

The impact of the rise of using solar energy in GCC countries

N.W. Alnaser^{1,*} and W.E. Alnaser²

¹ Department of Architecture and Interior design, College of Engineering, University of Bahrain, Kingdom of Bahrain, Bahrain

² Department of Physics, College of Science, University of Bahrain, Kingdom of Bahrain, Bahrain

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Abstract. The research and the prototype projects in the GCC countries were in place since 1970's which first was started in Kuwait, followed by Saudi Arabia in the 1980's, United Arab Emirates in the 1990's, Bahrain, Oman and Qatar in 21 centuries. Now all GCC countries had conducted, relatively, large project in solar and wind energy, especially Kuwait (currently about 70 MW among a plan of 2000 MW by 2030), UAE (currently about 300 MW among a plan of 2500 MW by 2030) and Saudi Arabia (with an ambitious renewable energy target of 3450 MW by 2020 with a further 6000 GW envisioned by 2023 and to 200 000 MW by 2030). Such an acceleration in the use of solar and wind energy would have an impact. Major impacts are: (1) Major reduction in the solar electricity prices in the region; (2) More investors in renewable energy business; (3) Rise of innovative design of houses to utilize its structure in installation and integration of renewable energy devices; (4) Rise of many service and maintenance of solar technology companies; (5) Establishment of new academic programs and courses in solar and other renewable energy technologies in the higher education institute and technical organizations; (6) More concern and studies on disturbances to the main grid due to solar connection; (7) Major reduction in carbon footprint per capita in GCC countries; (8) Use of more efficient and low consumption household and industrial devices; (9) Boost in battery industry for solar electricity storage.

1 Introduction

GCC countries had the passion in using renewable energies since 1970's. This is no surprise for GCC countries, as it is blessed with an abundance solar energy, as the annual average solar radiation within the GCC countries is relatively equal to 1.1 barrel of oil equivalent per m². The radiation is the highest in Kuwait, in June–July, (8200 kWh/m²) and the lowest in Oman (6400 kWh/m²). The radiation is low in January–December (4200 kWh/m² in the UAE and 3200 kWh/m² in Bahrain) [1]. The first large solar energy project in the region was in Kuwait (by Kuwait Institute for Scientific Research, KISR), followed by Saudi Arabia (by King Abdulaziz City for Science and Technology, KACST) in the 1980's, United Arab Emirates in the 1990's (by Masdar), Bahrain (by Bahrain Petroleum Company and now by the Sustainable Energy Unit SEU), Oman and Qatar in 21 centuries. Among these projects is the full solar air-conditioned school (The British School) in Kuwait using PV and solar thermal applications in 1970, full PV operated fuel filling station in Bahrain at Al Hora area in Manama, Bahrain, in 1980, The Solar Village PV system 350 kW (2155 MWh) to provide AC/DC electricity for remote areas from 1981 to 1987 [3].

Now all GCC countries had conducted, relatively, large project in solar and wind energy, especially Kuwait (currently about 70 MW among a plan of 2000 MW by 2030), UAE (currently about 300 MW among a plan of 2500 MW by 2030) and Saudi Arabia (with an ambitious renewable energy target of 3450 GW by 2020, with a further 6000 GW envisioned by 2023 and to 200 000 MW by 2030). Table 1 sheds light on current large projects [2,3]. Figure 1 illustrates the current and future planned solar projects in the pipeline in the GCC countries [2]. However, it is thought that more major solar projects – at GW scale – will be announced officially, i.e. an installation of the world largest PV project (GW size) during the visit of the Chinese president to UAE in middle of July 2018. Currently, Saudi Arabia was in talks to develop the world's largest solar power plant in entering an agreement to develop a \$200 billion solar power plant, that's anticipated to be up and fully running by 2030 (200 GW) of solar power, which is approximately double the amount of solar energy produced globally last year and more than 100 times as large as the new next biggest solar plant project which would generate more than 100 000 jobs [4].

The literature survey leads us to conclude that there is a great development of solar energy in GCC countries in accelerated steps without underpinning it with strategic policy development plans, which will surely have an impact. This paper is attempted explore these impacts.

* e-mail: nalnaser@uob.edu.bh

Table 1. Summary of solar PV development in the GCC countries [2].

