Gulf Research Center

Knowledge for All

Sustainability and Competitiveness: A Pragmatic Approach to Solar Energy Transition in the GCC Countries

Imen Jeridi Bachellerie

GRC GULF PAPER

September 2013

GRC PAPER

Sustainability and Competitiveness: A Pragmatic Approach to Solar Energy Transition in the GCC Countries

Imen Jeridi Bachellerie*

The drive towards a long-term sustainable and clean energy future takes it for granted that it is pivotal to expand the use of renewable energy sources (RE). Such imperative has motivated political, economic, and socio-technical innovations around the world, whose objectives are to advance related technologies and maximize their deployment.

For the Gulf Cooperation Council (GCC), whose economies are most heavily dependent on oil and gas, a RE transition – albeit possible – remains particularly challenging. In the region's extreme aridity and with the increasing risks in global warming, the massive needs for air-conditioning and water desalination are driving high increases in domestic energy consumption. This trend leads the GCC countries to burn mounting shares of their hydrocarbon reserves, which affects their capacity for future exports and related revenues (see Table 1).

Most GCC governments have recognized the imperative to improve the sustainability of their economies and energy systems. They have started to explore energy conservation and diversification avenues in order to move away from the current fossil fuel consumption trends. In particular, interest in RE technologies has been growing over the last decade. Studies and deployments have multiplied, and the role of solar power and solar thermal technologies has been endorsed through institutional reforms and Research and Development (R&D) investments.

* The author would like to extend special thanks to Dr. Antoine Zahlan who contributed towards this research study through numerous exchanges. Thanks are also due to anonymous reviewers for their comments that considerably improved the quality of the paper.

Nonetheless, until now, these technologies account for only a negligible share of the region's electricity capacity.

Truth is that substantial financial and energy resources have been invested in expanding the GCC electricity and water sectors: electricity installed capacity more than doubled, from nearly 46,600 MW in 2002 to almost 98,000 MW in 2009,[1] and desalination capacity grew from 10.1 million Cubic Meter/day (MCM/d) in 2000 to 25.5 MCM/d in 2008.[2] Yet, RE (mostly solar) deployments do not exceed 175 MW in the GCC countries;[3] this capacity remains insignificant if we compare it to current fossil-fuel based capacity of the region, which, at the time of writing, stands above 110,000MW.[4] Undeniably, for wider and faster deployment of RE solutions to happen in the region, several barriers at the technological, political, and social levels would need to be overcome. This paper attempts to look at what is preventing the GCC countries from effectively pursuing the renewables opportunities.

Indeed, besides the geographic constraints, the economies in the region are characterized by energy-intensive industrial projects and lifestyles and by excessive and inefficient energy consumption patterns, resulting in record-high per capita energy and CO2 emissions. Correspondingly, the GCC governments' policies have continuously prioritized the modernization of their economies through ramping up urbanization, industrial diversification, and through exploiting the competitive advantage of cheap access to hydrocarbons. Indeed, the recent socio-economic growth in the region has heavily drawn on subsidized and ever-expanding use of fossil fuels – thus trumping any sustainable energy imperatives or environmental concerns that would have advanced the RE agenda.

Furthermore, in view of the GCC countries' future economic plans, such energy demand is predicted to increase; so, unless a dramatic change in developmental trends and lifestyles occurs (which is unlikely), any potential transition to energy systems that incorporate RE solutions will have to be in tune with the current socio-economic priorities of the region. The question then is: how can a widespread deployment of RE technologies build on the reality of regional growth strategies driven by fossil energy subsidies, industrial expansion, and the imperative of competitiveness?

The paper argues that incentives for a clean energy transition should pave the way for both enhanced sustainability and competitiveness of the region's economies. In this sense, the following paradigms:

1. *Khaleej Times* 2011.
2. ESCWA 2011, 18.
3. If we include the recently completed plants of Oman PDO's West oil field solar thermal (7MW) and Abu Dhabi Shams1 Concentrating Solar Power (100MW).
4. Research and Markets 2013.

1) Minimizing energy waste to enhance economic competitiveness,
2) Transferring solar technology (and know-how) through access to intellectual property rights that build a knowledge-based industry (KBI) and
3) Collaborating regionally to integrate RE findings and optimize resources, can create opportunities for the GCC countries to optimize their energy use, diversify into knowledge-based solar industries, and maximize deployment of related RE solutions, in the long run.

In the region, renewable and nuclear energy diversification plans tend to have priority over efficiency measures, although conceivably this should be the other way around. Accordingly, any energy diversification policies in the GCC region, namely the incorporation of RE technologies in the existing energy systems, should be preceded by the adoption of conservation measures that rationalize use of energy in the region. It is clear that excessive consumption, energy losses, lack of awareness about real energy cost, as well as environmental problems are all indicative of current insufficient attempts in the region to minimize waste in the energy consumption and production systems. This naturally undermines the economic viability of present and future RE technologies. Hence, we maintain that energy efficiency (EE) policies should be adopted – as an integral phase – to optimize the technical readiness of the region's energy systems in incorporating RE solutions.

Obviously, there are many areas where the continuous growth of the region's economies may be made more sustainable. But the emphasis of this paper is on the electricity and water sectors, as they consume increasingly large volumes of fossil fuels in the region, and their cost-effectiveness can easily be improved by substantial reduction of waste. The paper highlights the socio-economic effects of conservation measures, in relation with national consumption, and examines the opportunities and challenges that solar energy solutions can present in both this prospect and eventual sustainable energy transition.

Past experiences in the GCC countries have highlighted the suitability of the local climate for both solar power and solar thermal energy. But the deployment of such solutions still asks for the identification of the most appropriate applications, and further R&D activities are required to adjust materials, efficiency, and cost-effectiveness of related technologies to the local conditions. In this sense, getting over dependence on technology imports and foreign know-how still constitutes a challenge that should be addressed in priority. The paper argues that transferring solar energy knowledge to the region – namely through access to intellectual property – can help build competitive clean-tech industries in the region. It emphasizes the role international cooperation and joint projects can play in both advancing and adjusting related technologies to GCC needs. So, beyond the construction of pilot plants or clean-tech clusters that deploy imported solutions and expertise, pursuing solar energy opportunities should involve the creation of the required socio-technical conditions for these initiatives to translate into embedded technologies in the long run.

Against this background, the present R&D capacity of the GCC countries in solar energy is delineated first, with emphasis on some studies and projects that detail the cost and efficiency of related technologies. In doing so, the analysis demonstrates the existence of real overlapping interests and activities in this field throughout the region, and attempts to explore opportunities for collaborative research on this priority area. Indeed, with common challenges related to climate, resources, and development patterns, it is argued that GCC countries could highly benefit from putting their experiences together and sharing solar energy R&D findings, which they have so far accumulated on their own. In particular, the sectors of green buildings, solar cooling, and water desalination seem most appropriate for such collaboration.

1. Energy Diversification and Sustainability: Drivers and Challenges

1.1. Soaring Demand in the Power and Water Sectors

As hydrocarbon-intensive developments in the region have become more constraining, the imperative for energy alternatives has risen, and governments have been compelled to look for solutions. In particular, the rapid pace with which the region's electricity and water demands have increased during the last decade provided the most compelling reason for energy conservation and diversification discourses in the GCC countries.

The region's socio-economic expansion has indeed been accompanied by an average electricity demand growth rate of about 8.85 percent per year – the fastest in the world; power consumption hit 352.1TWh in 2008 (Table 1) – accounting for more than double the consumption of Turkey but with only half of the population – and is projected to continue growing by 7 percent to 8 percent annually for the next decade.[5] Furthermore, a 2011 report by the Arab Petroleum Investment Corporation (APICORP) estimates that the region will need to invest around $58.2 billion to expand its power generation capacity by 49 GW between 2012 and 2016.[6] Similarly, it was estimated that sea water desalination capacity in the region will reach 41.1

5. El-Katiri 2011, 4-5; and IEA 2010.
6. *Khaleej Times* 2011.

MCM/d by 2016,[7] up from 25.5 MCM/d in 2008, and that GCC countries will invest more than $100 billion in their water sectors between 2011 and 2016.[8]

Table 1: GCC electricity, water and energy indicators 2008

	Electricity capacity (MW) [a]	Electricity consumption (TWh) [b]	Desalination installed capacity (thousands of cubic meter/day) [d]	Electricity and water energy consumption as percentage of total primary energy supply [g]	Electricity and water energy consumption as percentage of net exports of energy [g]	Percentage of mineral fuel and crude oil in total exports [c]	Solar economic potential (CSP + PV) (TWh/y) [e]	Coastal potential for CSP (TWh/y) [f]
Bahrain	2,777	10.2	783	60%	81%	80.7%	33.3	21.0
Kuwait	10,944	45.7	2,390	40%	8%	94.9%	1,527.5	134.0
Oman	3,991	13.6	960	29%	11%	80.6%	19,408.1	497.0
Qatar	3,164	20.1	2,049	15%	4%	89.6%	793.0	324.0
KSA	45,774	186.7	10,598	30%	8.4%	88.2%	124,573.9	2,055.0
UAE	19,947	75.8	8,743	67%	54%	39.7%	1,991.0	538.0
GCC	86,597	352.1	25,523	40%	16%	72.8%	148,326.8	3,569.0

a. El-Katiri; Saudi Arabia: ECRA and UAE: ADWEA, DEWA, SEWA and FEWA.
b. IEA 2010.
c. based on GOIC Gulf Statistical Profile 2008.
d. ESCWA 2011.
e. DLR 2005.
f. Alnaser, Trieb, and Knies 2007.
g. based on statistics from Bahrain EWA, Kuwait MEW, Oman: only for electricity generation-OPWPC; Qatar: based on financial report of Qatar Petroleum (2009) and estimated cost of MBtu for a typical GCC utility by Booz (2010); Saudi Arabia: only for power plants-MWE; UAE: US Energy Information Administration (2011); and IEA (2010).

Booz and Co estimated that desalination alone accounted for 10 to 25 percent of the region TPES; in Booz & Co 2012. Accordingly, the energy consumed in power and water production in Oman and in KSA could have reached at least 39 percent and 40 percent of the country's total primary energy supply, respectively.

Although the most important water demand is currently due to the agricultural sector (70 percent of total)[9] – through overexploitation of groundwater resources,

7. NCB Capital 2009.
8. Booz & Co 2012.
9. The share of agriculture in the individual Gulf countries varies between 45 and 88 per cent, while municipal demand accounts for 9-50 per cent of the total water demand; naturally, industrial water accounts for the difference; see NCB Capital 2009, 3. ESCWA 2011, 9.

especially in Saudi Arabia and the UAE[10] – ramping up urbanization and economic diversification projects will cause municipal and industrial water shares to grow in the entire region. In 2008, an average of 80 percent of the total needs in municipal and industrial waters was covered by seawater desalination,[11] and this proportion is likely to increase in the face of growing groundwater deficit in the region.

1.2. Fossil Resource Challenges and Depletion Prospects

Inexorably, with such forecasts in power generation and desalination, fossil fuel consumption in both sectors will soar. In this context, and beyond the negative environmental effects of increasing oil and gas combustion which are detailed later, the economic impact of future consumption has been particularly highlighted as likely to be extremely costly as well. In addition to costs associated with mitigating climate change effects in the region – like frequent and intense heat waves, loss of rainfall, water scarcity, sea water rise and salinized water[12] – the hydrocarbons exports or the high-value of petrochemical industries of the GCC countries would likewise be very negatively affected, which would further strain the GCC national budgets.

According to the GCC utilities statistics, the energy consumed in power and water production reached an average of 40 percent of the total primary energy supply of the GCC region in 2008. This represented 16 percent of its total net exports of fossil fuels (see Table 1). Furthermore, electricity generation in Kuwait has increasingly been based on heavy and crude oil since 2005, and the country has become a net importer of natural gas since 2008.[13] Similarly, due to constraints in domestic natural gas supplies, the share of heavy and crude oil in generating electricity in Saudi Arabia is increasing.[14] On the other side, dwindling hydrocarbon reserves or periodic gas shortages – especially during peak summer demands – have already constrained economic projects, caused blackouts, or halted some electrification and desalination projects in a number of GCC states (such as Bahrain, Kuwait, and Oman).

Certainly, the growing energy demand in the region and the prospects that this will remain unchanged have particularly motivated voices in the energy sectors

10. Between 2002 and 2007, the GCC countries' groundwater withdrawal rates surpassed the natural renewable recharge rates nearly to the point of depletion (e.g., Kuwait 2,465 percent in 2002, and UAE 2,032 percent in 2007); ESCWA 2011, 7.
11. NCB Capital 2009, 9. Desalinated water reserves in the region do not exceed 2-5 days, according to Thomas M. Missimer et al. 2012, 88; but some GCC governments (Abu Dhabi, Dubai, Qatar) are building and replenishing aquifers through water desalination in order to have up to 90 days of water reserves and be able to meet demand during times of shortages; in MEED 2010.
12. Jalilvand 2011.
13. Kuwait Ministry of Electricity and Water 2009, 228; and EIA 2011.
14. Saudi Arabia Ministry of Water and Electricity 2007, 37.

