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A review of renewable energy and solar industry growth in the GCC region

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Abstract

Historically reliant on fossil fuels for their economy, the Middle Eastern countries are now determined to foster an increased share of renewable energy (RE) in their total energy production. The Gulf Cooperation Council (GCC) nations, such as Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and United Arab Emirates, have each set different strategic goals of producing certain share of their total energy from renewable sources within the next two decades. This paper reviews the recent progress in RE expansion, in general, and solar energy programs, in particular, within the GCC region. Among all forms of alternate energy, solar power is a preferred choice for its relatively advanced technology and seemingly limitless potential in the region, daily average solar radiation typically exceeding 6kWh/m^2 with 80-90% clear skies throughout the year. The Arabian Peninsula is witnessing a steady growth in the following key sectors: utility-scale solar power plants, solar desalination industry, and solar photovoltaic manufacturing facilities. Assessment of how locally established research-driven technology clusters and key market players play a role in rapid deployment of RE technology are also identified. Status of planned RE projects is reviewed, challenges facing the industry are investigated and country-wise reflected share is presented.

Keywords: GCC nations; renewable energy; solar and wind power, solar desalination, technology clusters

1. Introduction

The GCC nations, i.e. Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and United Arab Emirates, are essentially hydrocarbon-rich economies heavily reliant on oil and gas for domestic consumption as well as export revenues. All the GCC nations feature on the list of top 25 countries contributing highest carbon dioxide emissions per capita [1]. Such high ecological foot-print is in part a reflection of escalated but unsustainable development across the region. Rapid urbanization and socio-economic growth in these countries has led to an upsurge in energy demand. Also,

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maintaining modern life-style in a predominantly arid environment further aggravates the situation. The GCC population is expected to reach 53.5 million by 2020, a 30% increase over that of 2000 [2]. The same source predicts the GDP of the region to grow by 56% over the same period. Amidst vulnerable oil prices, increased awareness of dwindling fossil fuel reserves and rising global environmental concerns, a switch towards more energy efficient ways and integration of alternative resources in the current energy mix is an impending call. While the extent to which these countries foster renewables in their energy mix is subject to individual cases and respective political will, accrued and sincere interest in RE capacity addition is discernible throughout the region.

This contribution holistically explores the potential of renewable energy (RE) in the GCC nations with special focus on the solar energy sector. The drivers and key players in the renewables market are identified. Country-wise projects, both current and planned, are enlisted and eventually aggregate share is forecasted. Inhibitors/ challenges, if any, in reaching the full potential for RE integration within the GCC region are also investigated.

1.1 Energy Overview

Total Primary Energy Demand (TPED) in the Middle East is currently met by approximately equal share of oil and gas. In 2035, even under World Energy Outlook's '450 scenario' with ambitious global warming mitigation measures, oil and gas are still likely to remain *primary energy sources* in this region with a projected share at 44% and 52%, respectively [3]. According to BP by the end of year 2011, the GCC nations collectively held 20.4% and, with the exclusion of Bahrain, 29.9% of the world's total proven reserves of natural gas and oil, respectively [4]. Note that these figures are lower than the usually quoted estimates in literature because they often unwittingly include the entire Middle East. Hydrocarbon reserves, at current production rate, are expected to last from as little as 8 years of oil for Bahrain to up to more than 100 years of gas for Kuwait, Qatar and UAE [4]. While these countries currently produce *oil* in surplus, unprecedented consumption is increasingly likely to switch the scenario. Despite being world's largest oil exporter with 16.1% of world's total and GCC's biggest oil reserve, crude oil export in Saudi Arabia can falter by as much as 3m barrels/day by the end of 2028 [5]. Recent technological advancement in combined cycle gas turbines coupled with heavily subsidized electricity from gas-fired plants has led to a paradigm shift in domestic demand towards *natural gas*. UAE is world's sixth largest gas reserve yet, paradoxically, in recent years it has started to import natural gas from its neighbours. Domestic consumption of natural gas clearly surpassed the production both in UAE and Kuwait in 2008 and 2009, respectively [4]. While in Bahrain as well as Saudi Arabia natural gas consumption has remained at par with production for the last decade (1999-2009) [4, 6]. Qatar is the only GCC country that emerges as a net exporter of natural gas without undue stress on its reserves.