Country	Solar energy target share in total installed capacity	Primary energy sources	Maximum solar insolation (kWh/m ² /year)	Current operational solar projects	Future projects
Bahrain	5% of all renewable including solar (2020)	Oil, gas	2180	0.5 MW solar plant at the Bahrain University 5 MWp Bapco pilot plant	5 MW solar project at Al Dur power and water plant
Kuwait	1% in 2015, 10% by 2020 and 15% by 2030	Oil, gas	2200	See Table 1 in reference [2]	50 MW solar project across the country
UAE	7% of all renewables by 2020, 25% 2030 and 75% by 2050	Oil, gas	2285	See Table 2 in reference [2]	1000 MW Mohammed bin Rashid Al Maktoum Solar Park
Qatar	20% of all renewables with solar incorporated by 2030 and 15% solar by 2018	Oil, gas	2113	Establishment of solar PV manufacturing plant in Ras Lafi	Stadiums with solar technology cooling for the football world Cup 2022; 1000 MW solar PV plant in Doha
Oman	10% by 2020	Oil, gas	2500	See Section 3.5 in reference [2]	300 kW solar project at Al Mazyonah-Dhofar; 1000 kW solar project in Haima, 28 kW PV and storage system at Al Mathfa-Dhofar; 100 kW PV in Hijji
Kingdom of Saudi Arabia	54 GW from renewables including solar technology	Oil, gas	2200	See Table 3 in reference [2]	1000 MW solar plant in Makkah; 10 MW Al-Khafji plant; 1.8 MW King Abdullah Petroleum Studies and Research Centre

2 Technical and strategical issue on solar technology utility

Before involving in discussing the impact of the rise of using solar energy in GCC countries, it sounds better to highlight some technical and strategical issues on solar technology utility in these countries. These are the followings:

- currently, there are investments and plans to use solar energy in GCC countries that is gaining a momentum; however, the recent developments in the technology used for extracting gas and oil from shale rock formations places a big question mark on the GCC countries' energy plans including the use of renewable sources of energy [5];
- electricity demand in the region has been increasing at an annual rate of around 8% –faster than the growth recorded in any other region of the world. It is estimated that over the next decade the GCC countries will need to

add 100 GW of additional power to support their economies, which are running at twice the growth rate of major advanced world economies [5];

- sustainable energy in GCC states has been considered since 2008. Resource efficiency programs, clean technology research, alternative energy projects, green building codes, green economy strategies, and public transport systems have become a part of mainstream news. The GCC states have started to have a stake in the transition to sustainable energy and have already undertaken some policy, projects, and sector-wide efforts, which will boost the investment and its effect on the environment. However, many of these policies and plans are not actually enforced or imposed [6];
- the region is appropriate for PV and solar thermal applications on a large scale with little presence of clouds do not exceed only 20% of the year [6], which highly qualify these countries to use solar heating and cooling applica-

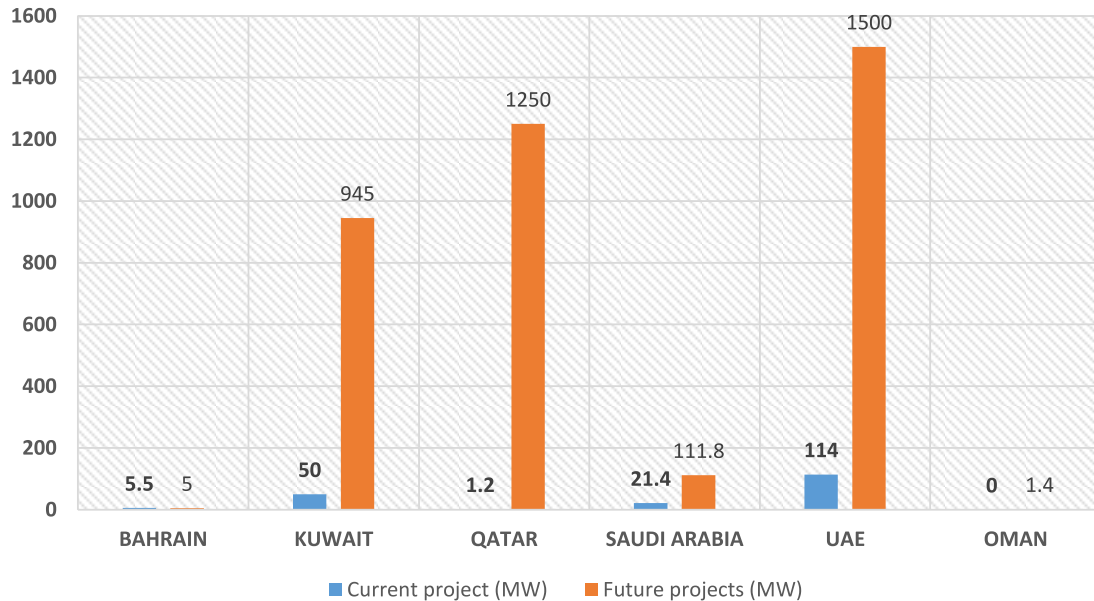


Fig. 1. Current and future planned solar projects in the pipeline in the GCC countries [2].

