6.9
Norway	10.0	11.7	1024	7.6	4.7	7.7
Poland	8.0	14.4	1263	6.2	4.3	8.3
Portugal	13.0	20.8	1824	4.3	14.9	3.0
Spain	13.5	20.9	1833	4.3	15.5	2.9
Sweden	11.0	14.1	1235	6.3	7.1	5.7
Turkey	5.0	19.9	1746	4.5	3.2	10.1
Ukraine	2.5	15.0	1313	5.9	−1.1	<25
United Kingdom	10.5	12.1	1059	7.4	5.4	6.9

pump storage dams for later use. The eastern countries can use this PV energy generated in KSA at their peak load hours. This PV energy can shave the load peaks and help them in achieving higher load factors which will decrease the grid LCOE. India, Pakistan, and China are developing countries where higher future load growth is predicted.

HVDC transmission from a very-large-scale PV plant has an added advantage that voltage conversion at the PV side is not required. The nighttime in this project can be used for repair and maintenance. HVDC analysis is performed with a 4 GW PV plant in KSA. The same economic parameters of PV plants are used as mentioned in Table II.

4 GW PV generation and HVDC transmission analysis is performed for the following options shown in Table V. The first four options are for eastern customers of China, India, and Pakistan while the other five options are for the western potential customers of Turkey, Greece, the United Kingdom, and Germany. The HVDC routes are possible via three neighboring countries which are Oman, Egypt, and Syria. In the current political situation, the route via Syria is not feasible because of the ongoing war while the other two countries are allies of KSA and safe passage for HVDC lines is possible. The distance between KSA and China and Germany are more than 3000 km while India, Pakistan, Turkey, and Greece are nearby potential customers. Chinese populated cities located at eastern parts and are located the most far away from KSA. UK in the west is also very far from KSA where London is located around 4500 km from Tabuk. The feasibility analysis of this project is based on the capital cost, NPC, LCOE, and payback period where the project life is taken as 50 years.

The losses in HVDC transmission are in converter stations and transmission cable. The converter losses are taken as 1 percent per converter.[54] The line losses depend on the length of the conductor which are calculated by I^2R. Losses range from 4.4% for Turkey to 20.3% for China. The results of these scenarios are shown in Table VI. The most economically feasible scenario for energy export is Turkey via Syria with a capital cost of 6.7 BUS$, an NPC of 4.78 BUS$, and an LCOE of 4.5 ¢/kWh. The payback period of this scenario is just 9 years, but the route of this option is via war affected Syria. In the east, Pakistan and India are economically feasible with an LCOE of 5.2 ¢/kWh, 6.2 ¢/kWh, and 7.5 ¢/kWh for Gwadar (Pakistan), Karachi (Pakistan), and Ahmedabad (India), respectively. The energy exports to China, Germany, and London via HVDC transmission is not economically feasible as the NPC is negative and the LCOE is higher than 10 ¢/kWh.

In these scenarios, Karachi is a megacity with power shortage. Karachi electric supply company (KESC) is a privatized company responsible for the generation and distribution of electrical power of Karachi. KESC buys electrical energy from a national grid and still uses scheduled load management in peaks hours. KESC does not have enough finance to develop new energy producing resources and