Total electricity generation in the Middle East is expected to more than double under current policy scenario from 734 TWh in 2009 to 1829 TWh by 2035 [3]. AlNaser and AlNaser (2011) estimate that the region will need to increase their installed capacity by 80% (~ 60 GW) from current generation capacity of 75,000 MW to meet the demand in 2015 [7]. In their previous work [8], a longer-term estimate is 100 GW of additional power generation requirement in the GCC by 2020, translated into $ 25 billion investment over a period of first 6 years. Figure 1 illustrates the regional share in energy consumption totals charted from Economic Intelligence Agency (EIA) projections [2]. Growth in total consumption is almost exponential as it doubles after every twelve years i.e. from over 200 mtoe to over 400 mtoe (2000 -2012) and from over 300 mtoe to over 600 mtoe (2007- 2019). The average year-on-year growth for total GCC electricity consumption over the period of two decades (2000-2020) is expected to be 5.91% [2], while the world annual average stands at 2.3% [3]. Bulk of electricity consumption comes from air-cooling needs of built environment. This is followed by energy intensive industries such as water desalination.

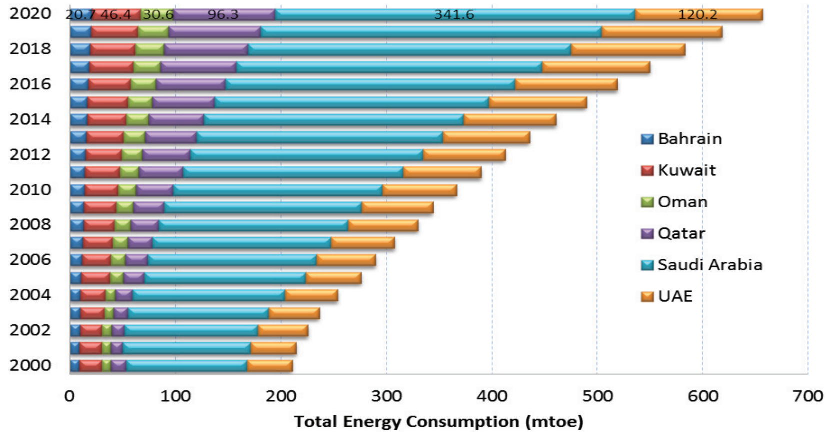

Fig. 1. Country-wise share in total energy consumption, million tonnes oil equivalent. *Note:* statistics for the period 2000-07 are actual, 2008-10 estimated and 2011-2020 are forecasted [2].

Energy-intensive culture, sourced essentially by non-renewables, undoubtedly pushes environmental degradation to precarious levels. A GCC population of 0.6% contributed 2.7% of total global CO_2 emissions in 2010. Inter-country comparison reveals Saudi Arabia has the highest carbon footprint (446 Million tons of CO_2/ year) in the region, approx. 1/16th and 1/12th that of China and USA, respectively[9]. Since the population strength varies dramatically between the Gulf countries, *per head* energy indicators reveal the other side of the coin. Owing to a resource-wasteful culture, the GCC nations score quite poorly on global scale in TPES/ capita and CO_2 emissions/ capita. In Fig. 2, Qatar and Kuwait have highest ecological stress rate per capita. Qatar's oil and gas industry accounted for up to 67% of total emissions in 2009 and 67% of electricity consumption due to air-cooling alone; Kuwait's air-cooling and water needs accounted for 70% of electricity consumption in 2010 [6]. USA statistics closely follow the GCC countries with per capita TPES almost equal to that of Oman and per capita CO_2 emissions higher than that of both Oman and Saudi Arabia.