GRC PAPER

to advocate conservation and diversification.[15] Similarly, the region's electricity and water authorities have gradually become aware of the necessity and possibilities to cut down domestic fossil fuel demand. Yet, conservation efforts remain circumscribed to certain production or consumer's segments and hence have limited impact on the increasing national demands and emissions.

1.3. Climate Change and Protection of the Environment

Conversion of energy into electricity and heat represents the main source of total CO2 emissions in the GCC countries. Thus, as power and water production are bound to escalate in the whole region, the "business as usual" scenario, in which the same fossil fuels are used, would lead to CO2 emissions increase by about the same proportions. According to some studies, the recognition of such a fact has made the governments in the region strive to either limit forecasted increases or search for non-fossil sources of power generation, namely solar or nuclear energy.[16]

Certainly, Bahrain, Kuwait, Saudi Arabia and the UAE have all considered the nuclear option to meet such energy demand challenging prospects. However, due to various socio-political factors these diversification plans have been abandoned in Bahrain and Kuwait, but they continue to be pursued in Saudi Arabia through King Abdullah City for Atomic and Renewable Energy (KA-CARE), and are certainly well on the way to being established in the UAE through the Federal Authority for Nuclear Regulations (FANR). Four nuclear plants with a total capacity of 5.6GW are expected to be completed between 2017 and 2020 in Abu Dhabi. These will contribute to meet a projected peak demand of at least 33GW in the UAE by 2020. However, with natural gas expected to meet up to 25 GW of generation capacity, there still remains room for 2.4GW of alternative energy-based capacity. It is worth mentioning here that – in parallel with the nuclear option – Abu Dhabi has strongly advanced the RE agenda through the Masdar initiative; initially, the authorities announced that RE electricity would account for 7 percent by 2020, but they have pushed back the target to 2030.[17]

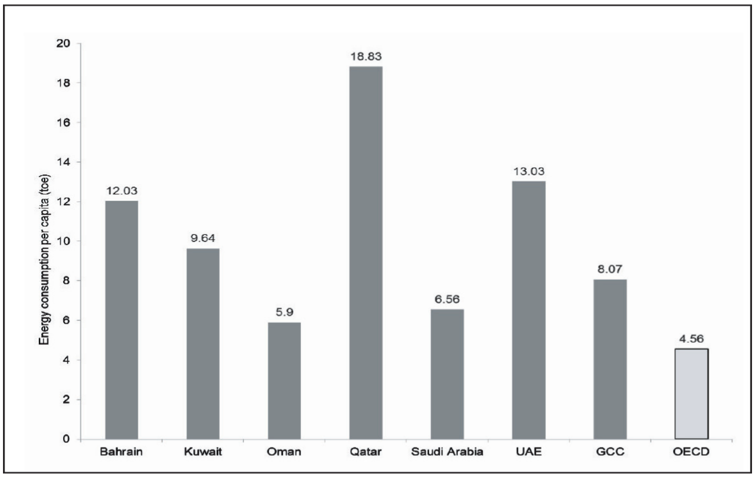
As far as the global warming issue is concerned, the GCC governments are signatories of the United Nations Framework Convention on Climate Change (UNFCCC) and have also ratified the UN's Kyoto Climate Change Protocol since 2005. Carbon Capture and Sequestration (CCS) had the preference of the hydrocarbon sector in some GCC countries – namely Abu Dhabi in UAE, Bahrain and Kuwait. But to better comply with the Kyoto Protocol, some solar energy

15. Speech of Kuwait Petroleum Company CEO in KPC Media Centre 2011; and speech of Aramco CEO in *Financial Times* 2010.
16. Qader 2009.
17. FANR 2009, and Bloomberg 2012.

deployments projects have also been designed and submitted by the UAE to the UNFCCC Clean Development Mechanism program (UNFCCCCDM).

Nevertheless, as developing states with no binding emissions targets, the GCC countries have only timidly looked for RE opportunities to cut emissions and generate carbon credits. Overall, per capita CO2 emissions in the GCC countries remain the highest in the world and unsustainable demands – especially in the power and water sectors –indicate that there still remains plenty of scope for further conservation and environmental measures in the region. Per capita energy use continues to be record high in the GCC countries (see Fig. 1)

Figure.1. Energy consumption per capita (toe) - 2008



Source: Based on IEA Key World Energy Statistics (2010).

1.4. Global Solar Energy Industrial Prospects

Despite common arguments about solar energy's low efficiency and high cost, recent advances in related technologies and materials have played in favor of re-exploring the solar energy option in the region. Indeed, as the solar industry is developing worldwide, it has been emphasized that the importance of R&D will increase in the future, and new technologies can make solar energy more and more cost-effective.[18] Thanks to scientific advances addressing the efficiency of collection and storage, and based on clean energy proven markets, it is expected that cheap solar energy will be technically feasible as soon as 2020.[19]

GCC governments and energy stakeholders have paid attention to such global innovation trends; they have decided to fund local R&D programs or international

18. Jalilvand 2011.
19. RAND 2006.

basic research to advance the development of new solar technologies as well as clean energy storage solutions. For instance, through different international collaboration initiatives, Bahrain Petroleum Company, Kuwait Investment Authority, King Abdulaziz City for Science and Technology (KACST), Qatar Science and Technology Park (QSTP), and Abu-Dhabi based Masdar have financed projects to explore both electricity generation and storage devices based on Photovolatic (PV) or Concentrating Solar Power technologies. More generally, by targeting next generation technologies or furthering current deployment activities in foreign energy markets, GCC investors aspire to have a long-term positive return on their technology and commercial investments.[20]

It is worth mentioning here that studies had already emphasized the present financial benefits of deploying existing RE technologies in the GCC context; for instance, some argue that apart from saving on gas consumption and imports in general, deploying photovoltaic (PV) panels as wall cladding would also allow a reduction in the hydrocarbon-based air cooling demand in the building sector and hence increase the efficiency of its energy use.[21] Others underline that taking into account the health benefits – due to reducing GHG emissions – in the final cost of a PV KWh would show the economic viability of such technology. Indeed, unlike fossil energy use, RE deployments can indirectly lead to cuts in government budgets in both the health and environment sectors.[22]

Nevertheless, such financial incentives seem to have not attracted enough consideration among the region's decision makers. In addition to the aforementioned investment choices, some GCC countries have become motivated by more tangible industrial aspects linked to solar energy – without necessarily, linking them to local deployment strategies. As photovoltaic power generation is expanding globally, and given the fact that the region has plenty of silicon and cheap access to energy, poly-silicon manufacturing has attracted investments in Saudi Arabia and Qatar, especially. These manufacturing ventures come as part of local industrial diversification plans, and hence – like many other energy-intensive industries in the region – are mainly building on the GCC's competitive advantage of cheap access to energy. So, unless these industrial developments are accompanied by a comprehensive strategy for widespread solar deployments in the region, they would only exacerbate energy demand and the CO2 footprint.

20. Such a statement was more or less expressed by KIA managing director Bader al-Saad in Trade *Arabia* 2009.
21. Radhi 2010.
22. Harder 2011.

2. Progress of Solar Energy Knowledge in the GCC Region[23]

Investigations of the region's solar potential, led by local and international research institutions, have systematically shown that both PV electric and CSP thermal solutions could be appropriate to the local climate as they would yield important power outputs. It has been estimated that the total economic solar potential of the region amounts to 148,326.8 TWh/year, which represents 421 times the power demand in 2008 of all the GCC countries (see Table 1 also for solar potential figures per country).[24]

Interest in developing solar energy sources was expressed in some GCC countries as early as the mid-1970s. Between the late 1970s and early 1990s, Saudi Arabia and Kuwait spent around $250 million to investigate some solar energy applications and their technical feasibility under their climate conditions. Initially, these research and demonstration projects were implemented in cooperation with international research institutions and industries, but were then followed by further research studies conducted in KACST and other universities in Saudi Arabia, and by the Kuwait Institute for Scientific Research (KISR).[25]

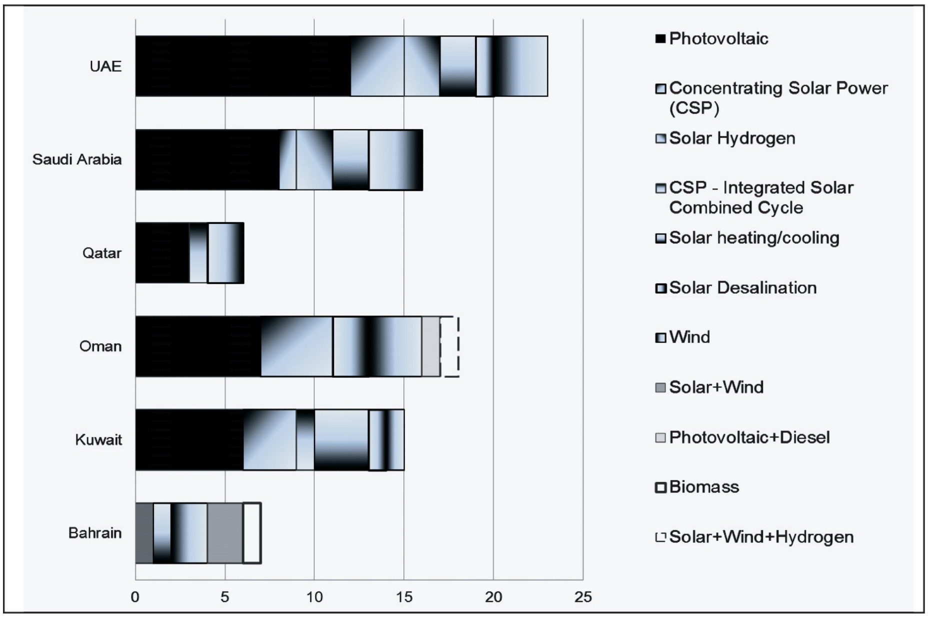
More recently, interest in RE has been expressed by all GCC governments. This has translated into further research studies – conducted jointly with international research teams to explore newer solar technologies – or demonstration projects deployed domestically to assess the technical and economic viability of renewables. While during the 1970s and 1980s RE investments were made to mainly explore solar energy potential and related solutions for water and power production – with no involvement of the local industrial sector – RE initiatives of the last decade were motivated by energy-related and economic sustainability imperatives, and hence involved several actors and partnerships among governmental, private, academic and international organizations.[26] So, whereas earlier investments were confined to academic research projects that took place outside any industrial or institutional local contexts, the more recent ones were directed to both deploying RE technology

23. A comprehensive report on renewable energy sources and their development in the GCC region can be found in Jeridi Bachellerie 2012.
24. "The technical potentials are those which in principle could be accessed for power generation by the present state of the art technology. The economic potentials are those with sufficiently high performance indicator that will allow new plants in the medium and long term to become competitive with other renewable and conventional power source, considering their potential technical development and economies;" in DLR 2005, esp. 55 and 56.
25. A summary of Saudi Arabia and Kuwait first research programs and investments in solar energy can be found in Jeridi Bachellerie 2010.
26. Like the newly established International Renewable Energy Agency (IRENA) based in Abu Dhabi.

in larger R&D projects or pilot plants as well as the setting up of governmental institutions dedicated to the advancement of RE in the region – namely QSTP in Qatar, KA-CARE in Saudi Arabia, or Masdar in the UAE (See Appendix: List of GCC Institutions working on Renewable Energy and energy efficiency development). Among these pilot deployments, one can cite rooftop PV systems in Masdar City (1MW), KAUST buildings (2MW) in Thuwal (KSA), and Qatar Exhibition Center (12MW); PV plants by Aramco-Naizak (3.5 MW) in Riyadh, Shoya Shell and Saudi Electricity Company (0.5 MW) in Farazan Island, or by Masdar (10 MW) in Abu Dhabi; and solar thermal plants by Oman Petroleum Development Oman (7MW) in its West oil field, and Masdar Concentrating Solar Power Shams1 (100MW) in Abu Dhabi.

Some smaller deployments were also made in the region as private initiatives; the main aim was to reduce the energy requirement in buildings, and/or respond to green design regulation, like LEED (e.g., Pacific Controls headquarters in Dubai). Such deployments were generally intended to set a positive example or convey an environment-friendly image at a national or regional level (see Table 2).