tions, Concentrated Solar Power (CSP) and PV applications since the global radiation is relatively high (from 1920 to 2450 kWh/m²/year). The summer demand in the region is about 10.8 GW, and this demand supplied from combined-cycle turbines fueled with cheap legacy gas and expensive imported LNG. Using solar power plants can introduce about 3.5 GW of nominal PV capacity and can be stored to overcome evening peak (10:00 to 11:00 pm), where thermal storage, energy storage (e.g. pumped storage where available), production of portable water at off-peak times and electricity trading with neighbors at irregular peak times can be utilized. These solutions have become economically attractive as they have less capital cost compared to gas turbines [7]. For this reason, GCC countries have launched a sense of the importance of converting part of its electrical energy produced by fossil fuels to alternative energies;

– the six GCC countries are located in an arid and solar zone. They occupy latitude 17°N to 32°N and longitude 35°E to 60°E. The following information imposed itself for inclusion to allow comparison of technical, economic and policy issues between these countries:

- the mean yearly solar radiation in Bahrain is, approximately, 2180 kWh/m² [1]. The share of RE in Bahrain is planned to reach between 5 and 7% from electricity power generating capacity by 2030 [8],
- Saudi Arabia has a yearly average solar radiation of 2200 kWh/m² [9,10]. Research and development activities show that solar energy has diverse practical applications in the KSA. The share of renewable energy is 30% Electricity generation,
- UAE has huge solar potentials with the mean annual solar radiation of 2285 kWh/m² and average sunshine of 10 h per day [11,12]. However, high-humidity and dust particles in the atmosphere reduce the solar intensity [13]. However the government of the UAE had set a target of 7% energy mix by the year 2020, 25% by 2030 and 75% by 2050 [14],

- Kuwait's annual solar radiation is predicted to be between 2100 and 2200 kWh/m² [15]. The average daily sunshine hours/year for Kuwait range from 7 to 12 [16]. Kuwait plans to expand the share of RE in the country's energy mix by 1% in the year 2020 and up to 15% by 2030 [17];
- Oman has an annual solar radiation, varying from 2200 to 2500 kWh/m² [18]. The highest solar radiation in Oman is in Marmul, followed by Fahud, Sohar and Qairoon Hairiti [19],
- Qatar is a country with abundant solar resources, reported to be up to 2113 kWh/m²/year for the ground measured yearly average, calculated considering the 4-year period of coincident data [20]. Studies show that the presence of high-ambient temperature in Qatar coupled with dusty conditions affect the performance and reliability of PV panels [21]. A recent study shows that Qatar solar potentials are equivalent to 1.5 million barrels of crude oil annually with an average sunshine hours in Qatar are 9.5 across the year [22];

- it had been reported that the drop in the output of the PV electricity (PVD), as a function of dust accumulation;
- measured as mass per unit area (ds) – which nearly applicable to all GCC countries can be calculated from the following relation [23]:

$$\begin{aligned} \text{PVD (in\%)} &= (\text{PV}_d/\text{PV}_{nd})_{\text{drop}} \\ &= 100 - 99.66 \exp(-0.035 d_s), \end{aligned} \quad (1)$$

where PV_d is the output of the dusty and PV_{nd} is the output of non-dusty (clean) PV.

The actual solar electricity gained from each kW installation of PV in GCC countries can be estimated from the following relation, which takes into consideration the dust accumulation and sky turbidity [24]:

Table 2. PV installation in GCC countries with cost per solar Watt [25].

Project name	Location	Type of installations	Capacity (Max Peak DC)	Year built	Cost	Annual generation	Normalized annual generation
1 Masdar	Abu Dhabi, UAE	Ground Mount	10 MWp	2009	\$5/W	17.5 GWh	1.75 MWh/MW
2 KAUST Solar Park	KAUST Saudi Arabia	Rooftop	2 MWp	2010	\$7/W	3.3 GWh	1.65 MWh/MW
3 Saudi Aramco Solar Car Park	Dhahran Saudi Arabia	Mixed (car park, rooftop, trees, pole mount)	10.5 MWp	2012	\$10/W	17.5 GWh	1.67 MWh/MW
4 KAPSARC Project-1	Riyadh Saudi Arabia	Ground Mount	3.5 MWp	2013	\$4.5/W	5.8 GWh	1.66 MWh/MW
5 KAPSARC Project-2	Riyadh Saudi Arabia	Ground Mount	1.8 MWp	2014	\$3.5/W	2.9 GWh	1.61 MWh/MW
6 Kuwait oil company	Umm Gudair Kuwait	Ground Mount	5 MWp	2014	\$5.6/W	8 MWh	1.68 MWh/MW
7 BAPCO pilot project	BAPCO, Bahrain	Mixed (14 locations)	5 MWp	2014	\$5/W	8.3 GWh	1.66 MWh/MW
8 TATWEER	Bahrain	Ground Mount	1 MW	2016	\$1.5–1.8	1.9 GWh	1.9 MWh/MW

Actual solar electricity produced in

$$\text{kWh} = \text{Installed Power (in kW)} \times 3.6 \times 365, \quad (2)$$

while the maximum estimated solar electricity yield – which assumes a regularly cleaned PV and clear sky with no turbidity – can be estimated from the following relation:

The maximum estimated solar electricity produced in

$$\text{kWh} = \text{Installed Power (in kW)} \times 4.6 \times 365. \quad (3)$$

The figures 2.8 and 4.6 are related to the system performance, which is related to PV efficiency, and its performance under warm–hot environment like GCC countries. Table 2 shows the PV Installation in GCC countries with cost per solar Watt. It clearly shows that each installed kW is expected to produce, annually, about 1650 kWh of solar electricity, i.e. daily 4.5 kWh [25].

