Sustainable Energy Research and Development in Kuwait

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Abstract

An overview of the prospects of the use of alternative energy, namely solar and wind energy in the countries of the Gulf Cooperation Countries (GCC) is discussed. Future targets and project for the use of sustainable energy are outlined. The energy production and demand for energy in Kuwait is presented. Research and development of renewable enrgy in Kuwait is presented. Research efforts at Kuwait University and Kuwait Institute for scientific research are discussed in detail. The Shagaya project is targeted to provide 15% of electrical power requirement in Kuwait by 2030. A 70 MW part of the project is under construction. The use of building integrated solar panels is being expanded.

Introduction

In December 2015, the ***United Nations Climate Change Conference*** brought together 195 countries in reaching an agreement to reduce greenhouse gas emissions worldwide, and stem the global warming tide by 2100. The historic ***Paris Agreement***[1], to which the Gulf Cooperation Council (GCC) countries were also the signatories, set a milestone for governments to reduce energy consumption, seek low-carbon energy sources, and exhibit commitment towards these goals. Energy sustainability garnered significant attention as part of the Paris Agreement, with many governments and organizations, incorporating energy and sustainability. Within this broad frame, the dynamics of energy sources, and their implications in accelerating development in GCC countries is explored and presented here, unfolding trends and future outlook for energy sustenance.

Established in May 1981, the Gulf Cooperation Council (GCC) includes six member states -- *Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates* (UAE)[2]. GCC states are the largest producers of oil and natural gas, and their *energy policy* holds implications for *global energy economics*, as four of the GCC States, Saudi Arabia, UAE, Kuwait and Qatar, hold membership of the *Organization of Petroleum Exporting Countries* (OPEC), while Qatar is the world's *fifth largest producer of gas*.[3] The

wealth of these states emanates from exporting crude oil and gas, considering that Saudi Arabia is the largest exporter of crude, and Qatar the largest exporter of natural gas. On the other hand, the six GCC countries in the top 14 per capita emitters of carbon dioxide in the world due to domestic gas and oil consumption[4].

Over the years, the *very factors responsible* for the region's industrialization and economic growth, created spiraling demands on energy and water, both areas of high consumption, which along with the fall in global oil prices, is compelling a 'rethink' among the GCC states for reshaping their energy policies, in response to changing realities, curbing the culture of waste, and rationalizing economy. A strategic shift to *alternative energy sources* is the direct outcome of the demands of changing times, compelling GCC states to look beyond their respective *economic comfort-zones*, for a *strategy of diversification*, enabling them to move away from sole reliance on petroleum, oil and gas, towards a *sustainable energy-intensive future*.

Underlying the *diversification mission* is the need to look beyond oil and gas, and seek viable *alternative energy avenues*, *abundantly available*, yet *lying unexplored*. This mission opened the door for potential benefits of profoundly available *solar energy*, a resource awaiting exploitation, for its economic value and long-lasting benefits. Indeed, the GCC states are privileged by virtue of their location, lying in the *global sunbelt*, the natural resource available in abundance, and ideally suited for solar photovoltaic (PV) deployment, which could strategically enhance their *power-generation capacity*, *saving cost* and *energy*. Also wind energy can also be a source of alternative energy.

Overview of Renewable Energy in GCC

GCC States share common interest in renewable energy's potentialities, and are diverting their attention towards exploring the viability of abundantly available natural solar and wind resources for energy generation. All GCC States are going through the **energy *demand-supply tussle***, with increasing demand outstripping supply, making alternative technologies an attractive option for governments to envision plans and strategies for moving away from sole dependency on oil and gas towards diversified sources for energy generation to meet growing energy demands[3,4,22]. Plans are already being drawn, and implemented in several GCC states towards economic diversification in the larger interest of reducing consumption pattern, and enhancing energy efficiency through alternative renewable energy sources, with several governments announcing plans, projects, strategies and targets for energy sustainability.[3] For instance:

- **Kuwait** is aiming at 5% energy generation through renewables by 2020, and 15% through CSP, PV and Wind energy by 2030.

- **Bahrain** is driven towards 5% energy capacity through renewables by 2020.
- **Qatar's** target is to develop 20% energy capacity by 2030
- **Oman's** 2015 target is for 5% energy efficiency.
- **Saudi Arabia's** set targets for 2022 are to achieve 9.5GW, and by 2040 achieve 54 GW.
- **UAE** is endeavoring towards 24% clean energy by 2021

With profusion of renewable energy resources, the GCC region lying in the solar belt, is endowed with abundance of solar radiation, while wind energy potential looks equally promising in Kuwait, Oman and Saudi Arabia. Both solar and wind power could effectively be harnessed for energy efficiency. Desalination prospects also stand to gain through the deployment of renewable energy technologies , providing cost-effective alternatives. R & D projects exhibit promising outlook of solar technologies in lowering energy costs, and enhancing energy efficiency. Though all GCC States have put forth their ***vision and plans*** for renewable energy applications, the policy and regulatory framework is yet to be set to streamline implementation of plans for achieving energy efficiency targets, as well as creating a conducive environment for *public-private-external* investments for large and small scale projects. Concerning investments, the first phase of Kuwait's mega project, the Shagaya Renewable Energy Park has been tendered, and the next two phases are to be offered for public-private investment, while Dubai's Mohammed bin Rashid Al-Makhtoum solar park followed the auction path.