Figure 2. Main Renewable Energy R&D projects per GCC country



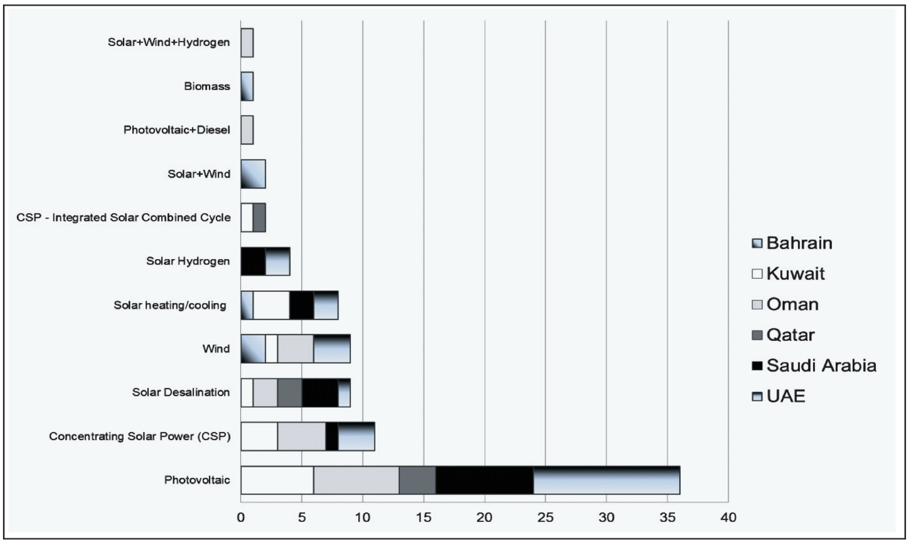
Sources: Author compilation

In general, a mapping out of the region's aggregate experience shows that the UAE and Saudi Arabia lead the way in terms of solar energy R&D and demonstration projects (see Fig. 2). Qatar, however, is a new player in this field, whereas Oman, Kuwait or Bahrain institutions initially led some scientific research studies and then focused their efforts on feasibility studies for potential deployment.

2.1. Researched Applications for Solar Energy

Many of the RE experiments – through tested or computer-generated solutions – were conducted by the different GCC institutions separately. Put together, these would understandably provide a significant and accurate knowledge about solar technologies and their adaptability to local contexts. A closer look at the multiple solar projects in the region indicates that the most commonly investigated solar technologies are photovoltaic (PV) power, followed by Concentrating Solar Power (CSP), and then solar desalination solution (MSF MED or RO) (see Fig. 3). However, solar cooling, which should have been more researched by all GCC countries for obvious needs, has unjustly received little attention.

Figure 3. Main Renewable Energy R&D projects in the GCC region per technology



Sources: Author compilation

More specifically, Tables 2, 3 and 4 present a compilation of the main solar applications that received particular research and/or investment focus in the GCC countries. They illustrate different solar power generation solutions in the region, with detailed information on the technology used, its efficiency, and related levelized cost of electricity (LCOE) for 1KWh, when available. Overall, these simulation studies, R&D activities, or pilot plants confirm that the region can have several possible openings to develop its solar technology sectors and potential markets. They also indicate the existence of overlapping areas of interest among the energy, construction and manufacturing stakeholders of the region.

For instance, taking into account the high solar potential for photovoltaic technologies, where the Global Horizontal Irradiance (GHI) in the GCC ranges between 4.5 and 6.5 KWh/square meter,[27] BIPV or PV power generation were thoroughly investigated and results show that these applications could be very appropriate to the region's actual needs (see Tables 2 and 3). In particular, it was found that the operational energy of a building can be reduced by 350 KWh/y for each square-meter of PV panels used as wall cladding (see Table 2).[28]

Similarly, it was estimated that solar water heating can save between 10 and 15 percent of national electricity consumption in the GCC countries.[29]

Second, as electricity demand in all GCC countries peaks in the summer months (April-October) at hours of the day when GHI is highest in the entire region, PV power generation seems naturally attractive to mitigate the peak load. Such an option would certainly save important amounts of fossil energy, given that the peak load is almost the triple of the winter demand.[30]

Third, PV technologies seem to be particularly well designed for off-grid applications in the region. Many studies on the different GCC countries' context have shown that these applications could present services equivalent to conventional solutions (Table 3). For example, there are feasibility studies of non-grid-connected PV power plants in Oman under the supervision of the Omani Rural Power and Water Authority. Indeed, a strategic imperative related to PV deployment could be about land development, where the challenges of electrification, costs of power transmission, and losses due to large distances constitute a hurdle for the socio-economic inclusion of communities, especially in large territories like that of Saudi Arabia.

Similarly, thanks to high Direct Normal Irradiance (DNI) values in the region, the CSP potential of the GCC countries (see Table 1) is huge which means that this technology should not be overlooked. Table 4 shows that CSP applications in the GCC countries can comprise water desalination, integrated solar combined cycle

27. DLR 2005, 55.
28. Radhi 2010.
29. Alnaser and Flanagan 2007.
30. Al-Ajlan et al. 2006.

(ISCC) plants, thermal enhanced recovery (EOR), with clear advantages in terms of production cost or industrial flexibility (see Table 4).

Table 2: Comparative table of different solar energy solutions in the GCC Building Integrating Photovoltaics (BIPV)

Building-Integrating Photovoltaic (BIPV)

Country	Technology	Case Study/Feasibility/Project	Assumed Module Efficiency	Cost	Reference
Bahrain	Photovoltaic RWE Shott Solar or Kyocera PV - KC200GT Japan (ASI Glass; thin film modules based on amorphous silicon)	. A simulated making-over of Al Moayad Tower: Available area for panel installation is 16,000 square meter (850 KW of solar capacity), producing 3GWh/year. The shading effect of the solar films/panels should also reduce the cooling requirement (70-80 percent of total electricity needs).	20 percent	Cost of the tower solar make-over 11 million UK pounds	Alnaser, Flanagan and Alnaser (2007)
Kuwait	Photovoltaic Mono-Crystalline BP585L Saturn	. 25 sampled houses: Average electricity production of PV modules mounted on the roof could reach 64 MWh/year (50 percent of the total electricity needs).	13.54 percent	-	Al-Mumin and Al-Mohaisen (2006)
United Arab Emirates	Photovoltaic Sanyo Single Crystalline Silicon Cells	. A simulated 445 square meter of 67.1 KW PV panels are integrated into the envelope case of a commercial building as wall cladding in UAE: - Actual annual consumption of the building is 2,069,201KWh (Abu Dhabi case); - Electricity output of the PV system is 39,545 KWh/year; - Energy saving due to both the PV output and the decrease of cooling energy demand due to the thermal insulation effects of PV modules can attain 155,420.2 KWh, i.e., around 350 KWh/square meter; - When the saving in cooling demand is taken into account, the pay-back time of the PV system is reduced from 29.8 to 6.5 years (Abu Dhabi).	15.2 percent	-	Radhi (2010)
Kuwait	Photovoltaic Siemens SR100 Poly-Crystalline modules	. Over 10 months (excluding the hot July and August), a simulated grid-connected 20 KW PV array mounted on the roof satisfies 70 percent of the total electricity demand of the building. The efficiency of the inverter is assumed to be 93%.	-	-	Abdullah, Ghoneim, and Al-Hasan (2002)
Building-Integrating Photovoltaic (BIPV) and Thermal air-conditioning					
United Arab Emirates	Photovoltaic panels SunPower E19 and Thermal Collectors	. Masdar City rooftop deploys 1MW of PV panels that provide 30 percent of electricity demand. They are mounted on a canopy structure to provide shade. Thermal collectors provide 75 percent of its hot water.	-	-	Masdar
United Arab Emirates	Photovoltaic and Solar Flat Plate Collectors/ coupled with Absorption chillers.	. Pacific Control Systems Headquarters -120,000 sq.ft - deploys 50KW PV system for lighting and 100 tons of solar thermal air conditioning - equivalent to 350 KWt - to provide 25 percent of the building cooling requirement.	-	-	Pacific Control Systems (2008)

Source: Author compilation

Table 3: Comparative table of different solar energy solutions in the GCC Photovoltaic (PV) power generation

PV Power generation

Country	Technology	Case Study/Feasibility/Project	Assumed Module Efficiency	Cost	Reference
Kuwait	Photovoltaic	. A 1 MW PV station in Kuwait: if installation costs are $4/W - discount rate at 5% - then the Levelized Cost of Electricity (LCOE) would be $0.16/KWh, which is comparable to fossil fuel-based cost of $0.12/ KWh at $50/barrel of oil.	15 percent	LCOE is $0.16/KWh	Ramadhan and Naseeb (2011)
Oman	Photovoltaic	. A simulated 5 MW PV station in Marmul (Oman) would generate 9 GWh annually, with Capacity Factor of 20.6 percent, and the Levelized Cost of Electricity would be $0.21/KWh, which is comparable to Diesel-based electricity generation (even without taking into account the benefits from reducing GHG emissions).	11.7 percent	$0.21/KWh	Al-Badi, Al-Badi, Al-Lawati, and Malik (2011)
Oman	Photovoltaic Thin film and monocrystalline panels	. A 100KW PV in Hidj ; a 292 KW PV in Al-Mazyunah; a 1,500 KW PV in Hij; and a 28 KW PV in Almathfa (Oman).	-	$0.24/KWh in small PV/ Diesel hybrid systems (10%solar) $0.25 /KWh in large grid-connected PV projects	Authority for Electricity Regulation, (2010)

Table 3, continued

Qatar	Photovoltaic panels	. A simulated 100MW PV station with capital costs of $5/W, a lifetime of 25 years and 3% of discount rate would produce 246.5 GWh. The Levelized Cost of Electricity would be $0.12/KWh, which is twice as high as a gas turbine unit generation cost.	10 percent	$0.12/KWh	Marafia (2001)
United Arab Emirates	Photovoltaic Mono-Si BP Solar 90W	. A simulated grid-connected 10 MW PV plant, at $5.5/W, discount rate of 5% and capacity factor of 28 percent would yield 24.4 GWh/year and a LCOE at $0.16/KWh against fossil-fuel-based cost of $0.082/KWh in the UAE.	-	$0.16/KWh	Harder, MacDonald Gibson (2011)
United Arab Emirates	Photovoltaic panels First Solar Thin Film and Crystalline Silicon	. Masdar City Plant. A small-scale plant connected to Abu Dhabi grid (UAE), deploys 10 MW of PV panels to power Masdar City energy requirements.	9.7 - 10.8 percent	$0.117/KWh	Masdar, and CDM Project Design Document ADFEC 10 MW Solar power Plant
United Arab Emirates	Photovoltaic panels Thin Film	. Mohamed Bin Rashid Al Maktoum 10 MW PV Plant. A small scale plant under construction in Dubai (UAE) to be connected to the grid. It should deploy 10 MW of PV thin film panels, generate 15,743 GWh/y and reduce emissions by 8,115 tons of CO_2 annually. Project estimated cost: Dh109 million.	-	-	CDM Project Design Document The Mohamed Bin Rashid Al Maktoum 10 MW PV Plant
Grid-Connected PV power generation					
Saudi Arabia	Photovoltaic Mono-Si BP Solar 90W	. A simulated grid connected 5MW plant in Bishah (Saudi Arabia) with a plant efficiency of 28.3 percent would produce 12.4 GWh annually, with a Levelized Cost of Electricity of $0.20/KWh.	-	$0.20/KWh	Rehman, Bader, and Al-Moallem (2007)
Saudi Arabia	Photovoltaic panels	.A simulated grid-connected 50 MW PV station in Riyadh (Saudi Arabia), would yield 83.45 GWh.	-	$0.216 - $0.24/KWh	Al-Ammar and Al-Otabi (2010)
Off-grid Hybrid PV/Diesel power generation					
Saudi Arabia	Photovoltaic Kyocera Solar Modules	. A simulated hybrid system with 2.5 MW PV, 4.5MW Diesel generators and 1 hour Battery Storage would meet the annual electricity demand of 15,943 MWh of Rawdhat-Bin-Habbas (Saudi Arabia), with a cost of $0.17/KWh at a diesel fuel price of $0.1/liter.	10-15 percent	$0.17/KWh	Shaahid, and El-Amin (2009)
Hybrid PV/CSP Power generation					
Oman	CSP Concentrating Solar Troughs and Tower Technologies; and Photovoltaic	. A 200 MW PV/CSP plant in Adam and Manah (Oman).	-	Cost of projects: $600million	Tendered by Public Authority for Electricity and Water as a Build -Own-Operate Contract (2011)

Source: Author compilation

Table 4: Comparative table of different solar energy solutions in the GCC Concentrating Solar Power (CSP)

CSP power generation

Country	Technology	Case Study/Feasibility/Project	Assumed Module Efficiency	Cost	Reference
United Arab Emirates	Concentrating Solar Power (CSP) Parabolic Troughs	. Shams1. A utility scale 100 MW deploying 2,496 CSP parabolic troughs to supply 286 MWt of thermal energy - which corresponds to gross power generation of 100MW - to be fed to the steam turbines of the plant. The solar field will provide 68 percent of the total 231 GWh generated by Shams1, while natural gas the remaining 32 percent. LCOE is estimated to be $0.16/KWh at subsidized price of 6.63 AED/MBtu (Abur Dhabi) for natural gas; and drops to $0.12/KWh at market price of 25 AED/MBtu.	-	$0.16/KWh	CDM Project Design Document Shams1 100 MW Solar Power Plant Completed in 2013
CSP power generation and seawater desalination					
Oman	Concentrating Solar Power (CSP)	. A simulated 100MW using CSP parabolic trough technology, with a capacity factor of 40 percent, would yield 1,018 GWh. If combined with a RO or a MED desalination unit, the system can achieve 95 percent saving on fossil fuel in a conventional plant during base-load operation.	-	$ 0.4/cubic meter	Gastli, Charabi, and Zekri (2010)
Solar thermal Enhanced Oil Recovery (EOR)					
Oman	CSP Glass Point Mirrors	. An array of 7 MW would produce 11 tons/hour of high-pressure steam capable of extracting 33,000 barrels of oil (ODO Oil fields - Oman).	-	-	Petroleum Development Oman (2012) Completed in 2013

Source: Author compilation

2.2. Centralized vs. Distributed Solar Deployments

Although solar energy experimentation in the region is four decades old, technology deployment is still in its early stages. The most recent feasibility studies or utility and private sector-led deployments show that, in all GCC countries, stakeholders still favor small to mid-scale solar plants and centralized over decentralized solar deployments.