Nearly all of the GCC countries have set relatively low prices of electrical energy unit (kWh), not to encourage more energy consumption and waste but rather to assist the citizens in overcoming the harsh–hot and warm weather that nearly prevail for 7 months. Nearly 70% of household electricity is used for air conditioning. The temperature in GCC countries reaches up to 60°C (Kuwait) in mid-summer and relative humidity of about 75% like Bahrain and UAE. Its only few months where people in GCC countries do not use air condition.

In 2011, energy subsidies accounted for 15, 32, 28, and 15% of all government expenditures, respectively in Kuwait, Saudi Arabia, the UAE, and Qatar. Since that time; however, the GCC region has been accelerating a trend to develop more open energy markets with less subsidies in order to ease the burden on government budgets already strained by the prolonged global oil price slump. The prices of electricity had increased from 2011 to now about 4–6 times.

The average cost of kWh in GCC countries is now 6 c\$, while in 2011 it was only 2 c\$ for residential, while for commercial it was 6 c\$ in 2011 and jumped now to 12 c\$ [26]; this is still much less than the tariff in USA (13 c \$/kWh). The relatively low tariff for kWh in GCC countries is not an encouraging factor to install PV systems on rooftop to produce solar electricity. This price makes the payback period (PBP) too large (about 100 year for a 7 kW with cost of USD 3/W). PBP can be easily estimated by using the following relation:

$$\text{PBP} = [\text{cost of total PV system}/(\text{solar electricity produced in kWh} \times 3.0 \times 365)]. \quad (4)$$

For example, in Bahrain, for a full 7 kW photovoltaic system the customer will pay USD 9100 (PV panels plus invertors and charge regulators). If the government purchase each kWh at a cost of 1 c\$ (3 fils) then the PBP will be 118 years, while if the tariff is purchased at a cost of 26 c\$ (100 fils) – if Feed-In-Tariff is initiated – the PBP will be 4.6 years. More accurate calculation of PBP can be made by referring to reference [27].

All GCC countries had signed the Kyoto Protocol and there acceleration in using solar and other renewable energy is driven mainly by their respect and obligations toward the climate change. The previous delay in using renewable energy at a large scale is attributed to lack of sufficient awareness, high capital cost, fear of moving from secure and conventional energy resources to uncertain and irregular clean renewable energy sources, lack of clear regulations and incentives, lack of industrial motivation, lack of expertise and know-how and lack of adequate of information about these new technologies [6,28].

The average electricity consumption per capita in GCC countries exceeds 10.000 kWh; this meanly due to harsh environment, lack of natural vegetation, lack of natural water, dusty nature of region, high solar radiation. All these

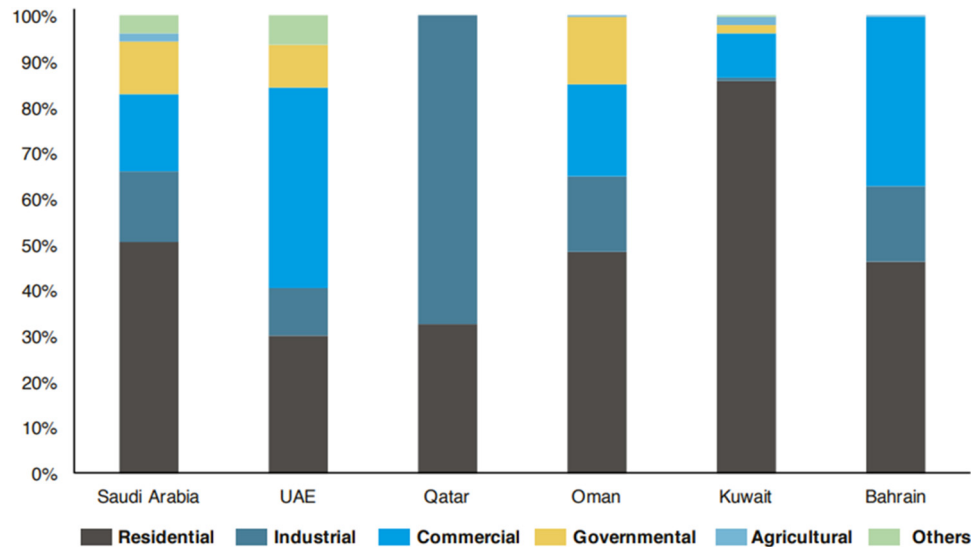


Fig. 2. Sectoral energy consumption in 2015 [30].