For R & D activities, renewable energy is claiming priority attention in all GCC states, involving researchers in innovative ventures based on institutional research endeavors at institutional and national levels, as well as involving regional and international collaboration, expertise and advanced technologies. Scattered as these efforts are, deployment of renewable energy technologies for GCC to achieve energy efficiency and sustainability, critically requires policies and regulations to oversee effective deployment of alternative technologies for capacity building and sustainability of energy efficiency. R & D values are increasingly proving beneficial concerning projects determining renewable energy potentialities and applications, with key initiatives taken by Kuwait University, Kuwait Institute for Scientific Research, Sultan Qaboos University in Oman, Qatar Foundation, and King Abdullah Petroleum Studies Research Center in Saudi Arabia. Besides, International cooperation is increasingly observed in supporting public and private efforts in the region for exploring the benefits of renewable technologies.

Energy Production and Demand in Kuwait

Kuwait, situated in the northern edge of Eastern Arabia, at the tip of the Arabian Gulf, shares borders with Iraq and Saudi Arabia. The country, populated by 4.2 million people, (*1.3 million Kuwaitis, and 2.9 million expatriates, as per Public Authority for Civil Information December 2015 statistics,*), is foreseeing rapid and growing demand for electricity and desalinated water, and dependent on oil for their production.[5] Faced by mounting pressure to expand production, the State is compelled towards increased consumption of fossil fuels to meet domestic energy demands. In 2008, the value of fuel supply to power plants approached $4.5 billion, at a subsidized $50/barrel, to generate 52 TWh/year of electricity.[6] Kuwait heavily relies on revenues from fossil resources. and with monthly average price of Kuwaiti oil export in 2008 reaching about $90.54/barrel[7] (it stands around $40/barrel in 2016), it is easy to understand how domestic electricity demand puts a serious burden on the government finances. Kuwait's power capacity, which stood around 11,600 MW in 2008, needs to double by 2020,[8] if the country is to meet its spiraling demands for energy in construction, residential and commercial sectors. In fact, electricity consumption has continued to grow at an annual rate of 7.25 percent between 1999 and 2009, and during the last five years, the peak demand staggeringly grew at an annual rate of 12 percent, yet could not adequately match the enhanced generation capacity.

With one of the world's highest per capita power consumption rates, 16.75 MWh/capita in 2008,[7] and an average annual growth rate of electricity demand, exceeding 8 percent for the next decade, it has become critical for Kuwait to accelerate the implementation of new power plants to cope with such rapid expansion in demand, necessitating the private sector's involvement. The MEW's ambitious plan called for exploration of *alternative energy sources* for power generation, with *renewable energy* technologies being one of the options. The plan professed rationalization of energy use to cover the rising demand, while curbing annual growth. [5]

As regards water, Kuwait's 95% reserves are produced from seawater desalination, from five desalination plants. The country's per capita water consumption is one of the highest in the world, reaching 37,707 imperial gallons in 2008. The increasing demand is necessitating the need for Kuwait to spend about $21.3 billion on power and water projects in the framework of its 2010-2014 development plan, for enhancing its desalination capacity from 423 million imperial gallons per day (MIGD) in 2008, to meet the future demand. In addition, the growing cost of fossil fuels for electricity generation is negatively impacting the environment, with increased carbon emissions in Kuwait, which grew by an average of 5.3 %.[8,9] The rising electricity consumption, and

associated environmental risks, necessitated integration of clean technologies, and development of renewable energy sources, as the preferred options.

The climate change agreement, and the above power and water demand, necessitated a '*rethink' on the State's energy policy*, leading to exploring the dimensions of a*lternative energy*, diverting national authorities and institutions attention on *alternative energy* as a vital field of research. Directions were thus set for innovative initiatives for studying the *untapped potential* of *solar and wind energy* sources, for assessing their appropriateness for cost-effective energy options, and conservation.