Distributed supply options entail greater delegation and sophistication of control systems to facilitate their (distributed sub-networks) connection to the wider electric network. Unfortunately, most of the GCC utilities have poor information and data communication flows (intelligence) on their grids and on related electricity supply and demand behaviors. Moreover, the region's networks would need to deploy smart grid technologies to enhance the overall flexibility of their power transmission infrastructure[31] and eventually to allow the monitoring of electricity supply fluctuations from distributed – and intermittent – energy sources, like solar. Thus, the present state of the region's networks cannot, at least in the short term, favor the multiplication of solar decentralized deployments.

In this sense, the intermittent nature of solar power supply should also be mitigated through various demand side management and energy saving measures like deploying smart metering devices in the region's electric systems, as these would enhance efficiency and reliability of the power supply in general. Such technical enhancements in the region's networks would underline the related imperative of putting energy efficiency policies first, to optimize the solar energy transition in the GCC region.

2.3. Institutional Context and RE Targets

In parallel with the increase of investment in R&D efforts or pilot plants for the last few years, public bodies were established throughout the region to advance RE knowledge and/or identify opportunities for public and private investments in non-fossil energy resources. Organizations like Masdar in the UAE; Electricity and Cogeneration Regulation Authority, or KA-CARE, in Saudi Arabia; Qatar Foundation in Qatar; and Authority for Electricity Regulation (AER) in Oman have been engaged in studying the technical and economic feasibility of solar technologies in their countries, and advancing some deployment projects. Furthermore, technology parks, universities, R&D laboratories or scientific societies in the GCC countries

31. According to Siemens Middle East, the GCC utilities have just started working on plans to install Phasor Measurement Units (PMU) in critical areas of their networks and – in the future – to install Wide Area Monitoring systems to ensure power quality, propagation and blackout prevention. See Chodimella 2013.

also contribute to the effort; they have initiated programs to map out solar physical potentials and explore solar applications for the region, or organized conferences and seminars to raise awareness and disseminate technical information. The common goal of such diverse initiatives is to further the technological development of renewable energy in their countries and to promote linkages with related industries (see Appendix: List of GCC Institutions working on Renewable Energy and energy efficiency development).

In view of these developments, it is expected that the GCC governments would be industriously pursuing RE opportunities. However, for the time being, progress on the organizational (structural) side is not complemented by RE policies or financial and regulatory frameworks for adoption and subsequent widespread use of these technologies in the region. This is all the more problematic when we consider the fact that every GCC government has set RE targets ranging from 5 to 10 percent of their domestic energy needs by 2030.[32] Indeed, it remains unclear how these targets will be met in a timely manner. However, one should mention the financial framework – called "Green Pricing Mechanism"[33] – that was specifically designed for Abu Dhabi's CSP plant Shams1, where the cost of electricity was estimated at $0.16/KWh, almost six times higher than conventional electricity in Abu Dhabi. The Shams1 electricity cost incorporates two types of subsidies: fuel (Shams1 being a hybrid plant) and distribution subsidies as well the payment of an additional premium by the Abu Dhabi government to the RE producers through a 25-year power purchase agreement. Such a financial scheme resembles a Feed in Tariff but remains unattractive as it weighs considerably on the budget of governments.

Institutional improvements (entities and policies) are important to a future renewable and sustainable energy transition. In particular – in the absence of legal and financial frameworks for utility-scale solar deployments – the GCC governments could face some investment barriers. Their major solar projects would likely follow a project-basis development pattern – sometimes as public infrastructure initiated by the government – or as public private partnerships (PPP), where independent power production (IPP) schemes will be complemented by power purchase agreements with GCC authorities or utilities.

But more constrainedly, it seems that in the short to mid-term the GCC countries would tend to focus on centralized solar pilot plants with large capital investment till appropriate and cheaper technologies are developed for wider and

32. Seven percent by 2030 in Abu Dhabi; five percent by 2030 in Bahrain and in Dubai; 10 percent by 2020 in Oman; 5GW of solar energy in Saudi Arabia; and 10 percent by 2020 in Kuwait. See Jeridi Bachellerie 2012.
33. Neurhof 2010.

distributed deployments. In this regard, and depending on outcomes, one can expect that specific incentives (or frameworks) may then be introduced to promote the most promising technologies and solutions.

3. Current and Potential Stumbling Blocks for Solar Energy Transition

Besides problems that pertain to the absence of RE policies and financing models, many other obstacles will continue to prevent faster development and uptake of existing technologies and potential solutions. These obstacles include newness of technology and its economic and technical viability in local climate conditions; political-economic issues surrounding energy prices in the region; wasteful electricity and water consumption patterns; technical inefficiencies and losses along the supply systems; as well as lack of awareness about real production costs of these commodities and the sustainability imperatives of such resources.

Together with other factors, such obstacles impair the readiness of the GCC energy systems to incorporate solar energy solutions and hamper the achievement of the region's solar energy aspirations in general.

3.1. Newness of Technology and Dependence on Technology Import

Consistent with the prevalence of centralized solar plants in the region, the newness of technology explains the trend towards limited (confined) versus widespread deployments. Indeed, the region's recent pilot plants are mostly intended to demonstrate an imported technology that still requires monitoring and evaluation in local climate conditions. Deployment of experimental as well as more established technologies has certainly helped in better appreciation of both the potential and current limitations of solar energy in the region. In particular, low technical efficiency issues due to dust and humidity are still considered as serious disadvantages to widespread adoption of existing solar technologies. In addition to such factors, experts have also pinpointed the vulnerability of storage devices under the region's high temperatures.[34] These technical challenges for solar energy collection and storage call for further efforts to searching new materials and enhancing the techno-economic viability of deployments in the local context (see Tables 2, 3, and 4 for different solar electricity costs per KWh).

The region's experience also shows that, apart from some academic research and case studies (some of these are listed in Table 2, 3, and 4), the most significant solar

34. Discussion with the Solar Test Facility (STF) manager at QSTP during a EU-GCC Clean Energy Network event held in Doha, Qatar, from May 7-9, 2012.

energy deployment, R&D or demonstration projects were conducted in cooperation between one of the GCC governments' state authority on the one side and a foreign research institution or company on the other side. Such joint schemes were often designed and implemented by the international partner; the local counterparts had little command of the technical know-how or the choice of technology involved in the project, thus indicating an overreliance on foreign knowledge and expertise.

3.2. Non Integration of Findings

It is worth noting that the aforementioned technical obstacles are common to all the GCC countries. However, although technology challenges and climate conditions are the same, and despite the fact that similar solar applications were researched within different cooperation frameworks in the region, intra-regional (bilateral or multilateral) cooperation is scarce -to non-existent in the solar-energy field (See Appendix: List of GCC Institutions working on Renewable Energy and energy efficiency development).

Such a fact has certainly limited access to the wide range of experimentations and tacit knowledge accumulated in the region. For, while there are many experiences within various national institutions, the scattered approach to solar energy development among the GCC institutions (and even sometimes within the same country) does not allow for building on others' findings or failures. Rather, it has led in the past – and may well continue in the future – to duplication of experiments and investments, and hence wasted time and resources.

3.3. Scarcity of Local Competencies

In every strategy that aims to develop solar energy in the region in the future, one should take into account the current skill gap and the dearth of training centers specialized in Renewable Energies.

For instance, in a study conducted in 2007 in Bahrain to explore the constraints in disseminating BIPV in the country, the most striking impediments were found to be the non-availability of expertise, the lack of education and knowledge of sustainable design and PV systems, as well as the absence of governmental financial support provided to contractors to train the engineers.[35] The latter factor points to yet another issue linked to the nationalization of the labor force in GCC companies. Indeed, the fact that most technical positions are occupied by foreigners can explain the lack of (government) financial support for training; hence the trend among contractors to sub-contract expertise from abroad to overcome challenges.

35. Alnaser and Flanagan 2007.

One should also take into account the unwillingness of nationals to undertake menial or manual jobs such as fitting and maintaining solar panels, as they would prefer to be managers, technical advisors, or researchers. Accordingly, it seems that targeted (i.e., directed) education, training, and nationalization incentives will have to be implemented together in order to overcome the deficient local RE labor market and competencies. Obviously, this should happen in accordance with the RE technology applications that will be adopted in the region and the knowledge required to manage and operate them.

Beyond research training programs, like those enjoyed by academic representatives from Bahrain's University of Bahrain, Kuwait's KISR, or Saudi Arabia's KACST, exhaustive learning of the whole solar energy (PV or CSP) value chains will be needed, with insights into new technologies, R&D, quality control, and industrial practice. In addition to universities, the learning endeavor will need to be championed by vocational education initiatives, as well as the participation of the private sector in technical training in every GCC country.

3.4. Energy Waste, System Losses, and Subsidies

Apart from the extreme climate conditions, the excessive energy demand in the GCC countries is found to be largely due to wasteful electric and water consumption patterns in the region. People in the GCC countries spend most of their time inside buildings, and this is mostly true for the period from April to November each year, when, for example, electricity consumption per household trebles in comparison with the winter months. However, the absence of conservation and energy efficiency measures that are widely and effectively implemented exacerbates these patterns as well as the deficit of resources, i.e., hydrocarbons and scarce water. Along with waste-inciting prices of energy, technical inefficiencies and losses inherent in the electricity and water systems of the region are responsible for the continued unsustainable use of fossil energy.

3.4.1. Energy Losses

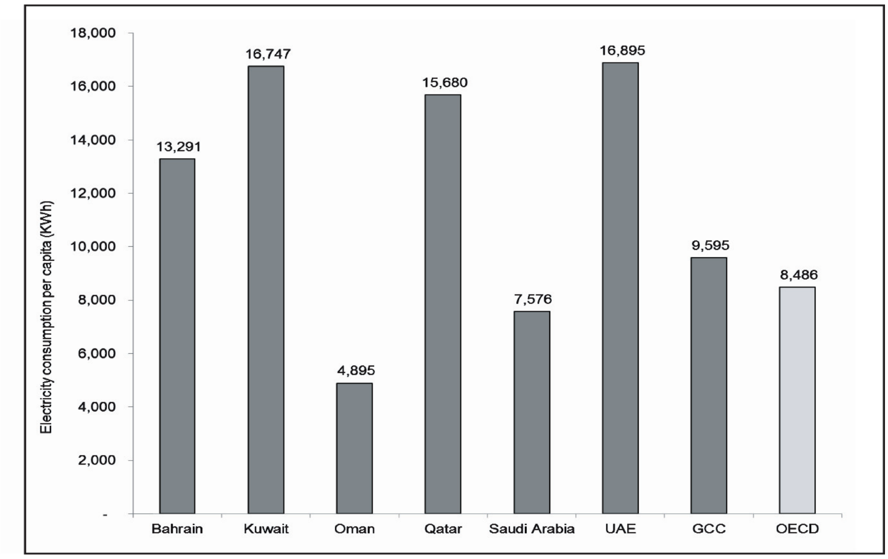
It has been estimated that electricity supply for an average GCC household can reach 48 KWh/day whereas in Europe it does not exceed 28 KWh/day.[36] Such consumption explains the record high per capita electricity consumption in the region (see Fig.6). Badly insulated buildings, inefficient electrical equipment, and constant use of air conditioning are directly responsible for such large demand and indicate that there is much opportunity for technical and political action to conserve energy in this sector.