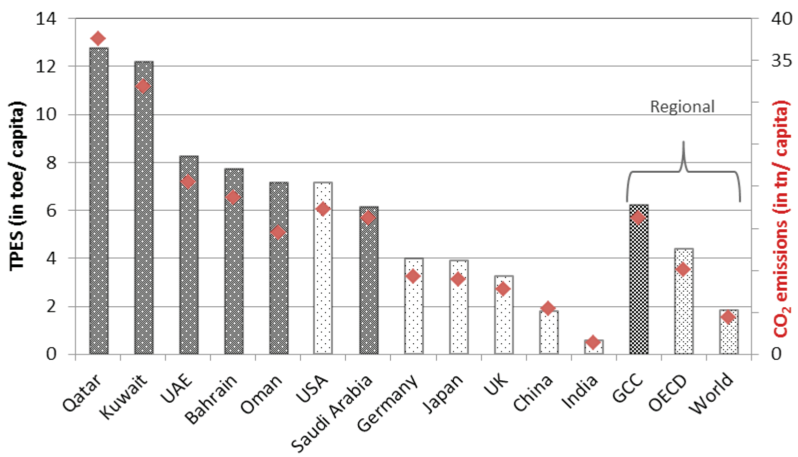

Fig.2 Global context: Per capita energy (in decreasing order of magnitude) and environmental indicators in GCC countries and some of world's major economies in 2010. Data source: [9].

2. Renewable energy drive

Potential opportunities in the region for generating power from renewable sources, such as solar and wind, are aplenty. However, interest in RE has, more or less, been subject to volatility in oil prices. In other words, time and again efforts in this regard have dampened whenever oil prices have stabilized. Nevertheless, lately GCC nations are undertaking consolidated, ambitious initiatives, to tap the region's abundant sun for long-term energy needs, in an attempt to scale up from prevalent state of 'pilot and demonstration programs'. The local governments are the initial investors; however, region's potential for renewable energy profitability, once technologically proven, will act as catalysts for foreign investments [10]. A brief overview of the key motivators is presented under the following section.

2.1 Potential

Among renewables, solar and wind are the fastest growing sectors, primarily due to indigenous abundance, favourable environment and relatively advanced technological development. Compared with standard forms of electricity generation, such as from natural gas and nuclear, solar power plants are faster to build. Solar technologies have also emerged as strong proponents in resourcing various other energy needs such as heating, cooling, drying, desalination, etc. As the technology improves and fossil fuel prices escalate, solar technology costs are becoming competitive world-wide, with one study estimating PV generated electricity to become more economical than conventional power by 2025 [11]. There is also a strong correlation between solar power generation and general peak electricity demand, primarily air conditioning loads typical of GCCs, during the day and in summers. With regards to wind technology, although Oman and Kuwait have high wind power densities and Qatar somewhat reasonable, figures aren't as encouraging for Bahrain, Saudi Arabia and UAE. Solar potential is 10 times more than the next prospective- wind power-in UAE, for example [7].

2.2. Drivers

The many-fold benefits that can be derived from developing RE technology sum-up the 'drivers' behind the initiative and can be broadly classified into three categories: energy, economy and environment. However, since the three E's are inter-coupled, a mutual overlap is often possible. Depending on the country in question, some or all of these may apply; the order of priority may vary.

Energy

- Finite resources and limited access to cheaper hydrocarbons- increased and expensive NG import
- Freely available abundant sun and wind
- Better management of the demand-supply gap by compensating for indigenous shortage of oil or gas or both
- Channelize and prioritize investment in energy- and water- efficient measures, including development of viable clean energy technology
- Align the energy infrastructure for a foreseeable future without oil and gas
- Become potential RE exporters with breakthrough technological advancement

Economy

- Limit domestic fuel consumption to recover revenues through increasing the share in export
- Divert the local demand away from highly subsidized hydrocarbon resources to extend their life and secure a more sustainable source of income for a longer period of time