Renewable Energy in Kuwait

Due to its strategic location, Kuwait is blessed with profusion of sunshine, and exposed to high levels of solar radiation, providing the country with enormous amounts of solar energy, the key source for generating solar-based electricity. Studies conducted on *renewable energy sources* (RES), primarily *solar and wind*, explored the potential and possible applications of RES in Kuwait. The country exhibited highest performance indicators as regards Direct Normal irradiance, appropriate for Concentrating Solar Power (CSP), while an equally high global horizontal irradiance, was found to be useful for photovoltaic systems.

Kuwait's average high ambient temperatures, during long summer period, was particularly found to be appropriate for deploying CSP technologies, for enhancing the photovoltaic system's technical potential, as well as the technology's economic potential for large scale solar systems vis-a-vis electricity consumption**.** [8]

Based on an analysis of 20 years of weather data, collected by Kuwait Institute for Scientific Research (KISR), the College of Technological Studies investigated the hourly insolation on differently tilted surfaces for each month of the year. The results indicated immense potential of solar radiation, encouraging the use of photovoltaic energy for electricity generation..[9] Despite the promising findings, the country's harsh weather negatively affected the photovoltaic cells performance, as humidity, dust, and sandstorms formed a layer of crust on solar panels surface, compromising their effectiveness, and necessitating regular cleaning of panels.

The potential of wind power was also studied for generating electricity, based on *wind energy assessment* for annual full load hours, indicating its potential for economic viability in Kuwait. In 2006, KISR's *Coast & Air Pollution department* studied wind energy's *characteristics, potential* and *applicability* in Al-Wafra and Al-Taweel, Kuwait's inland flat desert areas, and the results provided a promising outlook of wind energy's

potential, which could effectively be harnessed in meeting Kuwait's growing energy demands for domestic and industrial needs. The findings were also promising for implementing large-scale wind systems for reducing the demand for new conventional power plants. Harnessing *wind energy* as an alternative source thus provided an attractive option for energy conservation, while minimizing cost in Kuwait.[11]

Research and Development (R&D)

Kuwait has been dynamically involved in scientific research within the systems of higher education, university, institutions, authorities, foundations and research centers. At the State level, Kuwait University (KU), the State's sole national university, envisions to be distinguished in Higher Education and Scientific Research. How this vision is dynamically laying the roadmap for prioritizing and developing scientific research at KU that effectively contributes to economic growth and national development is clearly visible in strategic objectives of research.

Since 1980/81 until mid2015/16, KU through the research sector (RS) funded over 13,971 projects, with sciences, engineering & petroleum, and health sciences collectively accounting for 76.8% (10,736) projects, and an additional 23.2%(3,235) projects attributed to arts and humanities fields. Currently, within a single academic cycle 2015/16, RS midyear statistics enlisted 630 projects, 61.6% (388) ongoing, 14.3% (90) completed, and an additional 24.1% (152) projects under review, reflecting the vibrancy of scientific research at KU.[12] Of the 388 ongoing projects, 17.5% (68) were priority and collaborative projects with external institutions, the domains responsible for some of the most significant projects addressing such pressing issues as *renewable energy, solar and wind energy, photovoltaics, desalination, oil and natural gas, carbon emissions,* etc., all areas of strategic relevance to Kuwait, GCC, and beyond, holding far reaching and global implications.

In fact, Priority research has predominated over **three decades of KU's efforts** in probing areas of critical significance. These priority research areas include ***Oil/water/energy resources, Energy conservation, Air/water pollution, desalination and water purification, Renewable*** and ***Alternative Energy sources, Water Resources Management & Technology, Enhanced Oil Recovery,*** and ***Heavy Oil Exploration & Production*** as areas that needed priority research attention, and constituting active fields of scientific research at KU. It is precisely in this context that enlisted here are some of the recent research studies that are actively being pursued in the areas of *Renewables, Energy* and *Water* at Kuwait University.

KU Projects in Energy and Water Areas[13]

Over the past *five* years, **43 research projects** have been granted in the broad fields of *energy* and *water, desalination, photovoltaics, solar and wind energy, alternatives* & and *renewable* at KU. Of these, 31 projects are supported by KU, and 12 are being pursued in partnership with external institutions (IMEC, KMIT, KFAS, etc.). In addition, 15 priority projects are currently ongoing at KU in the areas of *renewable energy, solar energy, photovoltaics, desalination, drinking water, grey and brackish water, water resources, electricity grid, oil & gas, air quality, energy generation* and *conservation*, all holding potential for large-scale applications, investments and economic viability. Some examples of currently ongoing and completed *Priority Research Projects* at KU are summarized here, and include:

- **Continuous low temperature, membrane-free water desalination using directional solvent and solar energy –** The Research aims to design, construct and test a continuous, low temperature, membrane - free desalination system that can utilize solar energy storage and thermal energy storage (TES), based on the directional solvent extraction (DSE) process.