36. Alnaser, Flanagan, and Alnaser 2008, 1315.

Water demand in the region is also characterized by excessive consumption. In particular, municipal (potable) water demand per capita is extremely high by international standards, attaining 152 cubic meter/year (CM/y) compared with an average of 98 CM/y for OECD countries (see Fig. 7).[37] But, apart from culture-specific behaviors vis-a-vis water usage, supply system losses represent an important reason for the excessive national demand. For instance, water leakages in Qatar and Saudi Arabia water distribution networks were estimated to reach 30 percent.[38] The efficiency of municipal water distribution in the GCC region was considered to be less than 50 percent according to another study.[39] This figure is well above 'the ratio between the net consumption and the actual water withdrawn', which according to ESCWA should not exceed 15 percent in urban areas.[40]

Such poor performance of the region's urban water networks leaves a large scope for improvement. To give an example, the water distribution networks of five cities in Saudi Arabia are likely to cost SAR17 billion for repair of leakages between 2009 and 2015.[41]

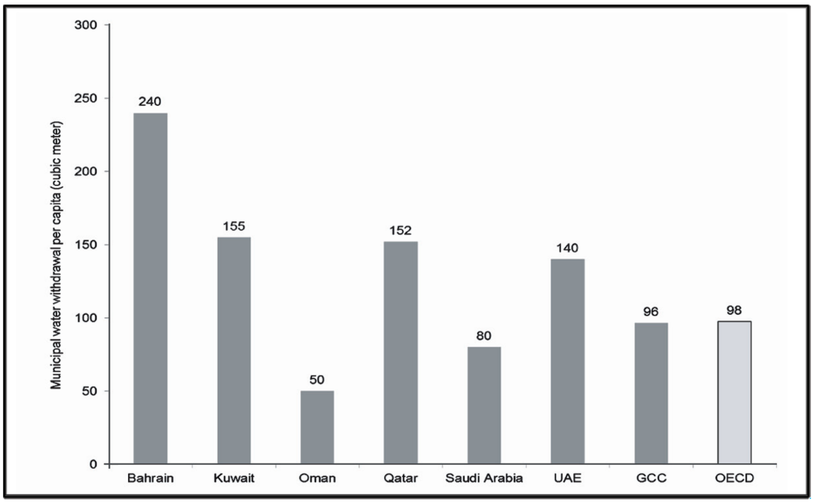
Figure 6. Electricity consumption per capita in the GCC (KWh) - 2008



Source: Based on IEA Key World Energy Statistics (2010).

37. Average per capita water use in the ESCWA region, which includes the GCC countries, is 80 CM/y. See ESCWA 2011, 8.
38. KSA figure: NCB Capital 2009; Qatar figure: Kahramaa 2008.
39. Trieb 2007.
40. ESCWA 2011.
41. NCB Capital 2009.

Figure 7. Municipal water withdrawal per capita in the GCC (cubic meter per year) - 2007



Sources: Based on ESCWA 2011 (data from World Bank, World Development Indicators. Available at: http://data.worldbank.org/indicator) and FAO, AQUASTAT, available at: www.fao.org) More recent water data are very scarce in the region. NCB Capital have estimated that, between 1998-2007, total water demand in the GCC region increased at an average annual rate of 5.8 percent, whereas aggregate population has grown at CAGR of 3 percent. However, taking into account the temporary economic slowdown between 2009 and 2011, these trends may have been affected. NCB Capital (2009), 3-4.

3.4.2. Subsidies and Cheap Access to Energy

Besides technical inefficiencies in the production and distribution systems, the excessive and wasteful consumption is equally – and rightly – thought to be exacerbated by pricing policies that benefit both national utilities and consumers. Indeed, cheap access to energy, electricity or water, disincentivizes the consumption and production sectors to rationalize their use or to deploy energy-efficient measures and equipment.

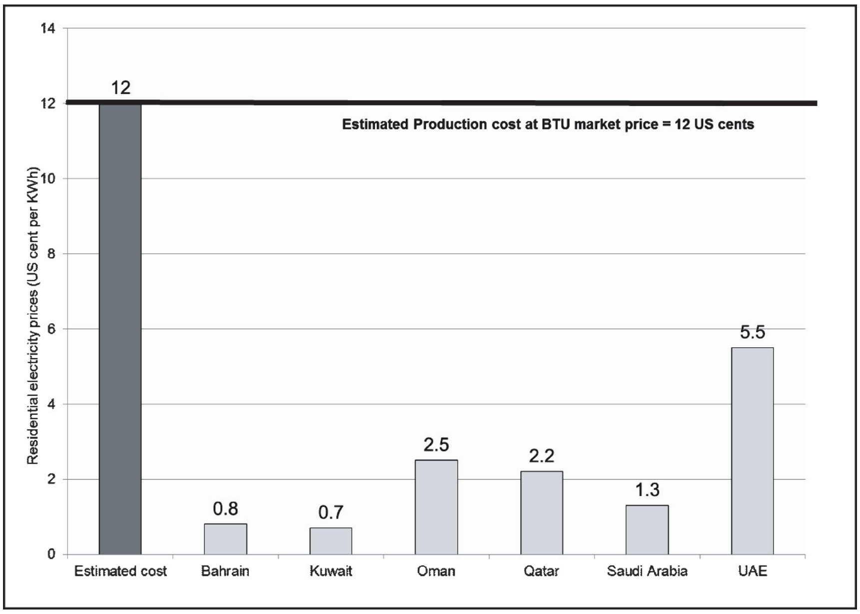
For instance, utility sectors in the region have always benefited from the government's fuel and distribution subsidies. So, whereas in a typical gas combined cycle plant in the region, electricity production costs $ cent 12/KWh at market energy price,[42] the average tariff that incorporates government subsidies does not exceed $ cent 3/KWh for the end users (see Fig.8).

42. The cost is calculated based on market price of $7.2/Million British Thermal Unit (MBTU). See Booz & Co 2009.

As a result, when compared to subsidized hydrocarbon-based electricity, solar technologies are found to be particularly uncompetitive in the GCC region (For solar electricity cost, see Tables 2, 3, and 4).

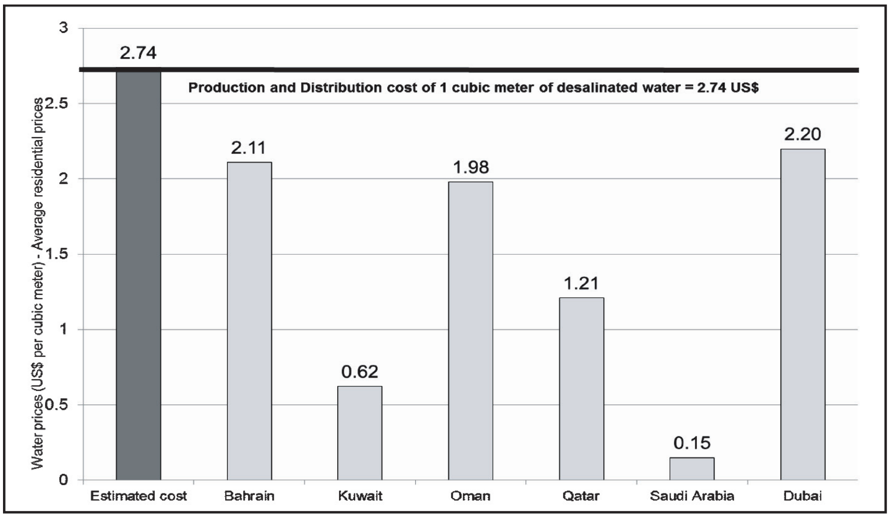
So, in addition to draining national budgets, fossil energy subsidies adversely impact the potential uptake of renewable energy technologies in GCC countries. Similarly, because of governmental subsidies, water tariffs in the region are much lower than the real production costs of this commodity (see Fig.9).

Figure 8. Residential electricity prices in the GCC compared to estimated generation costs (US cent/KWh) - 2008



Sources: Based on El-Katiri, Interlinking the Arab Gulf: Opportunities and Challenges of GCC Electricity Market Cooperation (2011). Residential electricity price for the UAE is the average of Abu Dhabi and Dubai tariffs for expat-residents. Estimated production cost: Booz & Co, A New Source of Power: The Potential for Renewable Energy in the MENA Region (2009).

Figure 9. Residential (domestic) water prices compared to production and distribution costs in the GCC (US cents/cubic meter)



Sources: Based on NCB Capital, GCC Water Resources (2009); Kuwait: Kuwait Ministry of Electricity and Water; Oman: OPWPC Annual Report 2010; estimated production and distribution cost ($1.64/cubic meter and $1.1/cubic meter, respectively): NCB Capital (2009)

4. Tuning Solar Transition to Socio-Economic Growth

The GCC governments have implemented aggressive economic diversification and industrialization plans for more than a decade now. Accordingly, local industry growth, job creation, better standards of living and urbanization have led to socio-economic priorities that inevitably intensify fossil fuel consumption and the environmental footprint of the region. This has certainly inhibited the agenda for sustainable energy in the region. However, such priorities are part of the countries' different future economic visions, where growth is essentially building on the region's hydrocarbon competitive advantage – i.e., inexpensive access to fossil energy –, turnkey projects, and imported technology and expertise.

It appears that the most challenging question for the GCC countries is to figure out how they could mitigate these issues and smooth their transition to clean and renewable energy systems. More specifically, the question is whether the development and uptake of solar technologies in the region could be built on its energy subsidies, industrial expansion, and the spirit of economic competitiveness that animate local growth?

Indeed, unless a sudden interruption or change in development trends and lifestyles occurs – which is unlikely – any potential transition to energy systems that incorporate solar solutions should be in tune with the current socio-economic priorities of the region. Accordingly, a solar energy strategy in the GCC countries needs not only to lead to enhanced energy sustainability but also to consolidate their economic development and competitiveness. In this context, in addition to the energy diversification drivers mentioned previously, support for solar energy transition would be motivated by the prospect that expenditure on their deployment would translate largely into money spent within the national economies.

We argue that a successful solar energy transition that leads to effective embedment of related knowledge and activities in the GCC economies should be envisaged through the following three main paradigms:

1) Minimizing energy waste to enhance competitiveness,
2) Transferring solar technology and know-how, through international cooperation and access to intellectual property, to build a knowledge-based industry, and
3) Collaborating regionally to share GCC solar energy knowledge and optimize financial and human resources.

As the region has obvious advantages in terms of physical potential, raw material, past experience, and cheap access to energy, it appears possible that, in the long run, a full-fledged solar industry will be built in this part of the world. This would also agree with the economic visions of the GCC countries, where future plans emphasize the importance of knowledge-based growth in achieving their socio-economic goals.

Furthermore, the solar power sector is relatively labor intensive, and large-scale deployments can generate significant job opportunities ranging from R&D and manufacturing industries, to installation, repair and maintenance (R&M) services. For instance, it was estimated that one MW of installed photovoltaic power capacity would generate seven permanent jobs, and one MW of solar thermal should create 1.2 permanent jobs.[43] All such solar energy industrial activities and services are also critical to the process of technology transfer; they provide opportunities to learn and train local engineers and technicians.

At the level of each individual GCC market, solar industries could be too costly an industry to create enough profit. Yet, these activities would be more

43. Renewable Energy Policy Network for the 21st Century REN21 2010, 19 and 34.; The projected power capacity in the GCC region has recently been estimated to reach 190GW by 2019; based on that, and if the GCC countries achieve 5 percent only of such capacity through solar thermal or PV deployments, then this would generate between 11,450 and 66,500 permanent jobs.

interesting – in terms of productivity, management, or mobilization of financial and human resources – in a context of collaboration between all of the GCC countries. Such collaboration could encompass the fields of R&D, manufacturing of components, human resources training, or include development of regional consulting and contracting firms for dealing with the designing of projects or financial mechanisms. Furthermore, once GCC-wide collaboration is well developed, the countries of the region have the option to collaborate with other MENA countries. The development of manufacturing and procurement service industries related to solar technologies in the region could lead to opportunities to export related devices and services to MENA markets.

However, in their path towards a long-term solar energy transition, the GCC countries have to move to better energy demand management. For, beyond enhancing the cost-effectiveness of their present energy systems in general, efficiency measures should also optimize the capacity of current and potential solar technologies to address demand challenges in the electricity and water sectors.

4.1. Energy Efficiency First

In general, as increasing the level of energy efficiency is congruent with development strategies that favor green growth in any country,[44] incentives for energy efficiency in the GCC region can also lead to the enhancement of national competitiveness through 'improving quality of consumption by reducing quantity of resources.' Indeed, as a consequence of energy (and money) savings, new production sectors can emerge – boosting domestic markets, raising the volumes of national exports, or reducing imports of produced goods. Hence, through efficiency, the GCC countries can also foster their capacity to innovate.