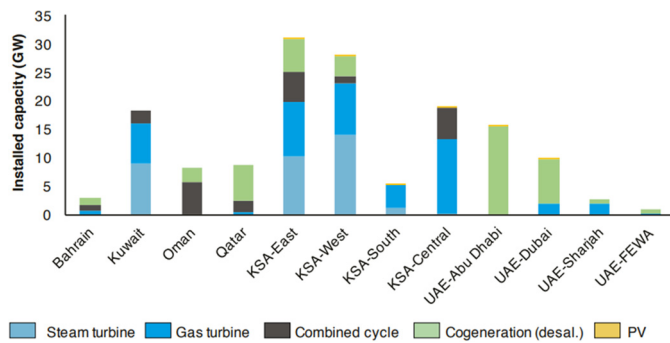


Fig. 3. Power and water capacity by technology type [31].

factors impose the GCC citizen to become heavily dependent to electricity utility, especially to air conditioning. Here comes the importance of investing and supporting research in solar cooling to make the cost of purchase of such devices affordable, reliable and low tariff; such product must be subsidized initially; in similar manner of subsidizing the LED lights in China during its initial launching.

The electricity consumption per capita in Bahrain is 19592 kWh ($\text{CO}_2/\text{capita} = 23.4$ tons), in Saudi Arabia is 9444 kWh ($\text{CO}_2/\text{capita} = 19.5$ tons), Oman 6554 kWh ($\text{CO}_2/\text{capita} = 15.4$ tons), Qatar 15309 kWh ($\text{CO}_2/\text{capita} = 45.4$ tons) UAE 11264 kWh ($\text{CO}_2/\text{capita} = 23.3$ tons), Kuwait 15213 kWh ($\text{CO}_2/\text{capita} = 25.2$ tons) and average world average is 3125 kWh ($\text{CO}_2/\text{capita} = 5.0$ tons) [29]. It is very noticeable that the per capita consumption in Bahrain is very high which attributed to warm and humid weather – nearly throughout the year.

Figure 2 shows the sectoral energy consumption in 2015, which is assumed not has been changed much [30]. The GCC produced 1.17 billion tons of CO_2 -equivalent in 2012 [29]. The bulk of CO_2 -equivalent emissions in GCC are related to energy production and consumption with 95% of emissions are energy related, with agriculture, waste

Table 3. Electricity production in terawatt-hours (TWh), consumption (TWh) and peak load (GW) [32].

Country	Production	Consumption	Peak load
Bahrain	14.1	12.6	2.9
Kuwait	68.3	60.5	12.8
Oman	31.3	31.3	6.1
Qatar	38.7	36.1	6.7
Saudi Arabia	304.2	274.5	56.6
UAE-Abu Dhabi	70.9	52.8	9.0
UAE-Dubai	39.6	38.4	7.2
UAE-Sharjah	5.7	10.2	2.2
UAE-FEWA	0.40	10.3	2.2
Total GCC	573.2	526.7	

and land-use changes making up the remainder [31] and of this amount, the power and water sectors emitted 438 million tons of CO_2 -equivalent.

All GCC counties have a mix of power and water desalination capacity (Fig. 3) with Saudi Arabia, more than 80.5 GW of power generation and UAE with the second-largest (almost 29 GW) while other countries have smaller capacities (Kuwait 18.3 GW, Qatar 8.6 GW, Oman 7.8 GW and Bahrain 2.8 GW [30]).

GCC countries use large amount of electricity to produce desalinated water (about 16 million m^3 per day) [32]. Notably, Bahrain, Oman and the three coastal regions of Saudi Arabia utilize RO technology. Kuwait and Qatar do not have any RO plants. A small number of thermal water-only plants, utilizing MED or MSF processes, exist in Kuwait and in the southern region of Saudi Arabia.

The magnitude of electrical production, consumption and peak loads is shown in Table 3 [30]. Saudi Arabia produces over half of all electricity in the GCC.

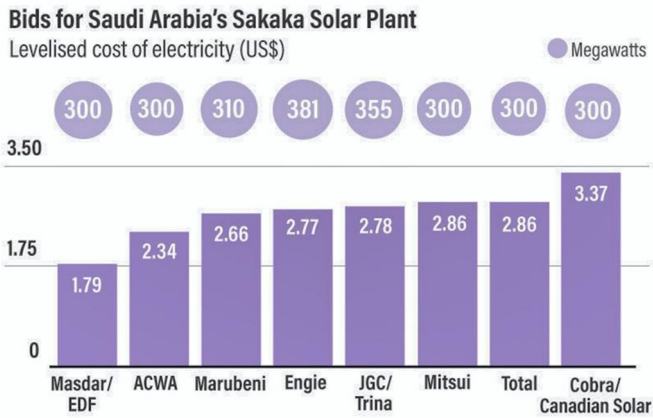


Fig. 4. Bid for Saudi Arabia Sakaka solar plant. It's a 300 MW solar photovoltaic plant. The tariff for each kWh solar is little as 6.7 halalas or 6.7 fils (or 1.79 cents) [34].