- **Thin Film Solar Cells Based on the Solution-Grown CZT(S/Se) light Absorbers**
  The project involved preparation and characterization of the absorber layer grown by the dip-coating method, and fabrication and characterization of photovoltaic devices.

- **Indoor air quality and energy conservation in combined chilled cooling and displacement ventilation system for Kuwait climate –** The research aimed at studying the energy impact of a chilled ceiling displacement ventilation *CC*/*DV* system aided with a personalized evaporative cooler (*PEC*) directed towards the occupant trunk and face. A simulation model is developed for integrating the personalized cooler with the ascending thermal plume.
  At equal thermal comfort level, the integrated *CC*/*DV* system, *PEC* model *resulted in up to 17.5% energy savings* compared to the *CC*/*DV* system without a *PEC*. When mixed air is used in the *CC*/*DV* system *additional 25% savings in energy* is realized when compared with energy used for the 100% fresh air without the *PEC*.

- **Potential of Greywater collection and reuse in Schools in the State of Kuwait --** A pilot scale greywater treatment plant was designed and tested. The pilot scale plant included screening, filtration, chlorination and UV disinfection. The results showed that *sand filtration operated at low rates was very effective in suspended solids removal*. For reduction of COD, BOD and total coliform concentrations, *UV proved to be more effective than chlorination* (5 and 10mg/1chlorine dosage) and was *recommended for removal of organics and disinfection of the greywater* collected from schools. A scheme design and capital cost of a treatment system comprising screening, sand filtration and UV disinfection was provided and tested for greywater generated at schools.

- **Advanced Crystalline Silicon Photovoltaics Research Program --** The energy band diagram of hetero-interface between p-type hydrogenated amorphous silicon (a-Si:H(p^+)) and n-type crystalline silicon (c-Si(n)) obtained using AFORS-HET one dimensional device simulations revealed that a p^+ inversion layer was induced at the hetero-interface, in the c-Si side, with or without the presence of a buffer intrinsic a-Si:H(i) spacer. By inserting an intrinsic a-Si:H spacer, the defect density at the interface was strongly reduced, which not only decreased the interface recombination, but also ensured proper formation of inversion layer. The study also suggested that *significantly reduced band-gap narrowing in the inversion layer emitter contributes to the higher open circuit voltage achieved in the HIT cell compared to c-Si cell with excellent front surface passivation*.

- **Microbiological and Chemical Assessment of Drinking Water Pollution in Kuwait City --** The Project aimed to: determine occurrence of indicator organisms in drinking water supplied in Kuwait, Correlate results determined by molecular techniques with those by conventional microbiological techniques, Identification of bacterial contaminants, Determine occurrence of chemical pollutants in drinking water supplied in Kuwait, Test some water quality assurance assumptions in Kuwait. The governmental authorities in Kuwait (Kuwait EPA and Ministry of Health) follow WHO water quality guidelines.
  Drinking water samples were collected from different locations in Kuwait city and analyzed for heavy metals, anions and microbial contents. The investigation shed light on one component of the complex microbial communities and incidence of hydrocarbons in potable water. The occurrence of diverse but the same group of hydrocarbons in all potable water samples implied *common source of contamination that got disseminated throughout the distribution network and resulted in the selection of bacterial community capable of sustained self-cleaning of available hydrocarbon pollution*.

- **Analysis of Electrical Power Generation and Demand for Electrical Utility in Kuwait --**The project aimed at investigating power generation systems, including cogeneration plants situated in Kuwait. Current situation and installed capacity of power plants was assessed, including reliability and availability of each unit and demand for electricity. Demand forecasting, statistical modeling, as well as simulation, was utilized to determine expected power output from current power plants and needed capacity under random failures.
  After analyzing all stations in general, *Sabiya Power Plant* was selected as representative for detailed reliability, availability and maintenance analysis of power stations in general. Sabiya Power Plant, which has 8 steam turbines and 13 gas turbine stations, was studied in detail; extensive data collected; and availability of station units determined. A simulation model was developed and used to analyze the effects of different maintenance policies on availability of these stations. The *results showed that significant improvements can be achieved in power plant availabilities if appropriate maintenance policies are implemented.*
  In this research, all six power plants in Kuwait with 43 steam turbine and 53 gas turbine units were analyzed. Data concerning failures, repairs and maintenances collected, and maximum possible production capacity of each plant determined.
  The demand for electrical utility is continuously increasing in Kuwait and is expected to reach over 90 million MW in 2025. Based on the installed capacities and availabilities. Modeling and analysis procedures and *the results presented in this report are expected to be useful guide for operational engineers and maintenance managers*.