Given the prospect that the power and water sectors are bound to expand – and so would their losses if everything remains unchanged – implementing energy-efficient practices and technologies for producing, distributing, and consuming these commodities would allow huge savings as well as a significant shift towards overall energy sustainability. By the same token, environmental awareness could be heightened among consumers and new energy-responsible behaviors and usages could emerge, therefore generating a socio-cultural shift towards wider acceptance of solar energy/renewables in the future.

4.1.1. Green Buildings and BiPV

There exist ripe opportunities to lower consumption, raise awareness, and bring down

44. ESCAP 2010.

subsidies for electricity and water in the GCC region. For instance, looking closely at the average water consumption of a typical GCC household, research indicates that conservation measures can achieve up to 50 percent reduction in domestic water demand.[45] Such a figure was corroborated in Abu Dhabi's Masdar city buildings, as they were found to consume 54 percent less water than average residences in the UAE.[46] More innovatively, energy-efficient urban planning and equipment as well as solar energy deployment in Masdar city were found to save up to 51 percent of electricity consumption compared to the country's regular household demand.[47]

One can argue that Masdar city specifications are not easily transferable to ordinary villas and buildings in the GCC region. However, in addition to changing consumers' habits and energy use patterns,[48] what this initiative demonstrates is that any energy conservation and efficiency strategies in buildings need to take into account the necessary deployment of clean technologies. Indeed, the simulation study mentioned earlier shows that introducing simple energy conservation measures in the residential sector like improving thermal insulation and using efficient glazing, together with water conservation measures, would collectively reduce the total energy consumption by 32 percent.[49]

According to GCC statistics, an average 50 percent of the electricity generated in the region is consumed by the residential sector, whereas the residential and commercial sectors (non-governmental buildings) account collectively for 65 to 80 percent of the electricity load.[50] It is clear that if energy efficiency measures are implemented for these sectors, this would lead to huge energy savings and, by the same token, reduce the amounts of money spent on water and electricity subsidies in these countries.[51]

Although adequate electricity and water tariffs should play a key role in promoting energy conservation – since end users would assume the economic cost

45. Taleb and Sharples 2011, 390.
46. *Solar Thermal Magazine* 2010.
47. Ibid.
48. Al-Mumin, Khattab and Sridhar 2003.
49. Taleb and Sharples 2011, 390.
50. Average of related GCC figures, sources Bahrain: Central Informatics Organisation 2007; Kuwait: Al-Mumin and Al-Mohaisen, 2006; Oman: Al-Badi, Malik, Al-Areimi and A. Al-Mamari (2009) and Al-Badi, Malik, and Gastli 2011; Saudi Arabia: Ministry of Water and Electricity (2007), UAE/Abu Dhabi: SCAD 2010; and UAE/Dubai: DEWA 2010.
51. Based on Masdar City case, where up to 50 percent of electricity consumption should be saved in the built environment, and given that actual consumption in the residential sector reaches an average of 50 percent of the electricity generated in the region, and given that subsidies for this sector can reach US cent 10.7 per KWh (e.g KSA), the total saving could reach more than $ 9 billion per year for total GCC.

of these commodities – in the GCC context, energy efficiency measures appear to be the main determining factor in rationalizing use of resources and enhancing their sustainability for years to come.

In general, conservation measures can include enforcement of building codes and principles of climate-responsive design, promotion of thermal insulation, establishment of energy-efficiency standards for equipment and appliances, and creation of awareness through government campaigns.

It is opportune to mention here that some energy savings in the built environment can be achieved through the use of PV panels. For, besides their electricity output, it has been shown that integrating PV panels as wall cladding systems can enhance the thermal insulation of buildings, and thus reduce their cooling requirements.[52] Considering that air conditioning accounts for more than 65 percent of electricity consumption in the residential and commercial buildings in the GCC region,[53] one can easily see the energy-saving potential of BiPV deployments in the region.

4.1.2. Subsidies for Local Content

It does not seem that curtailment of energy subsidies – especially in the electricity and water sectors – would realistically be adopted by local governments any time soon. Indeed, prevailing wealth-redistributive policies in the GCC countries, together with strategies to enhance competitiveness through cheap access to energy, do not favor a resolution such as a drastic revision of those prices. Thus, raising tariffs remains a contentious issue among GCC regulators and policy makers, and it is even more so following the economic slowdown of the last few years, as well as the advent of social uprisings in neighboring Arab countries. This is unfortunate as fossil energy subsidies make the opportunities for efficiency-gains less profitable in the GCC context.

Nevertheless, there should be room for regulating such subsidies in a growing industrial sector that is consuming increasing amounts of electricity and water. One can imagine that, in a collaborative approach with local authorities, cheap access to fossil energy for all energy-intensive industries and foreign investments could in general be conditioned on the achievement of increasing nationalization quotas in related sectors. Such mutually beneficial terms of collaboration can help governmental social policies for the nationalization of the labor market and hence alleviate their budgets. In this sense too, low energy prices for the solar manufacturing sector could be tied

52. Energy saving due to both the PV output and the decrease of cooling energy demand due to the thermal insulation effects of PV modules can attain 350 KWh/square meter; in Radhi 2010; see also Table 2.
53. Alnaser and Flanagan 2007; Hajiah, Maheshwari, El-Sherbini and Alasseri 2008, 309; Radhi 2010.

to the development of national human capital (or local content) in these sectors. Thus, the costly learning and knowledge acquisition endeavor that accompanies the transition to solar energy is partly sponsored by these industrial actors.

4.2. Technology Transfer and Capacity Building

In view of the GCC's past and present approach to RE and sustainability issues – i.e., overlooking the regulatory enabling frameworks – it appears that development of solar energy in the region will greatly depend on how related technologies become cheaper and more efficient.

As solar energy resources are site-specific, both the adaptation of technologies to the region's context and the acquisition of related know-how by local scientists and laboratories are crucial to decision-making about potential solar deployment in the region. First, the learning endeavor involved in these processes is "fundamental for the creation of knowledge and skills – an important element of technological capabilities required for the leapfrogging of industrial development pathways."[54] And second, while furthering the suitability and cost-effectiveness of solar technology to local conditions, local R&D and demonstration projects would eventually lead to the creation of technology niches in the region. These would in turn induce larger institutional support – in the form of policies and financial incentives – which would maximize awareness and acceptance of solar energy options in the long run.[55]

Renewable energy scenarios for major oil-producing nations like Saudi Arabia project that such countries in the region would rely on imported related technologies to begin with (until 2025) and then will consider indigenous development.[56] However, technology transfer, diffusion and development are a long learning process and it is never too early to start support programs that promote follow-through for emerging technologies.[57] So, should the GCC countries wish not to remain mere importers of foreign equipment and expertise, they must readily start transferring solar technology and know-how to the region through joint ventures, international R&D, and access to intellectual property.

As has been demonstrated in other clean-energy sectors, enforcement of intellectual property rights (IPR) can become a barrier to access and transfer of solar technologies to the region. Nevertheless, in the context of climate change, it is even more important to have access to emerging technological trends, instead of deploying

54. Sauter, R, Watson, J. 2008, quoted by Ravi Srinivas 2009, 36.
55. Mason 2009.
56. Al-Saleh 2009, 8.
57. Elliott 2007, 276.

older technologies.[58] The GCC countries should then take pro-active measures, including technology assessment and patent landscaping, while paying attention to their relevance and capacity for improvement. In particular, advanced technologies that can result in lowering the cost of solar power should be considered for acquisition and diffusion in the region. Such early technology acquisition processes will enable deployment of the most technically and economically viable solar applications in a timely manner.

For instance, notwithstanding the absence of solar regulatory frameworks in the region, Masdar investments in a foreign regulated market contributed to advancing solar technical innovations and accessing intellectual property. In a joint venture between the Abu-Dhabi based Masdar Power and the Spanish SENER, Torresol Energy has built Gemasolar CSP plant in Seville, and developed the molten salt receiver technology, an innovation capable of storing and releasing solar energy for 15 hours without sunlight.[59] It has been estimated that this technology could reduce the LCOE of CSP plants by 15 percent by the year 2020.[60] Logically such technology should be implemented in Abu Dhabi in the near future,[61] and thus transfer to the region the know-how and expertise gained abroad.

As observed in section 1.4., involvement in global solar industry development can be viewed by some local energy stakeholders as merely lucrative investment. However, from the perspective of a solar energy transition, government support for such international partnerships should be undertaken with the objective of building local industrial capabilities and initiating joint R&D activities with leading solar firms. This is critically important as a prospective solar energy industry in the region should be established on the sound basis of competition and creativity. For instance, beyond localizing manufacturing processes, the poly-silicon industry ventures in the region and its potential downstream development[62] should also involve R&D and lead to the engineering of PV cell technology that is relevant to the region's solar power challenges as well as aiming to be globally competitive.

In general, GCC energy stakeholders need to plan their solar initiatives – be they research collaborations, foreign-market power investments, local manufacturing or deployment by international solar system providers – in a way that they also help empower local institutions and scientists. Such partnerships can conceivably

58. Ravi Srinivas 2009, 7.
59. thefuturebuild.com 2011.
60. World Bank (2011), 8; LCOE stands for levelized Cost of Electricity.
61. Based on this experience, Masdar power discussed with Torresol to build a similar plan in Abu Dhabi. See *MEED* 2011.
62. For more information on these ventures, see section 1.4. Global Solar Energy Industrial Prospects

involve mandatory training of the local managers, personnel or engineering students. Correspondingly, industry-university linkage programs in the field of solar technology should be particularly enhanced in the region.

Moreover, to achieve their vision of knowledge-based economies, the GCC countries need to enhance their capacity for learning, build new competencies and acquire new skills so that they have access to scientific and technological knowledge and are able to exploit it.

In particular, a solar technology-based industry will require large numbers of skilled personnel to ensure proper and efficient use of imported technologies or to perform the necessary R&D-related activities. In this sense, a mere diffusion of foreign techniques in the region is not enough; it needs to be complemented by the development of a variety of educational institutions and R&D laboratories focused on the training of scientists and engineers in related areas and educational curricula at universities and technical institutes of higher education that are adapted to the evolving needs of home-grown solar industries.[63]

4.3. GCC Collaboration: Rationales and Priorities

In addition to their connection with GHG emissions and global warming to which the whole region is particularly vulnerable, the overlapping energy challenges and common interests in developing renewable power supply in the GCC countries point to real opportunities for regional collaborative research that would develop solutions to local technical and commercial obstacles to solar energy. Primarily, collaboration between the region's institutions should allow them to promote the most relevant solar technology on which funding or R&D efforts would be focused.

The GCC countries may differ from one another in terms of suitability of certain applications to their solar geographic potential, economic context, or financial resources. However, the similarities of their climate conditions and developmental patterns make it clear that accumulated experience in the region can be beneficial for each country individually. Their collaboration can lead to the formation of expert networks, scientific societies or councils that could find ways to locate, organize, transfer, and leverage solar knowledge throughout the entire region. They eventually would help improve specific solar applications or identify technologies, materials or skills appropriate for the region.

In particular, as the GCC countries face comparable electricity and water consumption patterns and urbanization trends, each one of them could certainly

63. This is based on an analogy with the development of the German chemical industry in the second half of the nineteenth century as studied by R. Mazzoleni. See Mazzoleni 2008, 688.

profit from improved solutions for Building-Integrating Photovoltaics or solar-thermal air conditioning. For those countries with large empty spaces, like Oman, Saudi Arabia, or the UAE, off-grid PV for remote locations or solar desalination should constitute an important field of R&D. So the convergence of different research initiatives undertaken in the region can enable each GCC country to gain technology insights on a specific solar application that is most relevant to their national interest. Correspondingly, any R&D or industrial investment based on such technologies would gather interest from different stakeholders in the region.

For instance, due to vital need for desalinated water, and considering the energy-savvy facilities that produce it,[64] collaboration that allows the identification of optimal solar desalination technologies should be promoted. Indeed, Saudi Arabia is sponsoring two different international R&D programs on solar-powered desalination. First, Jeddah-based KAUST is conducting research on solar thermal evaporation for water desalination with the National University of Singapore; and second, KACST is partnering with IBM to develop ultra-high concentrator photovoltaic (UHCPV) materials that will help build and power a 30,000 cubic meters per day solar desalination plant in AlKhafji. Such international R&D efforts need to be sustained. These can lead to the development of solar technologies and industries that are most relevant to Saudi Arabia's geographical conditions. However, joining efforts and sharing knowledge among national and regional institutions that work in the same field would accelerate deployment of the most efficient solutions in the whole region. Correspondingly, this could lead to market development in the whole region, as water and energy needs are similarly challenging.