3 The impact of the rise of using solar energy in GCC countries

It has to be understood that GCC countries are of need to use renewable energy in general and in particular solar energy for many reasons. These are: a) vulnerable to the threat of rising sea levels; b) industrial areas are expanding; c) high annual energy demand growth rate, which ranges from 7 to 10%; d) need of natural gas to meet its future energy demand; e) have very high solar radiation levels; f) set a Renewable Energy target in their vision 2030; g) need to open a green job; h) allow exchange of knowledge, technology and mutual cooperation. Such an accelerated use of solar energy after long slow maneuver to use this energy may have the following impacts:

3.1 Major reduction in the solar electricity prices in the region

The Renewable Energy Project Development Office's (REPDO) 300MW Sakaka project in Saudi Arabia reported the lowest PV LCOE (2.34 US\$ cents per kWh) [33]. Also, Masdar and its French partner EDF submitted the lowest offer for the project at 1.79 US cents per kilowatt hour (kWh) – as illustrated in Figure 4 [34]. The prices of PV panels had dropped from US\$ 76 to only US\$ 0.3 per Watt [35].

This drop in the prices is due to the availability of 100's of PV producers, offering more than 30 years warranty on PV panels, drops in solar system components. Table 4 lists the PV pipeline projects while Table 5 for CSP pipeline projects.

3.2 More investors in renewable energy business

GCC countries could reap multiple benefits from scaling up renewable energy use, including reducing water withdrawal by 11 trillion litres (or 16%) and saving 400 billion barrels of oil in the power sector, creating 2000 direct jobs and reducing the region's per capita carbon footprint 8% by

2030 [36]. This will attract investors to further use solar energy, as they are witnessing this acceleration in executing major successful solar project with relatively low cost. This might encourage other developer in renewable energy to introduce themselves to GCC market and offer attractive prices and facilities.

Currently, China accounted for a record 45% of the global investment total, up from 35% in 2016 followed by Europe (15%), United States (14%) Asia Oceania, excluding China and India, (11%), Americas, excluding Brazil and the United States, (5%), India (4%), Middle East and Africa (4%) and Brazil (2%) [37]. In 2017, Solar PV and wind power had dominated the investment, accounting for roughly 57 and 38%, respectively. Solar power was the only technology to witness an increase in 2017, with new investment up 18% relative to 2016, to USD 161 billion. The investment in Middle East and Africa had increased by 11% in 2017, to USD 10.1 billion, with substantial increases in Egypt (USD 2.6 billion), and the United Arab Emirates (USD 2.2 billion) [37].

3.3 Rise of innovative design of houses to utilize its structure in installation and integration of renewable energy devices

The installation of PV systems on a rooftop – making the building integrated with Photovoltaic – for power up to 7 kW for a relatively low cost (BD 3500 or US\$ 9100) – such as in Bahrain – is an attractive, especially if: a) customer receives financial support or loan with minimal interest; b) the government buy the generated solar electricity from the rooftop with a generous cost (Feed-In-Tariff). This will encourage houses developers to make the roofs more fit to allow large utilization of the roof to account for PV installation with no obstacles. Currently, in GCC countries, the available roof area for PV panels is about 18% only for flats and 25% for villas in Khobar, Saudi Arabia [38,39]. Researchers in the GCC countries started to pay more attention for the houses design to account for possible integration with PV [40]. It might also take into consideration in making use of integration with other promising and brand new technologies renewable energy technology such as wind, geothermal, biofuels, biomass, and hydro [41].

It has to be noted that, it has been already reported the advantage and disadvantage of using the rooftop. It was the 9.6 PV installed on the rooftop, in a house in Greece, reduces the heat in the building in summer by 17.8% but requires more heating load in winter by 6.7%! [42].

3.4 Rise of many services and maintenance of solar technology companies

Unfortunately, not all governments of the GCC countries had net metering facility, its only made in Bahrain. It is believed that with this accelerated use of solar energy utility, all GCC countries will introduce such a facility. Net Metering is a metering and billing arrangement designed to compensate distributed energy generation system owners for any generation that is exported to the utility grid. It

Table 4. PV pipeline projects in Arab region [33].