KU's Collaborative Projects – Some Examples[13,14,15]

- **Membraneless Hydrogen-Bromine Flow Batteries for Grid and Renewable Energy Storage – *A collaborative project with KMIT*--** The second-generation cell design described in the proposal is implemented, which incorporates a porous electrode for improved cyclability and power density. The cell includes a heterogeneous porous media for the cathode and an open channel for the electrolyte. A more sophisticated cycling setup, together with the newly leak-free cell, will enable demonstrating deep discharge cycles. A geometry optimization frame work using numerical simulation was developed top model the battery system and is being implemented in Kuwait. *Thermal and mass dispersion effects are being explored through both literature and simulation to serve as a starting point for modeling the flow-through porous cathode*.

- **Advanced Crystalline Silicon Photovoltaics Research Program -** The project is based on a cooperation between the photovoltaics research team at the Electrical Engineering Department at Kuwait University and IMEC, Belgium. IMEC (*Interuniversity MicroElectronics Center*), an advanced research organization in the fields of nanoelectronics and solar cells. Attached to this proposal is a description of the research capabilities at Kuwait University and IMEC in the field of photovoltaics.
  The project aims at developing advanced solar cells that utilize silicon-based photovoltaic structures. The main *objective is to achieve devices and modules that are competitive in terms of manufacturing cost reduction and improved efficiencies*.

The overall IMEC PV program follows a well-defined roadmap (International Technology Roadmap for PV(TRPV)) towards the reduction of the main figure of merit for terrestrial solar cells, the $/Wp figure. The contribution of the KU PV team towards the development of state-of-the-art solar cell devices and modules based on the i- PERL thin Si PV platform.

- **Approaches to Enhance the Sustainability of Energy Systems in Kuwait: Environmental impact and cost estimation of changing fuels in Kuwait's electricity grid --** The aim of this research is to assess different mechanisms for managing environmental impact and enhancing the sustainability for electricity generation units. The study investigates impact of switching power plants fuels on the concentration levels of air pollution and water consumption.
  The research would *demonstrate the extent to which system operation decisions (based on switching the fuel type) can mitigate the forms of impact and enhance the resilience and sustainability of the energy system in Kuwait.* The sustainability is measured through indicators including air quality,(e.g., NOx, SO2, and CO emissions) greenhouse gas emissions (e, g., CO_2 emissions), water availability, economic cost and electricity supply demand balance. The electric grid of Kuwait will be used as a source of data and as a geographic and temporal domain.

- **Next Generation Brine Desalination and Management for Efficiency, Reliability, and Sustainability --** Discharge from the desalination plants of Kuwait returns brines of high salinity to the Gulf that contain other contaminants, such as chlorine or chromium, impacting the environment of the coastal region. Conversely, wastewater discharges to the Gulf have low salinity but may drive eutrophication of coastal waters. Pressure retarded osmosis (PRO) is a promising source of renewable energy and an emerging membrane-based technology for recovering energy from concentration differences between water streams. *The proposed work examines the feasibility of using PRO to generate energy from wastewater and desalination plants in Kuwait by calculating the power density using a PRO zero-dimensional model.*
  Case studies on the potential re-use of treated wastewater effluent (TWE) and brine reject streams from three wastewater treatment plants (WWTPs) in Kuwait are discussed and compared to determine the maximum power generated from each of the WWTPs. The PRO power density (W) was studied as a function of hydraulic pressure (ΔP) at different feed and draw solution concentrations.

- **Calibration and Validation of NASA (SMAP) satellite for the retrieval of Soil Moisture and it's application to water resources and dust storms in Kuwait --** Soil Moisture, Active & Passive Satellite (SMAP) will carry the first combined L-Band radiometer and synthetic radar (SAR) with the objective to measure global soil moisture. This will *improve the estimate of water, energy and carbon transfer between the land and the atmosphere for climate applications. In Kuwait*, *SMAP observations of soil moisture are critical for dust storm prediction, air quality, human health, renewable energy, weather prediction, drought monitoring and climate change.* Kuwaiti project team is collaborating with NASA as an international partner on the calibration and validation of SMAP satellite data.
  KFAS is funding the Kuwait University project and Kuwait University is collaborating with NASA, Ministry of Defense, Kuwait (MOD) , Regional Organization for the Protection of the Marine Environment (ROPME), City College of the City University of New York (CUNY), Massachusetts Institute of Technology (MIT) and Masdar Institute of Science and Technology for the calibration and validation of NASA SMAP satellite. The project also engages local stakeholders who should benefit from the outcome of the project like, Kuwait Meteorological Center, Ministry of Defense, Ministry of Electricity and water and the Ministry of Health.
  Kuwait was selected by NASA amongst few other networks in the world, as a core calibration/validation site for the mission and is now an international partner with NASA for the calibration and validation of SMAP satellite which went into orbit in January 2015.
  Observations from SMAP satellite will greatly improve our understanding of the dynamic of surface condition and the interaction between the land and the atmosphere. In Kuwait, these *observations are critical for several applications, like Climate change, defense applications, renewable energy, dust storm prediction and monitoring of air quality, and human health.*