Collaborative R&D efforts can also cover other solar applications, especially those that can mitigate the peak load demand during summer, which is three times higher than during winter, in all GCC countries. Indeed, the main cause for the large seasonal variation in the annual load distribution is the surge in electricity consumption for air-cooling during the summer months. In this context, a program for collaboration could be to investigate how to supplement district cooling facilities with solar energy technology. Such deployments would obviously be centralized, thus facilitating monitoring and maintenance of the solar technology involved in the project. It might then be worth for institutes and industries in the region who work on solar cooling to share their experiences and R&D findings to promote what could be termed as Solar District Cooling.

In general, every party that shares the R&D and engineering of these or other

64. For the time being, most desalination facilities in the region are particularly energy intensive as they use multi-stage-flash technology, which consumes between 15 and 20 KWh/cubic meter. See ESCWA 2011.

solar technologies and industries on a regional basis can agree to invest to levels proportional to the benefits expected for their own countries (societies). Meanwhile, they also benefit from the creation of an 'ecosystem' where their products and services find better access to the markets of other regional partners.

Conclusion

Current and future plans of the GCC countries put forward an affirmative policy for development through modernization, industrialization, and economic diversification. Yet, the prospects of continuous socio-economic growth and global warming will correspondingly continue to put pressure on the region's energy, electricity, and water supplies. Such challenges make it essential that, in concert with conservation efforts, energy diversification plans be effectively implemented to ensure sustainability. They equally need to be implemented in a manner that allows related technologies to be embedded in the region's economies.

This connection is crucial, for, paradoxically, its absence explains the present gap between government discourses and practices. Moreover, such a gap gives the impression that the GCC countries' RE targets are not realistically achievable. Indeed, in the absence of clearly articulated strategies for a solar energy transition in the region, doubt is cast on such a transition's benefits. Accordingly, GCC RE targets need not be carried out as mere foreign technology imports and deployments, but they should also be planned as socio-technical and economic growth opportunities.

So rather than limiting the 'problematique' of solar energy transition to known drivers, i.e., depletion of resources, climate change, or GHG emissions, the approach of this paper broadens the debate to look for economic and industrial opportunities of solar energy resources. To initiate such a transition, it was argued that in the GCC context emphasis needed to shift from issues that pertain to regulatory and energy subsidy-linked constraints, to exploring possibilities for solar energy market development in tune with their economic priorities, local needs, and resources.

Hence, the paradigms of this analysis centered on: enhancing economic competitiveness through energy efficiency; diversifying the industrial sector through access to solar energy intellectual property; and optimizing financial and human resources through regional collaboration. It was argued that more than to increase the benefit of their resources, the efficiency imperative should enhance the readiness of the GCC countries to make the renewables transition. Money saving and optimization of the conventional energy system operations are critical to wider support for and deployment of relevant solar applications.

Similarly, while we are conscious that access to IP may fall short of a full solar technology transition, the learning processes that should be involved in transferring and adapting solar technology to local conditions would inexorably lead to the creation of technological niches in the region. These would further the governmental and social acceptance of solar energy. In this sense, international and local R&D efforts need to be sustained but focused on the region's priorities and its potential export market. This is paramount in order to develop a solar knowledge-based industry that is locally relevant and globally competitive.

Faced with similar climate, water and energy-intensive growth challenges, it is economically most sensible that the GCC countries should consolidate their resources towards developing solar solutions for the region. The upfront financial cost, shortage of national experts, or small national market potential for yet-to-be-locally-improved solar technologies can be mitigated through collaborative activities that encompass related R&D programs or engineering processes.

In conclusion, reflection about a possible solar energy transition in the GCC countries brings forward the potential for the region to build a regional innovation system around this sector. In fact, the increasing electricity and gas interdependencies within the region through the GCC Interconnection Grid or the Dolphin Gas Project further justify strong scientific and industrial cooperation in the area of solar energy supply. To this end, the focus should be on how current obstacles can be overcome, especially towards boosting collaboration and coordination. Certainly, as it has been the case since the 1970s, the top-down approach to past solar energy developments in the region suggests that governing elites and decisions makers need to be involved and promote regional cooperation. For, beyond the spirit of emulation within the decision making circles – through mere multiplication of initiatives and institutions – the capacity of the GCC organizations to integrate their capabilities and sponsor collaborative projects among local scientists and industries will be an enabling factor for a sustainable solar energy transition in the region.

Appendix - GCC Institutions

The GCC region is host to many institutions with interests in solar energy and energy efficiency. However, only a limited number of these institutions collaborate on pan-GCC initiatives and have a geographical scope beyond their countries. In addition, none of these institutions are complemented by RE policies and frameworks in their countries, which limit their effective impact on society.

List of GCC institutions working on Renewable Energy and energy efficiency development

Research Institutions					
Country	**Institution**	**Type**	**Sector**	**Solar energy/EE Activities or Main Interest**	**Geographies of interest**
Bahrain	Bahrain Center for International, Strategic and Energy Studies	Governmental Think Tank	• Socio-economic and security indicators	• Studies and research on energy security and diversification	GCC
Kuwait	Kuwait Foundation for the Advancement of Science (KFAS)	Non-Governmental Organization	• International Research Cooperation and Funding • Promotion of scientific and technological progress in Kuwait	• Solar Water Desalination	National and GCC
	Kuwait Institute for Scientific Research (KISR)	National science agency	• Fundamental and applied scientific research • Science and Technology Policies	• Environment • Grid connected and off-grid solar power • Solar Water Desalination • Green Building	National
Oman	Middle East Desalination Research Centre (MEDRC)	International Network	• Advisory and Funding	• International research partnerships on water desalination technologies	Middle East and North Africa (includes GCC)
	Renewable & Sustainable Energies Research Group (RASERG)- based in Sultan Qaboos University (SQU)	Academic Association	• Consultancy • Advisory and promotional campaigning	• Engineering and industrial applications of solar energy • Concentrating PV power	National
	The Research Council	Governmental agency	• Science and Technology national policies • Research Funding	• Green building and Eco House Design program	National
	Sultan Qaboos University (Engineering and Science Colleges)	University	• Academic Education and Research	• Investigation of solar energy technical potentials • Solar systems and applications • Energy efficiency in buildings	National
Qatar	Chevron and Green Gulf Incorporated Corporation Center for Sustainable Energy Efficiency - based in Qatar Science and Technology Park (QSTP)	Public Private Partnership - Corporate R&D Laboratory	• R&D of solar technologies • International cooperation and intellectual property investments	• Experimental facility for new and emerging solar technologies • Monitoring of energy efficiency devices	National
	Gulf Organization for Industrial Consulting (GOIC)	GCC organization	• Data management • Statistical Research • Advisory services	• GCC energy statistics • Market intelligence of the GCC industrial environment • Energy efficiency in the industrial sector	GCC
Saudi Arabia	King Abdul- Aziz City for Science and Technology - Energy Research Institute(KACST-ERI)	KACST: National Science agency ERI: Research Laboratory	• Science and Technology Policy making • Research Funding • Patenting	• Ultra High Concentrating PV power • Nano-materials for water desalination	KACST: National ERI: International

Continued: List of GCC institutions working on Renewable Energy, continued

	King Fahd University of Petroleum and Minerals - Center of Research Excellence in Renewable Energy (KFUPM)-CoRE-RE)	Research Laboratory	• Academic Education and Research	• Solar hydrogen • Solar energy storage • Economics of solar energy • Solar energy industry	National
	King Abdullah University for Science and Technology (KAUST) - Solar & Photovoltaics Engineering Research Center	Research Laboratory	• Academic Education and Research • Industry University Linkage	• Thin Film Solar cells • Flexible Electronics and Photovoltaics • Efficiency of Solar cells	National and International
	King Abdullah University for Science and Technology-Water Desalination and Re-use Center (KAUST – WDRC)	Research Laboratory	• Academic Education and Research	• Solar Adsorption (AD) water desalination • Combined AD cycles with Multiple Effect Distillation and Multi-Stage Flash technologies	National and International
United Arab Emirates	Centre Suisse d'Electronique et de Microtechnique - UAE (CSEM-UAE) based in Ras Al Khaimah	Research Laboratory	• R&D of solar technologies	• Solar insulation materials • Solar cooling • Solar islands	National and international
	Emirates Solar Industry Association (ESIA)	Industrial Association	• Advisory and promotional campaigning	• Reports on solar technology, standards, and product certification • Identification of solar industry/business opportunities	National
	Masdar Institute for Science and Technology (Abu Dhabi)	University	• Academic Education and Research	• Investigation of RE technical potentials • Concentrating solar Power (CSP) technologies	National and International
	Petroleum Institute Research Center (Abu Dhabi)	University	• Academic Education and Research	• Energy Efficiency • Technical efficiency of PV technologies	National and international

Regulatory and supervisory bodies

Country	Institution	Type	Sector	RE or EE Activities	Geographies of Interest
Bahrain	Committee for Renewable Energies in Bahrain	Governmental and industrial network	• Advisory	• National RE strategy • Dialogs between ministries and companies to explore RE technologies and their feasibility in public facilities	National
Kuwait	The Environmental Public Authority of Kuwait (EPA)	Governmental authority	• National standards and Certification for environmental compliance	• Energy conservation • Pollution prevention in the industrial sector though energy efficiency	National
	Ministry of Electricity and Water	Governmental authority	• Regulating the electricity and water supply • Transmission and distribution	• Energy efficiency programs • Development of grid connected PV and CSP power plants	National
Oman	Authority for Electricity Regulation (AER)	Governmental authority	• Regulating the electricity supply	• Road map for the development of six off-grid solar and wind power plants in remote locations of Oman • Regulatory framework for these RE plants	National
Qatar	Kahrama (Qatar General Electricity and Water Corporation)		• Regulating the electricity and water supply • Transmission and distribution	• CSP technology in combined cycle Co-generation plant	National
	Qatar Green Building Council	Network	• Advisory services and certification	• Assessment systems, Prospective, design and development of Green building • LEED and Bream programs	National and GCC region

Regulatory and supervisory bodies, continued

	Qatar Sustainability Assessment Systems (QSAS)	Public-private partnership network	• Advisory services and certification	• Green building standards • Partnership with US LEED, British BREAM, and Abu Dhabi Estidama	National
Saudi Arabia	Electricity and Cogeneration Regulatory Authority (ECRA)	Governmental authority	• Regulating and Licensing the electricity and water desalination industry	• National Renewable Energy Plan (NREP)	National
	Gulf Cooperation Council Interconnection Authority (GCCIA)	GCC Authority	• Trans-national power transmission • Electricity trading • Regulating the electricity exports between the GCC countries	• Interconnection of the six GCC States national grids • Support of the GCC electricity market	GCC
	King Abdalla City for Atomic and Renewable Energy (KA-CARE)	Governmental agency	• Supervisory and regulatory of RE power generation	• Implementation of Saudi Arabia RE development plan • Coordination with KACST, MWE, Saudi Power Procurement Company	National
	The National Energy Efficiency Program (NEEP)	Governmental	• Advisory services and promotional campaigning	• Energy Efficiency standards and building codes • Partnerships with Ministries and Aramco, SABIC, and Saudi Electricity Company	National
	Saudi Green Building Council (SGBC)	International network	• Advisory services and certification	• 'Greening' the building materials and concrete produced in KSA	National
United Arab Emirates	Abu Dhabi Regulation and Supervision Bureau	Governmental (Abu Dhabi)	• Regulating the water and electricity industry of the Emirate of Abu Dhabi.	• Power purchase agreement for ADFEC solar energy power plants	Abu Dhabi
	DEWA (Dubai Electricity and Water Authority)	Governmental (Dubai)	• Regulating the electricity and water supply of Dubai • Transmission and distribution systems	• Developing the 10 MW thin film-PV Al Maktoum power plant under the UN-CDM framework	Dubai
	Abu-Dhabi Future Energy Company (ADFEC) Masdar	Governmental company	• Design and supervisory agencies	Implementing Abu Dhabi RE and EE strategy through: • Attracting Clean-tech companies to Abu Dhabi • Higher Education and Research • Investment in emerging technologies • Reducing carbon emissions • Developing RE power generation plants and UN-CDM projects	Abu Dhabi and International
	Emirates Green Building Council (Dubai)	Network	• Advisory services, training and certification	• LEED based Building sustainability Assessment Tool (emphasis on water efficiency) • Green Building policies	Dubai
	Abu Dhabi Urban Planning Council (UPC)	Governmental authority	• Advisory services and certification	• Estidama: Urban planning initiative for sustainable development • sustainability system: Pearl Rating System • Energy efficiency and solar energy in buildings	Abu Dhabi

Source: Author compilation

Note: in Geographies of interest, 'International' is defined by partnerships with non-GCC organizations.

References

Abdullah, A.H., A. A. Ghoneim, and A. Y. Al-Hasan. "Assessment of Gridconnected Photovoltaic Systems in the Kuwaiti Climate." *Renewable Energy* 26, no.2 (2002): 189-199.