Country	Country	Capacity	Status	Client
Bahrain PV	Bahrain	200	Announced	EWA
Solar IPP (West Nile)	Egypt	600	Prequalification	NREA
Solar IPP (KOM OMBO)	Egypt	200	Bid Stage	EETC
Round 3	Jordan	200	Bid Stage	MEMR
Risha PV	Jordan	50	Financial Close	NEPCO
Water Authority Jordan	Jordan	30	Prequalification	Water Authority Jordan
KNPC	Kuwait	1000	Bid Stage	KNPC
NOOR MIDELET	Morocco	800	Bid Stage	MASEN
IBRI	Oman	500	Prequalification	OPWP
PDO-100MW	Oman	100	Prequalification	PDO
Qatar PV	Qatar	200	Announced	Kahramaa
Multiple Sites	Saudi Arabia	6400	Announced	RE PDO
Tunisia PV	Tunisia	70	Bid Stage	STEG
Tozeur PV	Tunisia	10	Bid Stage	STEG
Sweihanii	UAE	1,200	Announced	ADWEA
Dewa Phase V	UAE	300	Announced	DEWA
Total	11 860			

Table 5. PV pipeline projects in Arab region [33].

Country	Country	Capacity	Status	Client
Taqa CSP	Egypt	250	Announced	TAQA Arabia
West Nile CSP	Egypt	100	Announced	
Lebanon CSP	Lebanon	50	Announced	
Noor Midelt	Morocco	800	Bid stage	MASEN
Total		1200		

allows residential and commercial customers who generate their own electricity from solar power to feed electricity they do not use back into the grid [43]. A more attractive facility in to have a Feed-In-Tariff that enables households to have a payback not more than 5 years. Unfortunately, no GCC countries had announce the Feed-In-Tariff facility; only UAE had offered what is called “Grants and subsidies” which is legislated from the Renewable Energy Deployment Strategy (2009, 2011, and last updated in 2015) [44]. Among Arab countries who have Feed-In-Tariff, are Egypt and Tunisia [44].

This means any interruption in PV system will lead to money loss and waste. This will lead to the birth and establishment of many maintenance or Energy Saving Companies (ESCO). This will create more green jobs and green economy. This rapid hop toward use of solar technology will encourage the investor to open business in this solar energy business including PV panels, Charge regulators (MPPT), PV aluminum frames and structure, PV auto cleaning using nanotechnology, AC/Dc invertors and promotion and media companies in such field.

The impacts of different renewable energy pathways on ecosystems and biodiversity, and the implications of these impacts for transitioning to a green economy have been discussed in detail elsewhere [45].

3.5 Establishment of new academic programs and courses in solar and other renewable energy technologies in the higher education institute and technical organizations

The accelerated use of solar technology in GCC countries will attract students to get registered in Science, Technology, Engineering and Mathematics (STEM). Universities and academia must prepare to such move and should align their programs with such a need. It will be an opportunity to establish long-term partnership between universities in GCC countries with the other international universities in science and innovation collaborations. This will lead to boost in faculty and student exchange program and flying professor program as well as condensed international courses and programs. It will also lead to

working strategically with key stakeholders bilaterally across the world. This will foster closer people to people contacts in our shared interest in stability and prosperity.

It has to be noted that in USA, there is only 49 Bachelor's degrees programs in Sustainable Energy and 39 Sustainable Energy Master's degrees. In GCC countries, there is no single BSc in Renewable Energy or a diploma although a set of Renewable Energy education is proposed before 20 years through ISESCO by the current author [46].

Kandpal and Broman [47] had made a review of published literature (376 references) on renewable energy education initiatives across the globe, challenges faced, and potential approaches towards efficient and effective solutions as the 30 years, a large number of countries across the globe has initiated academic programs on renewable energy technologies and related aspects.

3.6 More concern and studies on disturbances to the main grid due to solar connection

One major reason for the fast dissemination of solar energy in the GCC countries, after long lag is due to many reasons among them is, renewable generation is made possible to connect to the grid, customers are made to receive incentives and are paid, appropriate deployment. Using solar electricity can be difficult to steer accurately and can cause surges, i.e. very rapid growth over a few months then nothing for a while, which is difficult for the installers industry.

Network integration is an important issue that must receive great attention in opting for large and fast use of solar electricity. Electricity networks were designed for loads not generators. Therefore, power can flow backwards where networks do this naturally and do it very well [48]. Networks integration has the advantage of eliminating the need for batteries and the need for local balancing.

Voltage control is important when using solar electricity at a large scale because embedded generators cause voltage rise. In countries networks are short and well-engineered then this is not an issue otherwise it is significant (Saudi Arabia, Kuwait and UAE).

PV electricity (considered herein as Distributed Generators, DG) is normally designed to be grid-connected and not to Island. The reason is considered as DG, because the PV system is producing and distributing electrical power back into our utility grid. Therefore, Islanding refers to the condition of a DG generator that continues to feed the circuit with power, even after power from the electric utility grid has been cut off. Islanding can pose a dangerous threat to utility workers, who may not realize that a circuit is still "live" while attempting to work on the line [48]. Designing to allow islanding is expensive and unlikely to be justified with a reliable grid. Anti-islanding protection can lead to "block-tripping" which is bad for the grid. This risk can be reducing by careful choice of inverters and their settings and having fault ride-through capabilities. This is significant when there is large demand in solar electricity (more than 20% of the main installed conventional electricity of the grid). The conventional system relies

on the rotating mass of all its conventional generators to provide inertia and keep the frequency steady at 50 Hz while PV electricity provides no inertia. This becomes a concern at high penetrations as once conventional is significantly reduced and taken off line. In fact operating low-inertia power systems is a current research challenge. Interconnector will help or expand the challenge [49].