- Economic diversification to lighten the burden on ageing power infrastructure
- Provide parallel energy support network to population boom and rapid urbanization characterizing most GCC nations
- Promote capacity development for a knowledge-based economy
- Through demonstrated sustainability win local popularity and international recognition

Environment

- Keep a check on carbon emissions and participation in global carbon credits program
- Facilitate climate change mitigation
- Live up to the globally felt urge for transition from carbon-based economy to sustainable economy

2.3. Targets

All the GCC nations endeavour to meet a certain share of RE in their energy mix at individual levels. Bahrain and Kuwait each aim to produce 5% of their energy from renewables by 2030 and 2020, respectively. Oman aims to produce 10% of its energy needs from renewable energy resources by 2020 [6]. Qatar has set a target to meet 16% of its energy production from renewables i.e. 1800 MW by 2018. And by 2020, to generate at least 2% of electric power in Qatar from solar energy approx. requiring 640 MW or more [12]. In April 2010, K.A.CARE of Saudi Arabia announced an ambitious 41 GW of target solar capacity by 2032 (with a technology split of 25 GW CSP and 16 GW PV) expected to contribute up to 16-22 % of the country's total energy generation [13]. An overall target is to generate a third of its electricity from renewable energy by 2030, which translates into approximately 54,000 megawatts of renewables facilities. In the UAE, Abu Dhabi is targeting a renewables share of at least 7% in its power generation capacity (along with 7% reduction in CO_2 emissions) by 2020 [2]. Although some ambiguity surrounds such 'per cent targets' in that whether this share is in peak energy demand or total installed capacity, it has been understood by the authors that Abu Dhabi's 7% refers to the share in peak demand. However, there is no clear proof. Dubai Government's Supreme Council of Energy set a similar target for renewable energy to supply 1% of Dubai's energy mix by 2020 and 5% by 2030 (1000 MW) under the Dubai Integrated Energy Strategy 2030 plan [14].

3. Renewable Energy Deployment

The GCC nations hold commonality across many fronts such as geographical proximity, topographical features, weather, socio-economic challenges, natural wealth (fossil-fuel resources), lack of fresh water resources, nature of governance and minimal taxation policies. Since the drive and challenges that arise from RE expansion are relatively harmonious in the region across nations, the road map to RE growth in this contribution is categorized based on status and nature of projects rather than the typical country-wise analyses. Renewable energy ventures in the Arabian Peninsula date back to as early as 1960s. A major milestone in the region was off-grid solar electrification of two Saudi villages, namely, Al-Jubaila and Al-Uyaina in the early 1980, followed by several other ad-hoc solar projects over the course of three decades [15]. Recently there have been a slew of existing and upcoming solar energy projects in the region with diverse applications, primarily in the form of stand-alone systems, utility-scale solar power plants, solar desalination projects and solar panel manufacturing industry. Most of such applications are centralized by entities or technology clusters (Appendix A), whose general aim is to become local hubs for renewable energy activity.

3.1 Stand-alone/ remote/ rural RE systems

- first wind-powered, electric water pumping system successfully installed in a remote location approx. 900 km south of the capital city of Oman- Muscat in 1996 [16].

- In 1997, UAE's telecom company Etisalat installed 33 passive cooled shelters and SPV powered remote GSM base stations (at an approx. US $ 10 million cost [8] & almost 600 kW total peak power [16]).
- Series of other solar powered off-grid projects are summarized in Table 1 [8, 16 & 17].

Table 1 GCC's stand-alone solar/ wind-powered systems

Country	Project	Location	Total peak power (in
Oman	Radio base stations	Inland	27
	LD repeaters	Executed in 27 sites	27
	Pay phones	Various	8
	TV and FM transporter sites	64 sites all over	22
	Wind electric water pumping	-	10
	Remote electrification (solar)	Rustak and Wadi Maval	2.6
	Water pumping systems	Haima, Maabar and Wilayat	8.3
	Remote electrification	Damanyat island and Izki hill	2
	Seismic equipment	10 sites	6.6
UAE	Highway traffic monitors	Dubai-Hatta/ Oman road	-
	Pay phones	Various	29
	Solar systems for cell	Various	9
	46 aviation warning LED	Dubai International Airport	5
Saudi Arabia	Highway devices; lighting systems	Various; two remote tunnels in southern mountains	-