- **AMPS: Adaptive Monolithic Processing for Solar --** In modern power systems, wind energy shares significant amount in electricity generation. Accordingly, the grid performance could be affected due to the natural behavior of the connected wind farms. This project *presents fast and efficient over current and under voltage protections against faults on both grid high voltage line and on medium voltage feeders connecting the wind turbine.* The proposed protection scheme based on measuring the voltage and current signals at PCC bus evaluation and analyzing these signals for fault detection. Thereby, the main objective is to keep wind turbines connected to the grid and to regulate the reactive power and voltage level during grid-transmission line faults. Under voltage, relay time delay settings proposed to fulfill the Fault Ride-Through (FRT) requirement. Moreover, over current relay settings is presented to isolate the wind farm from the grid during the internal wind farm feeder faults.

***Research Activities at Kuwait Institute for Scientific Research* (KISR)**

At the institutional level, *Kuwait Institute for Scientific Research* (KISR) has remained involved in R & D activities in the domain of *renewable energy* since 1970s and 1980s. KISR's early research focus was primarily on solar and wind energy, for reducing increasing demand for fuel, and offering an *alternative energy source* of potential economic value. The institution's thrust was on *basic and applied* research in the field of solar energy, for which support and funds were provided to test its deployment potential for power generation, heating, cooling and desalination. KISR's R & D activities during that period led to the grant of over 140 research projects, costing $50 million, involving teams of researchers, engineers and technicians, for implementing projects concerning a 100 kW Solar thermal Power Station (1979-84) and other small solar energy projects.

In 1986, KISR discontinued renewable energy projects due to issues of inadequacy, uncertainties and durability of designs, and cost-effectiveness. However, after a hiatus of several years, there was a resurgence of interest in KISR for research in solar and wind technologies, when in 2006, it initiated the review of solar desalination technology, assessing relevance, potential and status of this energy resource in the GCC, and more specifically in Kuwait, as regards the technology's futuristic outlook. KISR also investigated the potential of wind power generation in Kuwait, which led to the identification of some wind farms potentiality and performance, with cost analysis done on two different wind turbines models. The Building and Energy technologies department at KISR undertook studies on "Experimental Wind Power Stations in the State of Kuwait", "Kuwait Solar Radiation for Photovoltaic Applications" and "Application of Green Building System in Kuwait", while the Advanced Systems department studied "Integration of Distributed Energy Resource with Electric Utility Network", together with its technical and regulatory challenges.[16,17]

KISR's study in 2010 investigated the *cost economics of renewables*,[18,19] while other studies assessed technical and economic feasibility of grid-connected photovoltaic systems in Kuwait, showing that energy generated from a 20 KWPV met about 70% of the total building load, saving as much as $1625 over 10 months of simulation.[20] The studies major findings concerning grid-connected RE sources in Kuwait showed significant reduction in peak load. Also, when RES units were introduced in vertically regulated power system, it encouraged release of power, supporting sustainability of energy supply in Kuwait. [22]

As regards renewable energy deployment policies for long-term sustainability, Kuwait's interest in exploring, and adopting renewable technology applications is integrated within its futuristic outlook of energy effectiveness and efficiency through harnessing and deployment of RE technologies' potential. Given this fundamental objective, Kuwait aimed at producing 5% of its electricity from renewable sources by 2020 in view of increasing demand, which could reach 23 GW, necessitating RE installation to provide 1,150 MW to reach the set goal. An effort of this magnitude could only be achieved through huge investments, several stakeholders, notwithstanding the project development, legislative, financial and socio-economic complexities entailed in adopting RE technologies.

During 2009, nuclear energy also emerged as an option for ensuring continuous supply for growing energy demands. However, efforts in the nuclear field were abandoneded in 2011, confining nuclear program to research and training under KISR.[85] All through this period, electricity generation from renewable continued to gather momentum, with Kuwait's Ministry of Electricity and Water (MEW) official announcement of the the objective of generating 5% of its electricity from alternative sources by 2020, to ensure sustainability of Kuwait's energy needs.[21] As a result, a solar and wind technology based initiative was undertaken towards the deployment of 1000 MW as the country's drive towards RE sources for meeting future needs. As a result, establishment of a 10 MW photovoltaic solar plant complex, comprising 10MW wind farm, and 50 MW CSP facility, is underway. [21]