Al-Ajlan, S. A., A.M. Al-Ibrahim, M. Abdulkhaleq and F. Alghamdi. "Developing Sustainable Energy Policies for Electrical Energy Conservation in Saudi Arabia." *Energy Policy* 34 (2006): 1556-1565.

Al-Ammar, E., and A., Al-Aotabi. "Feasibility Study of Establishing a PV Power Plant to Generate Electricity in Saudi Arabia from Technical, Geographical, and Economical Viewpoints." Paper presented at the International Conference on Renewable Energies and Power Quality, Granada (Spain), March 23-25, 2010.

Al-Badi A., A. Malik, K. Al-Areimi and A. Al-Mamari. "Power Sector of Oman – Today and Tomorrow." *Renewable and Sustainable Energy Reviews* 13, Issue 8 (2009): 2192-2196.

Al-Badi A.H., A. Malik, and A. Gastli. "Sustainable Energy Usage in Oman – Opportunities and Barriers." *Renewable and Sustainable Energy Reviews* 15 (2011): 3780-3788.

Al-Badi, A.H, M.H. Albadi, A.M. Al-Lawati, and A.S. Malik. "Economic Perspective of PV Electricity in Oman." *Energy* 36, no.1 (2011): 226-232.

Al-Mumin A., and Abdullah Al-Mohaisen. "Greening the Kuwaiti Houses: Studying the Potential of Photovoltaics for Reducing the Electricity Consumption." *Global Built Environment Review* 5, no.3 (2006): 3-10.

Al-Mumin, A., O. Khattab and G. Sridhar. "Occupants' Behavior and Activity Patterns Influencing the Energy Consumption in the Kuwaiti Residence." *Energy and Buildings* 35 (2003): 549-559.

Alnaser, N.W., and R. Flanagan. "The Need for Sustainable Buildings Construction in the Kingdom of Bahrain." *Building and Environment* 42 (2007): 495-506.

Alnaser, N.W., R. Flanagan, and W.E. Alnaser "Potential of Making-over to Sustainable Buildings in the Kingdom of Bahrain." *Energy and Buildings* 40 (2008): 1304-1323.

Alnaser, W. E., F. Trieb and G. Knies. "Solar Energy Technology in the Middle East and North Africa (MENA) for Sustainable Energy, Water and Environment."

In *Advances in Solar Energy: An Annual Review of Research and Development* ed. D.Y. Goswami (UK: Oxford, 2007), 261-305.

Authority for Electricity Regulation (AER). *Regulatory Statement Renewable Energy Pilot Projects – Status Report,* April 2010. Available at: http://www.aer-oman.org/index.php?option=com_content&view=article&id=146.

Bahrain Central Informatics Organisation. *Bahrain in Figures 2007.* Available at:http://www.cio.gov.bh/cio_eng/SubDetailed.aspx?subcatid=120.

Bloomberg. "Abu Dhabi Pushes back Green Energy Goal to2030," January 17, 2012. Available at http://www.arabianbusiness.com/abu-dhabi-pushes-backgreen-energy-goal-2030-440945.html.

Booz & Co. *A New Source of Power: The Potential for Renewable Energy in the MENA Region.* 2009.

Booz & Co. "Fresh Water in the GCC: Addressing the Scarcity Problem." January 2012. Available at: http://www.booz.com/me/home/press_media/management_consulting_press_releases/article/50186772?tid=39979829&pg=all.

CDM Project Design Document ADFEC 10 MW Solar Power Plant. Available at http://cdm.unfccc.int/Projects/DB/SGS-UKL1237544831.86/view.

CDM Project Design Document Mohammed Bin Rashid Al Maktoum 10 MW PV Plant. Available on the UNFCC CDM website at: http://cdm.unfccc.int/Projects/Validation/DB/N2XPSCFQ0OAK62JS1A79WLSFTWLS7X/view.html.

CDM Project Design Document Abu Dhabi Solar Thermal Power Project, MASDAR. Available at: http://cdm.unfccc.int/Projects/DB/SGS-UKL1240326340.92/view.

Chodimella S. "Middle East Catching up on Smart Grid Technologies." April 9, 2013). Accessible at: https://blogs.siemens.com/smartgridwatch/stories/839/.

DEWA. Dubai Electricity and Water Statistics. Available at: http://www.dewa.gov.ae/aboutus/electStats2010.aspx

DLR. 2005. "Concentrating Solar Power for the Mediterranean Region." German Aerospace Center (DLR), Institute of Technical Thermodynamics, Section Systems and Technology Assessment, 2005.

El-Katiri, L. "Interlinking the Arab Gulf: Opportunities and Challenges of the GCC Electricity Market Cooperation." Oxford Institute for Energy Studies, 2011.

Elliott, David. "A Sustainable Future for Energy?" In *Sustainable Energy Opportunities and Limitations,* edited by David Elliott. Palgrave Macmillan, 2007.

EIA. *Country Analysis Brief, Middle East and North Africa.* Energy Information Administration, 2011. Available at: http://www.eia.gov/countries/mena/

ESCAP. *Assessment Report on Energy Efficiency Institutional Arrangement in Asia.* United Nations Publication, Thailand, 2010.

ESCWA. *Sustainable Production and Consumption Patterns in Energy and Water Sectors in the ESCWA Region.* ESCWA, 2011.

FANR (Federal Authority for Nuclear Regulations). UAE Government White Paper on Nuclear Energy (2008). Available at: http://fanr.gov.ae/ar/media/get/20090430_uae-policy-white-paper.pdf

Financial Times, May 3, 2010.

Gastli, A., Y. Charabi and S. Zekri. "GIS-Based Assessment of Combined CSP Electric Power & Seawater Desalination Plant for Duqum-Oman." *Renewable & Sustainable Energy Reviews* 14, no.2 (2010): 821-827.

GOIG. *Gulf Statistical Profile-2008.* Gulf Organization for Industrial Consulting Doha, 2009.

Hajiah, A., G. Maheshwari, A. El-Sherbini and R. Alasseri. "Optimization of Cooling Production in Kuwait Institute for Scientific Research Main Building." *KISR Scientific Report 2006-2008,* available at: http://www.kisr.edu.kw/Data/Site1/images/kisr_publications/978-999-06-95-05-2.pdf

Harder, E., and J. MacDonald Gibson. "The Costs and Benefits of Large scale Photovoltaic Power Production in Abu Dhabi, United Arab Emirates." *Renewable Energy* 36 (2011): 789-796.

IEA. *Key World Energy Statistics.* International Energy Agency, Paris, 2010.

Kahramaa. *Statistics Report, 2008.* Qatar General Electricity and Water Corporation, 2009.

Khaleej Times. "GCC May Pump over $58b into Power Projects." *Khaleej Times,* October 5, 2011.

KPC Media Centre. "CEO Address on the Occasion of the New Year." Available at: http://www.kpc.com.kw/MediaCentre/media/CEO_Address_2011.aspx

Kuwait Ministry of Electricity and Water. *Electrical Statistics, 2009.*

Jalilvand, D. R. "Renewable Energy for the Middle East and North Africa: Policies for a Successful Transition." Friedrich-Ebert-Stiftung Department for Near/Middle East and North Africa, Berlin, February 2012.

Jeridi Bachellerie, I. "Framework for a Renewable Energy Transition in the GCC: Finding the Right Paradigms." *Gulf Monitor,* Gulf Research Center, March 2010.

Jeridi Bachellerie, I. *Renewable Energy in the GCC Countries: Resources, Potential, and Prospects.* Gulf Research Center, March 2012.

Marafia, A.H. "Feasibility Study of Photovoltaic Technology in Qatar." *Renewable Energy 24* (2001): 565-567.

Masdar website, http://www.masdarcity.ae

Mason, M. "Clean Power from the Deserts? The Prospects for a Renewable Energy Transition for the Middle East and North Africa." Paper presented at the GCREEDER 2009, Amman (Jordan), March 31-April 2, 2009.

Mazzoleni, R. "Catching Up and Academic Institutions: A Comparative Study of Past National Experiences." *Journal of Development Studies* 44, no. 5 (May 2008): 678-700.

MEED. "Abu Dhabi Builds Strategic Water Reserve." *MEED* Issue 46, November 12-18, 2010. Available at: http://www.meed.com/sectors/water/water-supply/abu-dhabi-builds-strategic-water-reserve/3078278.article

MEED. "Masdar Considers Building Solar Powertower in Abu Dhabi." *MEED* Issue 18 (May 6-12, 2011). Available at: http://www.meed.com/sectors/power/renewable-energy/masdar-considers-building-solar-powertower-in-abu-dhabi/3096039.article

Missimer, T. M., S. Sinha, and N. Ghaffour. "Strategic Aquifer Storage and Recovery of Desalinated Water to Achieve Water Security in the GCC/MENA Region." *International Journal of Environment and Sustainability* 1, no. 3 (2012): 87-99.

NCB Capital. *GCC Water Resources (2009).* Available at: http://www.docstoc.com/docs/22748261/?key=Yzk3ODIyMTYt&pass=NzJmYy00YWE3

Neuhof, F. "Shams1 Gets out of the Blocks." Utilities ME, June 9, 2010. Available at: http://www.utilities-me.com/article-582-shams-i-gets-out-of-the-blocks

Pacific Control Systems, http://pacificcontrols.net/news-media/news_19.html

Petroleum Development Oman website, http://www.pdo.co.om/pdoweb/tabid/275/Default.aspx

Public Authority for Electricity and Water, http://www.aer-oman.org/images/5re.pdf

Qader, M. R. "Electricity Consumption and GHG Emissions in GCC Countries." *Energies* 2 (2009): 1201-1213; doi:10.3390/en20401201.

Radhi, H. "Energy Analysis of Façade-integrated Photovoltaic Systems Applied to UAE Commercial Buildings." *Solar Energy* 84 (2010): 2009-2021.

Ramadhan, M., and A. Naseeb. "The Cost Benefit Analysis of Implementing Photovoltaic Solar System in the State of Kuwait." *Renewable Energy* 36, no.4 (2011): 1272-1276.

RAND. "The Global Technology Revolution 2020." In-Depth Analyses, RAND, 2006.

Ravi Srinivas, K. "Climate Change, Technology Transfer and Intellectual Property Rights." Research and Information System for Developing Countries, Discussion Paper # 153, April 2009.

Rehman, S., M.A. Bader, and S.A. Al-Moallem. "Cost of Solar Energy Generated Using PV Panels." *Renewable and Sustainable Energy Reviews* 11 (2007):1843-1857.

Renewable Energy Policy Network for the 21st Century REN21. Renewables 2010 A Global Status Report, 19 and 34. Report available at: http://www.erec.org/fileadmin/erec_docs/Documents/REN21%20GLOBAL%20STATUS%20REPORT%202010.pdf

Research and Markets. "GCC Power and Water Desalination Industry Overview, March 2013." Available at: http://www.researchandmarkets.com/research/gcl2jb/gcc_power_and

Saudi Arabia Ministry of Water and Electricity. "Electricity, Growth and Development in the Kingdom of Saudi Arabia," 2007.

Sauter, R., Watson, J. "Technology Leapfrogging: A Review of the Evidence." Sussex Energy Group, SPRU, University of Sussex (2008)

SCAD. "Electricity Consumption by Sector." Statistics Center of Abu Dhabi (2010). Available at: http://www.scad.ae/en/Statistics/Pages/SubTopicTableGraph. aspx?TabID=3&TGID=896&SubTopicID=121

Shaahid, S. M., and I. El-Amin. "Techno-economic Evaluation of Off-grid Hybrid Photovoltaic–Diesel–Battery Power Systems for Rural Electrification in Saudi Arabia – A Way Forward for Sustainable Development." *Renewable and Sustainable Energy Reviews* 13 (2009): 625-633.

Solar Thermal Magazine. "Rooftop Solar Power PV System in Masdar City: One Megawatt." Available at: htt://www.solarthermalmagazine.com/2010/12/07/rooftop-solar-power-pv-system-in-masdar-city-one-megawatt (Last accessed November 2012)

Taleb, H.M., and S. Sharples. "Developing Sustainable Residential Buildings in Saudi Arabia: A Case Study." *Applied Energy* 88 (2011): 383-391.

thefuturebuild.com. Torresol Energy Commissions 19.9MW Gemasolar Power Plant in Spain. 2011. Available at:

http://www.thefuturebuild.com/torresol-energy-commissions-19-9mw-gemasolar-power-plantin-spain-27587/news.html (Last accessed November 2012)

Trade Arabia. "Kuwait Wealth Fund Mulls Renewables, Eyes Italy." September 29, 2009. Available at: http://www.tradearabia.com/news/BANK_167966.html

World Bank. "Middle East and North Africa Region Assessment of the Local Manufacturing Potential for Concentrated Solar Power (CSP) Projects." World Bank, January 2011.