3.2. Utility-scale power plants

Addition of large scale renewable energy installed capacity, both targeted and commissioned, is generally subject to change in policies, legislations, infrastructure, technical, executional or fiscal delays, etc. Below is a summary of planned utility-scale solar thermal plants in the region in order of their progress towards completion. Note that some other 'disputable status' projects could not be included here since latest project activity at the time of writing couldn't be cross-verified.

Table 2 Major solar power plant projects in the region

Location	Capacity	Project value (US$ million)	Facility type	Collaborators	Phase
Shams-1, Madinat Zayed, Abu dhabi, *UAE*	100 MW	600	768 parabolic mirrors, installed over 2.5 km^2 powering 62,000 homes; UN registered CDM project	Masdar-Abu Dhabi (60%), Abengoa-Spain (20%), Total-France (20%) stakeholders	Completed in early 2013
Al Abdaliya, Al Jahraa, *Kuwait*	220MW (combined cycle), 60 MW (solar)	720	Integrated solar combined-cycle (ISCC); 54 solar trough collectors	Partnerships Technical Bureau (Govt. of Kuwait), Toyota Tsusho Corporation (Japan)	Bidding
Al Dakhiliya, *Oman*	200 MW	600	CSP technology	Middle East Best Select (Germany), Terra Nex (Switzerland)	Impending local government approval

3.3. Solar desalination

An incredible 80-90% of the Gulf countries' potable water comes from desalination. Even if the best available large-scale technology were employed, for each m^3 of water produced at least 5 kWh of energy is required which translates into nearly 3 kg of CO_2 generation [15]. The Arabian Peninsula's large solar potential can sustainably be deployed to desalinize the freely available sea-water and compensate for the threatening freshwater deficit that would otherwise grow from 50 billion cubic metres per year (in 2007) to about 150 billion cubic metres per year by 2050 in MENA region [18]. The report also projects energy from solar thermal power plants to become the least cost option for desalted water (below 0.4 €/m³) within two decades. Below is a list of exiting/ proposed desalination units in the GCC:

- University of *Bahrain*: mobile solar desalination unit (1.5kW) producing 250 gallons of water.
- Solar thermal powered multi-stage-flash desalination unit installed in *Kuwait*.
- An optimized application is the development of the Seawater Greenhouse in *Oman*- a system that desalinates water and in tandem cools and humidifies the cultivating environment for growing temperate crops [19].
- Feasibility assessment of implementing a CSP desalination project (300 kW) to be jointly carried out by *Qatar* Environment & Energy Research Institute (QEERI), member of Qatar Foundation, and Spanish Research Centre for Energy, Environment and Technology (CIEMAT) [6]. The State of Qatar has also embarked on a program to develop the combined Solar energy powered dedicated Seawater Desalination Plant capable of producing water for irrigation at a rate of up to 50 m3 per second for indigenous agricultural purposes under the scheme called "Qatar National Food Security Programme (QNFSP)" [20].
- *Saudi Arabia* is the GCC's largest desalination industry and therefore, quite logically, at the forefront in solar desalination technology development. Its pilot solar desalination ventures date back to 1990s in Sadous and Solar Villages. IBM in partnership with a team of researchers from the King Abdul Aziz City for Science and Technology developed a solar electricity (ultra-high concentrator PV technology) run desalination plant that will produce 30,000 m^3 per day of fresh water for a city of 100,000 people at Al-Khafji [15], which was expected to be completed by the end of 2012 [21], but latest activity unavailable. There is an anticipated incremental diffusion of solar technology in KSA's desalination industry with plans to further install a plant capable of producing 100,000 m^3 on a daily basis – leading up to a whole fleet of strategically located desalination plants covering most of Saudi Arabia [7].
- *UAE*, being the third largest desalinator after the US and Saudi Arabia, is also taking initiatives to use solar energy for the purpose. The Environment Agency-Abu Dhabi (EAD) constructed 22 small-scale solar desalination plants and is planning eight more, each producing almost 11,000 cubic meters of water a year [22].