The GCC countries should work hard from now to make their interconnection with solar electricity, have the following features [50]:

- prevent the penetration of the harmonics into the power grid;
- avoid the requirement of having controllable at the DC side of the power inverter;
- control the power factor level at the point of interconnection with the grid;
- relaxe the constraint of synchronizing the inverter output voltage with the power grid voltage;
- extract (if possible) maximum power from PVG panels.

3.7 Major reduction in carbon footprint per capita in GCC countries

According to Arab Petroleum Investments Corporation, the GCC countries represent 47% or 148 GW of the current MENA power-generating capacity [51]. The harsh environment of GCC countries with natural water scarcity and the vision of the leaders of these nations for development and prosperity have led to a rise in the GCC's demand for energy. GCC countries would require US\$ 85 billion for the addition of 69 GW of generating capacity and another US \$ 52 billion for T&D over the next 5 years. The GCC power capacity needs to expand at an average annual pace of 8% between 2016 and 2020! Now assuming that if by year 2020 the solar electricity represents 5% of the installed electric power – which is 10.85 GW out of 217 GW – then the saved CO₂ emission will be nearly 95 million tons! This means that from year 2020 to year 2030 the saved CO₂ emission will be about 1 billion tons! This is a considerable amount if we know that GCC countries had produced 1.17 billion tons of CO₂-equivalent in year 2012 [29]! This will make the carbon footprint less than the current. It has to be noted that carbon dioxide (CO₂) – Global energy-related CO₂ emissions – grew by 1.4% in 2017, reaching a historic high of 32.5 Gt [52]. The GCC countries emission may have reached about 1 Mtons.

3.8 Use of more efficient and low consumption household and industrial devices

Due to the future reliability on solar electricity for use in houses, building and industry in GCC countries, it is expected that consumers will only purchase low consumption and efficient appliances and devices since each kW of solar electricity offers maximum of 1680 kWh (costing about US\$ 3000) annually while for this energy we need only 5732.4 ft³ of natural gas which costs about US\$ 7 only (knowing that each 1000 ft³ cost about US\$ 4. People will purchase 5 stars appliances. The air-conditions technology will witness great attention in GCC countries so that each

thermal ton should consume less than 1 kW of electricity. A current air condition will operate for only 40 min if fed with 1 kWh, 1 hr for washing machine (rated 1 kW), 125 hrs for an 8 LED light [53]! Remarkable effort, business and investment will be on reducing the electricity consumption to make such appliance cope with the relatively expensive solar electricity.

3.9 Boost in battery industry for solar electricity storage

With the large dissemination and fast growth of solar electricity, which is sustainable and free (after the subsidized pay-back period) investors and developers will think seriously in standalone solar houses or premises or factories, especially, for rural but tourist attraction location. This will make them to invest solar electricity storage devices, in particularly batteries. The storage will be important to overcome the mismatch between the time of generation and demand, although in GCC countries the time difference is mostly just a few hours while in UK and Ireland are much larger [49]. Storing cold, either in the building fabric (concrete) or in ice (same water each day which not consuming water) will be also an option for cool air storage at night making use of the excess of solar electricity. This technology is a straight forward and proven low-cost. It is also of low value when gas powered, but will become very valuable.

In 2016, the first hints of a storage-driven transformation of the electricity business had come in Hawaii where Sunrun company offered their Brightbox product – a combination solar-plus-battery product – with a price of 19 cents per kWh, which is almost 50% cheaper than grid electricity. By 2018, 1 in 5 new residential Sunrun solar customers in California was choosing to add storage [54]! The situation will be the same soon in GCC countries.

The prospects for solar plus storage are even more remarkable in the near future which is forecasted to witness steep declines in battery costs – by 50% in the next 5 years and by 70% by 2030. According to reports, batteries aren't just getting cheaper but will also reach far outstripping predictions. Bloomberg projected batteries crossing the US\$ 300 per kWh threshold in 2022 and will reach US\$ 109/kWh in 2015 and further to as low as US \$ 73/kWh.

4 Conclusion

The fast and accelerated execution of large PV technology projects in GCC countries will have an impact in the region. Beside the reduction in the Carbon foot print and further cost of the solar W (low cost of kWh) many new business will flourish such as battery storages for PV electricity, low power consumption air conditions and devices, boost in green job and green economy but policy makers must pay great attention to disturbance in interconnection to grids.

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