Alternative energy sources equally claimed the attention of Kuwait's oil sector, driven by the need to conserve fossil fuels for optimizing oil exports. The possibilities of using solar potential was explored by Kuwait Petroleum Corporation (KPC) in 2008, with its Research and Technology department holding workshops on "New Energy technologies," and "Renewable Energy Applications in the oil sector." The workshops involved cooperation of Kuwait's major research institutions, involving participation of Kuwait University, KISR, Kuwait Foundation for the Advancement of Sciences (KFAS), and Kuwait Oil Company (KOC), for multi-expertise in addressing solar

energy potential and viability in Kuwait, fuel cells used in desalination, methods of using renewable energy technologies in KOC activities, as well as future applications of renewable energy technologies[8] . Use of solar energy as an alternative to oil for producing energy, led KOC to launch two pilot solar-power schemes in 2012, and tenders announced for the construction of five MW photovoltaic power plant, as well as integration of CSP plant to produce steam for enhanced oil recovery.[24]

Since Kuwait's energy sector is heavily subsidized, a strategy of conservation is required, alongside rational use of power for bringing about attitudinal change towards wasteful consumption, including architectural design of buildings, which are invariably incompatible to Kuwait's climate. Building integrated solar panels have been integrated into several government buildings, schools, sun-shaded parking lots and in the oil fields. Kuwait's MEW to integrated 1MW worth of solar panels on the rooftops of two of its buildings. The new Kuwait airport terminal designed to integrate solar panels for electricity generation and generate 12 MW of power. Construction of the new terminal will start in September, 2016. Kuwait foundation for the advancement of science with KISR began a program of outfitting the parking areas sun shades with PV panels in several cooperative supermarkets.

Sectors Involved in Renewable Energy Research

The sectors critically involved in promoting renewable energy research in Kuwait and its applications, are KISR, KU, and several other public and private institutions, including Public Authority for Applied Education and Training (PPAAET). In this regard, KU Research Sector has already ventured into a national level research project on Alternative Energy and Photovoltaic in collaboration with IMEC, the Belgium-based Interuniversity Micro and nano electronics Center. KISR's is critically involved in mega projects concerning solar, wind. KFAS involvement in promoting and supporting alternative energy sources has been equally critical in rendering funding support and organizing workshops on alternative energies, water desalination, and renewable technologies applications.

In addition, Kuwait University also signed a collaborative agreement with IMEC (Belgium), for research and development in innovative *silicon solar cell* technologies, laying the basis for KU to join IMEC's wafer-based *silicon solar cell* program, to further the knowledge and expertise in advanced *silicon solar cell* processing technology. The agreement involved KU researchers to closely collaborate with IMEC researchers, at their facilities in Leuven, Belgium, and in Kuwait, and effectively contribute to the research program with their excellent technology-modeling and simulation expertise.

On its part, Kuwait University provided in-depth scientific understanding in exploring and validating directions for solar cell innovation towards *higher efficiencies and lower cost*. In 2015, KU Research Sector a organized a Second Symposium on "*New Trends in Photovoltaic Technologies & Applications within the GCC Region*". The symposium involved knowledge sharing and update on the dynamics and implications of new technology for the Region through a series of lectures, on critical advances in photovoltaic and silicon solar cells for oil and gas sectors, furthering the knowledge base, and providing encouraging outlook of renewable energy technologies potential.

On the water desalination front, RS took another strategic step towards KU-MIT collaboration for initiating a potentially significant and largest research project, for investigating the desalination systems through innovative and advanced technologies, for containing wastewater effluents and pollutants in the coastal region of Kuwait. Entitled, "*Next Generation Brine Desalination and Management for Efficiency, Reliability, and Sustainability*," the project brings together experts from Kuwait University and Boston-based Kuwait-MIT Center for Natural Resources and Environment (CNRE), for innovative and effective desalination technologies to counter negative economic and environmental implications of contaminants, a persistent and perpetual challenge to sustainable growth of Kuwait, which relies on over 90% of its freshwater needs from desalination. The project, with a grant of $5.5 million, has been awarded under the Kuwait-MIT (CNRE) *Signature Research Program*, and funded by KFAS, for accomplishing the project's objectives over the next three years.

The fundamental basis of the project stems from this critical need of addressing existing desalination challenges, through innovative *next-generation desalination systems* for effective management of wastewaters. The intent is to optimize environmental sustainability of Kuwaiti waters through *technology-workflow interface,* blending new ideas and methodologies within the framework of existing plant workflow activities. The project's key imperatives, entail three core areas:

- ***Electrical desalination for brine management***
- ***Power generation using brine and wastewater***
- ***Engineering for increased reliability***

The Shagaya Project[3]