3.4. Solar and wind pilot/ demonstration projects

Small to medium capacity renewable energy applications set up either for demonstration in urban environment or for R&D purposes are presented under this section.

- A self-contained mobile solar (1.9 kW) and wind power generator (100 W) erected on a trailer designed at University of *Bahrain* in collaboration with Long International construction company [17].
- *Bahrain* world trade centre: SPV (for outdoor lighting) and three parallel wind turbines, each 29 metre in diameter, with total output of 0.66 MW integrated into the building structure powering 11-15% of in-house needs when operational [6, 2].
- A self-sustained 'zero-emission house'-cum-laboratory powered by 4 kW PV and 1.7 kW wind turbine and 1.2 kW fuel cell module that converts energy stored in the form of hydrogen into

electricity; joint collaboration between *Bahrain* Petroleum Refinery and Berlin-based German Heliocentris, project cost estimated to be 100,000 euros; operational since March 2010 [8].

- Solar cooling in *Kuwait*: several small and medium capacity projects installed and tested in early 1980s using flat plate collectors and small Vapour Absorption Refrigeration (VAR) system of 5-10 tons cooling capacity. Among the noticeable installations: one for a school building and another 300 m^2 of collector area and 3 ten TR VAR chillers for a Ministry building [16]. Some of the challenges faced by solar powered cooling are their low conversion efficiency of 35% and water requirements that puts stress on arid zones desalinated water capacity.
- Solar cooling in *Ras-al-Khaima, UAE.* 10 Tr of refrigeration and 70 kW solar field, 2011, CSEM-UAE (Swiss company); PV and solar-island prototype testing facilities.
- A solar-hydrogen (HYSOLAR) plant producing 463 m^3 of hydrogen per day at normal pressure through water electrolysis powered by 350 kW PV field began in 1986 and ended in 1995 by Energy Research Institute (ERI), *Saudi Arabia* [6].
- In 1996, 1100 flat plate roof-top collectors for solar water heating were installed on 380 residences in King Abdul Aziz City for Science & Technology's (KACST) campus in *Riyadh*.
- Shams tower (not to be confused with Abu Dhabi's CSP plant with the same name) in Yas Marina F1 circuit, *Dubai* rated at 291 kW_p solar electricity.
- 850 kW wind power plant at Sir Bani Yas Island in *Abu Dhabi*.
- Solar powered stadiums are proposed to house the World Cup 2020 in *Qatar* [7].

3.5. SPV manufacturing facilities

Another emerging industry in the Middle East is the poly crystalline silicon manufacturing, raw material for solar cells, with an aim to meet indigenous needs as well as exportation.

- A $200 million solar panel factory in Bahrain in co-operation with a Dutch company was expected to be ready and create 200 jobs by end of 2012 [8], however, latest update could not be obtained at the time of writing.
- A $3 billion investment into solar panels component manufacturing plant (10,000 tons/year polysilicon, 20 million wafers & 19 million solar cells per year) in the western petrochemicals hub of Yanbu; a $380 million polysilicon plant to be built in Jubail, Saudi Arabia with initial production capacity of 3,350 MTPA by 2014 and plans to expand to 1200 MTPA and continue to diversify into manufacturing ingots and wafers by 2017 [6].

3.6. Solar thermal energy systems

- Petroleum Development Oman (PDO) contracted US-based GlassPoint Solar, in August 2011, to build a 7 MW solar steam generator for Enhanced Oil Recovery (EOR) at an oil field in Southern Oman with an aim to reduce natural gas consumption for thermal EOR up to 80%. The project went online in 2013 and produces a daily average 50 tonnes of emissions-free steam [23].
- Dubai's iconic tower- Burj Khalifa is using 378 collector panels, each 2.7 m^2 in area, since April 2010 to heat 140,000 L of water every day for in-house consumption with energy savings equivalent to 3200 kW per day. Additionally, condensate from the air-conditioning facility at Burj Khailfa, Dubai, is recouped to cool potable water and then collected on-site for irrigating tower's landscaping [8].