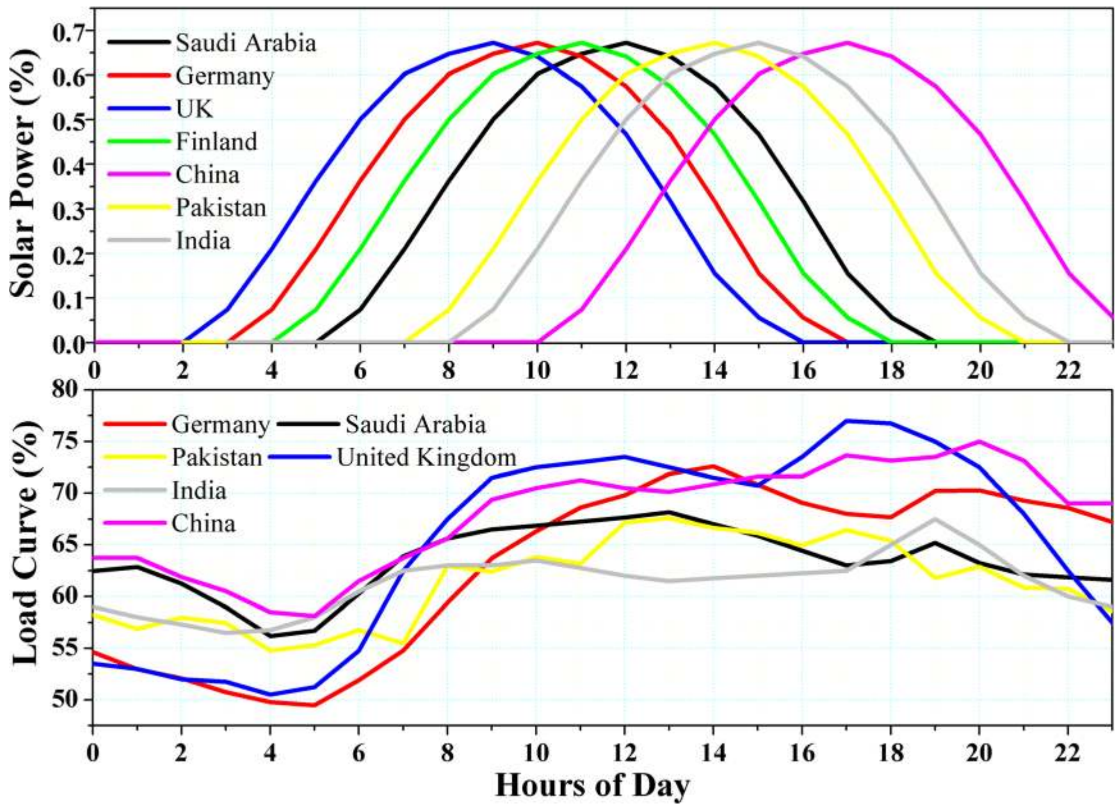

FIG. 3. PV energy generation and load factors of KSA and potential customers.[9,39,51–53]

TABLE V. Energy transmission by the HVDC project for various potential customers.

S	Start	Load Center	Country	Route	Distance Overhead	Distance Undersea	Cost
					km	km	BUSD
1	Al Ahsa	Karachi	Pakistan	Oman, undersea, Gwadar	1068	389	4.9
2	Al Ahsa	Gwadar	Pakistan	Oman, undersea	502	389	3.5
3	Al Ahsa	Ahmedabad	India	Oman, undersea, Pakistan	1756	389	6.5
4	Al Ahsa	Chengdu	China	Oman, undersea, Pakistan	5419	389	15.3
5	Tabuk	Munich	Germany	Egypt, undersea, Italy, Austria	2330	1234	11.4
6	Tabuk	London	United Kingdom	Egypt, undersea, Italy, France, undersea	3188	1278	13.6
7	Tabuk	Antalya	Turkey	Egypt, undersea	278	782	4.6
8	Al Qurayyat	Adana	Turkey	Jordon, Syria	757	0	2.5
9	Tabuk	Kalamata	Greece	Egypt, undersea	1158	673	6.3

energy imports are already in progress. KESC can be the first customer of KSA solar energy transmitted by HVDC.

V. CONCLUSIONS

Vision 2030 of KSA shows the path toward self-sustainability and solar energy export prospects of KSA. The PV energy generation capabilities of KSA are compared with the potential customers of European countries, China, India, and Pakistan using a 4 GW grid connected PV plant simulated in the capital of each country. The grid sale price is selected as half of the grid purchase price for residential customers of that county. The resources are compared on the basis on the area, solar irradiance, temperature, and household energy prices.

TABLE VI. NPC, LCOE, payback time, and capital cost of energy transmission by the HVDC project for various potential customers.

S	Start	Load center	Capital cost BUS$	NPC BUS$	LCOE Nominal ¢/kWh	LCOE Real ¢/kWh	Payback period Simple Years	Payback period Discounted Years
1	Al Ahsa	Karachi	9.1	1.91	8.6	6.2	12.8	30.1
2	Al Ahsa	Gwadar	7.7	3.50	7.2	5.2	10.6	18.9
3	Al Ahsa	Ahmedabad	10.7	0.03	10.4	7.5	15.6	<50
4	Al Ahsa	Chengdu	19.5	−10.1	21.4	15.5	34.8	<50
5	Tabuk	Munich	15.6	−4.01	14.4	10.4	21.5	<50
6	Tabuk	London	17.8	−6.61	17.0	12.3	25.7	<50
7	Tabuk	Antalya	8.8	3.77	7.6	5.5	10.8	19.7
8	Al Qurayyat	Adana	6.7	4.78	6.2	4.5	9.0	13.9
9	Tabuk	Kalamata	10.4	1.79	9.2	6.6	13.3	34.3

The vast area and high GHI of KSA show a huge potential of solar energy generation. This paper provides a detailed analysis of PV energy export prospects from the largest country of the Middle East, KSA, to potential customers based on the load curve and the time of PV generation. The load curve and PV energy generation in KSA show that PV energy generated in KSA is only available in Europe at off-peak hours while this energy is available in the eastern countries of China, India, and Pakistan at peak hours. The PV energy in off-peak hours reduces the load factor of the grid and increases the LCOE of European grids which make it unsuitable for energy export from KSA. The countries in the east of KSA are favorable candidates for PV energy export as the PV energy of KSA will improve the load factor of their national grids and decrease the LCOE of grids. The PV energy should be exported to the east from its generation to meet the second load peak and improve the load factor of the grid of that country. HVDC transmission of solar energy generated by PV panels is analyzed based on NPC, LCOE, and payback period. Pakistan, India in the east and Turkey in the north are economically feasible potential customers with an LCOE of 5.2 ¢/kWh, 5.5 ¢/kWh, 6.2 ¢/kWh, and 7.5 ¢/kWh for Gwadar (Pakistan), Antalya (Turkey), Karachi (Pakistan), and Ahmedabad (India), respectively. In these scenarios, Karachi of Pakistan is a megacity with power shortage at 1460 km from PV fields in Al Asha (KSA). The Karachi electric supply company (KESC) is a privatized company responsible for the generation and distribution of electrical power of Karachi is already buying electrical energy from the national gird. Karachi can be the first customer of KSA solar energy transmitted by HVDC by a CC of 9.1 BUS$. The NPC of this project is 1.91 BUS$ and LCOE of 6.2 ¢/kWh with a payback period of 30.1 years.

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