Having recognized the significance of *renewable energy* and *silicon solar cells* technology, Kuwait is on the threshold of *Shagaya Renewable Energy Multi-Technology Park*, integral part of the *Shagaya Renewable Energy Master Plan* proposed by KISR, a 70 MW venture, bidding for which was invited in June 2012. The project, to be accomplished in three

parts, include 10 MW wind energy, 10 MW PV, and 50 MW thermal, equipped with 10-hour energy storage for the plant to work after sunset. Construction on the wind farm is underway and the contracts for the construction of the PV and thermal parts of the projects were signed in 2015 and construction is underway[25]. The Shagaya project is expected to enable Kuwait to assess performance of different renewable technologies under climatic extremes, for Kuwaiti engineers to identify deficiencies or limitations of technologies, and undertake feasibility analysis for developing hands-on experience. According to KISR's Director General's recent statement at the *Sixth Middle East and North Africa Renewable Energy Conference* (MENAREC 6), held in Kuwait in April 2016, KISR's renewable energy program, the ambitious Al-Shagaya Project for renewable energy, has started building a solar power station and a wind power station. Launched few years ago, the Al-Shagaya renewable energy complex, spread over an area of 100 sq. km, with a compound capacity of 200,000 megawatts, is scheduled for operations by the end of 2016. As part of Innovative Renewable Energy Research program at KISR, the Al-Shagaya Project, when completed, would comprise three main facilities, a concentrated solar power plant, and two facilities for wind and PV research.

With the accomplishment of Phase–I of the Al-Shagaya Project, the second stage would involve offering investment opportunity to the private sector in a 500 megawatt renewable energy power stations, to be built in public and private sectors partnership. The project's second phase would oversee expansion of the plant's capacity to 1,000 MW, and further to 2,000 MW in the third phase. The project's first phase is to be financed by the government, while the second and third phases are to be offered to investors on Build-Operate-Transfer (BOT) basis over 25 years. The Shagaya plant is a joint Ministry of Electricity and Water (MEW) and KISR venture, with the project's power output to be bought by MEW, Kuwait's sole electricity producer and distributor.

Presently, Kuwait's interest in renewable energy stems from the spiraling demand for energy, and ***the country is aiming at producing 15% of its electricity, from renewables by 2030***. Also, according to KISR, the GCC countries plan to pump up to $100 billion into renewable energy projects over the next 20 years.

Considering Al-Shagaya's potential and versatility, a major challenge to the facility, however, is environmental, as Kuwait is prone to more than normal average of sandstorms exceeding neighboring countries average, during which sand particles could cause serious mechanical damage to solar cells' protective layers and anti-reflective coatings of PVs, causing solar cell modules output power to drop. Humidity is another factor that impacts on PV installations, with water vapor condensing on PV panels, compromising their optical performance, and causing short-circuiting. Hence,

both sand particles and humidity factors need to be duly accounted for in ensuring the solar cells effectiveness.

There is an increasing urge and awareness on the benefits of renewable energy sources in Kuwait, with institutions sharing interests and knowledge in the field, taking initiatives, funding projects, and exploring alternative energy sources and its potential applications through research. Scientific events, seminars, and training are also being organized by Kuwait's academic and research institutions, centers, public and private sectors, recognizing the advantages of renewable energy ventures. Yet, energy sustainability is a key challenge, which beyond R & D requires executives and decision-makers to formulate policies, develop regulatory and legislative framework for overseeing implementation of plans into actions for achieving the targeted goals. However, Kuwait's move towards energy efficiency, attaining water security, reducing consumption and saving energy, requires a strategy for exploiting solar potential to meet the country's water and electricity demands. Despite growing awareness of renewable energy's potential benefits, as yet, Kuwait lacks a unified strategy towards an effective national plan aimed at developing renewable energy sources, attracting investments and international cooperation, for building large-scale cost-effective plants that also involve stakeholders in the decision-making process for RE technology implementation.

Conclusion

Despite all the efforts and developments, renewable energy deployment is still at an early stage in GCC, yet ongoing efforts and increasing interest in the field, does provide a promising outlook for the future of energy sustainability in GCC through the renewables route. The renewable energy prospects in GCC is increasingly attracting foreign investors, keen on developing renewables potential, as technologies of future, building capacities, and opening the corridors for industries, manufacturing, and in creating job opportunities. For economic diversification,, and taking advantage of naturally available alternative energy resources, GCC States need to take steps towards building indigenous capacities through widespread utilization of renewable energy technologies, for which authorities must develop coherent strategies that facilitate implementation of renewable energy projects through appropriate energy and manufacturing policies, legal and financial frameworks that help attract investments, and ensure energy sustainability. In Kuwait, the Shagaya project will provide 70 MW power in the coming years and second phase of the project will fulfill the objective of providing 15% of the electricity by 2030. Building intergrated solar panel with utilized in more buildings to demonstrate the viability of solar power as an alternative energy

source. Research and development in this field should be continued to keep base with the new technological developments in solar, wind and efficient water production.

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