Besides the above-listed categories, various R&D projects including resource assessment and monitoring (both wind and solar), evaluation and testing of long term PV performance, hydrogen production and utilization, fuel cell development, solar cooling & drying, feasibility case studies of proposed solar/ wind/ hybrid plants have also been conducted or currently underway in the GCC.

4. Renewable Energy prospects and challenges

4.1. Future progress

The Abu Dhabi-based International Renewable Energy Agency (IRENA) estimates "the six GCC countries' returns through renewable energy integration could hit 200 billion U.S. dollars by 2030" [24]. A report forecasts 35-45 GW cumulative capacity additions in the Middle Eastern region out of a global 400-600 GW total RE market potential over the course of 2012-2020 [25]. Multi-billion-dollar worth projects are under serious consideration in the GCC and other Arab countries: (1) US $211 million Green City Project using Building Integrated Photovoltaic (BIPV) in Euro University, *Bahrain* [7]*;* (2) Large-scale solar thermal plants and a 750 MW wind farm in the south of *Oman* [26]; (3) The PV rooftop program across *Abu Dhabi* with a goal to reach 500MW installed capacity within 20 years; (4) US $ 10 billion wind farm to be located outside of Dubai- feasibility stage; (5) Desertec Industrial Initiative: a visionary project lobbied to produce large amounts of solar electricity in the Middle East and North Africa and export portions of it to Europe through an intraregional electrical network. While the countries embark on RE capacity building, it is worthwhile to assess the present state of affairs. Bachellerie projects RE generation for the six countries based on the data available in 2011 [6]. Table 3 sums up the findings.

Table 3 Country-wise projected capacity sourced from RE

Country	Projected Installed Capacity	Expected end of year	Remarks
Bahrain	30.67	2013	Cumulative addition over 2011-2013; RE share only 0.7% of 2011
Kuwait	141.38	2015	Nil deployment since R&D in 1979 up until 2012
Oman	213.98	2013	Subject to full deployment of proposed CSP plant (see Table-2)
Qatar	100	2014	In its entirety to come from proposed PV energy plant of polysilicon facility
Saudi Arabia	33.67	2012	3.17 MW installed in 2011, three more projects make up additional 30.5 MW
UAE	125.8	2013	More than 23 RE projects, of 20 are solar energy projects; 14 projects deployed

4.2. Inhibitors and challenges

Some experts deem the region's goal of 25 GW renewable energy market by 2020 to be far-fetched especially because required "infrastructure, skills and funding is not in place to support it" as noted by Abhay Bhargava, head of energy at Frost & Sullivan in [27]. The main inhibitors or impediments in the path of large-scale renewable energy deployment for the GCC region are identified as follows: (1) **Subsidized hydrocarbon power:** even as the technology progresses, it will take longer for solar and wind energy to become cost-competitive in the GCC as compared to other parts of the world, primarily because of inexpensive domestic electricity. According to the proponents of "rentier state" theory, GCC nations' rulers and citizens are bound in a societal contract under which subsidized lifestyle comforts are traded for political support [1, 28]; (2) **Inadequate regulatory framework:** while setting renewable energy goals is a good starting point, government enforced policy tools are equally necessary for effective implementation. According to a survey by Emirates Solar Industry Association, absence of feed-in-tariffs and broader regulatory framework is perceived as one of the major challenges in solar industry growth in the UAE [X2]. Lack of common consensus on climate change threat and the fact that there is no single governing body responsible for RE policy and implementation at GCC level is also seen as an impediment [5]; (3) **Financial impediments**: large upfront capital, risky investment, longer periods of return, absence of adequate finance mechanisms such as funding, subsidies, incentives and sanctions that would make an RE project financially attractive; (4) **Technical challenges**: environmental challenges such as heat, dust and humidity reduce the efficiency of solar collectors, such losses need to be accounted for before estimating meaningful output from any solar facility, patchy and variable power generation imposes grid-integration and transmission challenges; (5) **Societal constraints:** lack of localized technical expertise and skilled work force, insufficient training and development, inadequate interaction and knowledge dissemination between industry, scientific community and policy makers involved in this sector, market perception of utility companies, who are accustomed to steady generation, and investors, who in the absence of track record, are reluctant to finance such projects.

5. Conclusions

RE market is steadily growing in the GCC. Such paradigm shift in energy matrix is a sign of strong foresight and timely progress. However, while there have been innumerable feasibility studies on solar and wind energy deployment in the region, actual implementation is either limited to pilot/ demonstration programs or ‘future-visions’ with no explicit progress updates. In fact, till date Shams-1 is the only large-scale up and running project, the rest are mostly in pipeline with equivocal timeframes. Legally binding regulatory framework, adequate finance-mechanisms, country-level RE market strategies are some of the tools that will aid smart integration of presently appearing unattested-RE-goals. Localized technology clusters which orient and diffuse RE technology in the right direction, not only create awareness but also act as catalysts for other countries in the region to follow suit, of which the pioneering Masdar City project is an example. The oil-rich countries have risen from their perception and started to see the manifold benefits of developing renewable energy technology although at a cost, what remains is a committed follow-up.

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Entity	**Masdar City** Abu Dhabi, UAE	**King Abdullah University of Science and Technology (**KAUST) Saudi Arabia	**Qatar Science and Technology Park** (QSTP), Qatar	**Kuwait Institute for Scientific Research** (KISR) Kuwait	**Mohammad Bin Rashid Al Maktoum Solar Park** Dubai, UAE
Landmark features					
Current/ Ongoing	Masdar units- Capital, Clean Energy and City + MI, an independent research-driven graduate university. runs sustainable transport (driverless prts and electric cars) 10 MW solar PV facility, roof-top solar, number of pilot projects and several large-scale international ventures in solar and wind power 6 km^2 walled sustainable community with waste management and water conservation programs	Two innovative passive solar-wind towers; solar thermal panels (4134 m^2); 2 MW; roof-top PV arrays (16,567 m^2) off-setting 5.7% of total campus energy demand [8] sustainable transport system including shared electric cars, Segway, bicycles and shuttle buses awarded LEED Platinum Certification for eco-friendly building design	35,000 m^2 QSTP/GreenGulf testing facility for SPV and CSP technologies as well as other solar systems Solar Carbon Black Project to develop a reactor for solar thermal applications (project partners: Germany's Fraunhofer Institute, Federal State of Sachsen, Texas A&M and Qatar University)	140 RE research projects worth $50 million (since 1975)** including solar heating and cooling; water desalination; solar electrification of a school; KISR's Solar House (application laboratory); solar power plant at Sulaibia complex with 56 parabolic trough dishes. Such initiative, abruptly discontinued in 1986, is now regaining lost interest.	Bidding phase
Proposed/ planned	near-zero waste, carbon neutral, housing 40,000 residents, hundreds of businesses, 250 MW SPV & 20 MW wind power, solar water heating & desalination	solar desalination plant prototype; Research Park and Technology Cluster; various pilot projects	(a) $ 1.1 bn polycrystalline silicon manufacturing plant in Ras Laffan Industrial City (8000 MTPA)[+] (b) Chevron's $ 20 m Centre for Sustainable Energy Efficiency for RE deployment	KISR and MEW (Ministry of Energy and Water) collaborate for 70MW RE complex: 10MW PV plant, 10MW wind farm and a 50MW CSP	$3.3 billion, 1000 MW CSP and SPV installed capacity

Appendix A Renewable and sustainable energy research-driven technology clusters in the GCC region