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Renewable Energy Supply Options in Kuwait

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***Abstract*—**This paper compares planning results of the electricity and water generation inventory up to year 2030 in the State of Kuwait. Currently, the generation inventory consists of oil and gas fired technologies only. The planning study considers two main cases. The first case, Reference case, examines a generation inventory based on oil and gas fired generation technologies only. The second case examines the inclusion of renewables as part of the generation inventory under two scenarios. In the first scenario, Ref-RE, renewable build-out is based on optimum economic performance of overall generation system. Result shows that the optimum installed renewable capacity with electric energy generation of 11% . In the second scenario, Ref-RE20, the renewable capacity build-out is forced to provide 20% of electric energy by 2030. The respective energy systems costs of Reference, Ref-RE and Ref-RE20 case scenarios reach US dollar 24, 10 and 14 billion annually in 2030.

***Keywords*—**Generation inventory, solar, planning, TIMES, wind.

I. Introduction

PLANNING for electric energy supply is essential procedure for identifying and securing fuel sources, selecting economically and technically suitable energy conversion technologies, identifying potential challenges facing the electric energy supply system, and developing solutions addressing these challenges. One of the main tasks in the supply planning process is to identify the long-term primary fuel mix that is expected to run the generation plants. The identification of such mix is a result of an assessment reflecting the resources availability and economic viability [1]–[3]. The primary fuel types dictate the energy conversion technologies, e.g., steam, gas turbines or nuclear reactors, multi-flash or reverse osmosis etc., e.g., [4, 5]. Consequently, and based on the identified primary fuel mix, planning studies survey spectrum of energy conversion technology types taking into account the conversion efficiencies, availability factor (base or peak load generation systems) and other factors that are related to infrastructural issues (e.g., availability of suitable sites, fuel pipe lines, transmission lines, etc.) [6, 7]. Moreover, environmental impact and socio-economic assessments can be assessed based on the generation's inventory system [8, 9]. In summary, the main goals of supply planning studies are to minimize costs, maximize benefits, and reduce environmental impacts.

This paper focuses on the supply planning of the electric energy (as a secondary source of primary energy) and water (as a byproduct of electricity generation) in Kuwait. The Kuwait's electricity and water (KEW) sector is modeled and analyzed using the Integrated Markal-Eform System (TIMES) by Energy Technology Systems Analysis Program (ETSAP), International Energy Agency (IEA). The Kuwait Institute for Scientific Research (KISR) commissioned Lightbridge Corporation, USA to develop KEW using TIMES. The current electricity and water production sector in Kuwait is solely dependent on oil and its refined products and natural gas. The technologies that are used to convert primary energy to electric energy are mainly steam and gas turbine plants. As byproduct of electricity generation, the multi-stage flash (MSF) technology is utilized for producing potable water from sea water.

This work explores the potential capabilities of renewable energy systems as part of the electric generation inventory to meet part of the national electricity demand in the State of Kuwait. Section II provides a background on Kuwait's socio-economic and energy supply and demand aspects. Section III reviews the potential renewables that to be included in the generation inventory. Section IV presents the model solutions and analysis for optimum generation mix. Section V summarizes and concludes the study objectives and main results.

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II. Background

A. Overview

The State of Kuwait lies at the north-west corner of the Arabian Gulf, between 28º and 30º latitudes and between 46º and 48º longitudes. Its total land area is 17,818 km^2. Most of the mainland is a flat sandy desert gradually sloping towards sea level in the east. The western border land areas are 270 meters above sea level. About 6% of Kuwait's total area is inhabited. The weather is characterized by long, hot and dry summers and short, warm and sometimes rainy winters. Dust storms occur frequently with a rise in humidity during late summer. Typical extreme temperature ranges between the winter and summer is 0 ºC to 50 ºC.

By the end of 2010, the population was estimated to be 3.5 million with annual growth rate of 5.9% for the last 10 years [10]. In 2010, the gross domestic product (GDP) was US dollar ($) 135 billion with growth rate of 4% and it is relatively stable [11].

B. Energy Supply and Demand Records

The only available indigenous energy sources are oil and natural gas. These sources are managed by a state owned entity, Kuwait Petroleum Corporation (KPC), with its subsidiaries that are responsible for oil and gas production, manufacturing, exporting/importing and distribution. It is estimated that the available liquid oil and gas are 13,842 million tons and 50,517 billion cubic meter, respectively [12]. Currently, natural gas production is associated with oil production. Hence, The quantity of produced gas cannot be dispatched in certain quantities. In 2010, the total consumed energy in Kuwait was 188.6 million barrel of oil equivalent [12] with daily consumption average of 516,700 barrel of oil equivalent.

The dominant energy consumers are the electricity and water production, Industry and transportation sectors that are respectively claim 65%, 20% and 15% of the local primary fuel consumption. The electricity and potable water production sector consumes about 340,000 to 350,000 barrel of oil equivalent per day.

C. Energy Conversion System and Load Characteristics

The energy conversion system is state owned and operated plants by the Ministry of Electricity and Water (MEW). MEW is responsible to produce, transmit and distribute electricity and water in Kuwait. The system is solely dependent on oil, oil refined products and gas fuels, which are provided by KPC. The current total installed capacity is close to 12 GW. The current generation inventory technologies include 55% reheat steam, 20% non-reheat steam and 25% open cycle gas turbine plants [13]. The desalination capacity is about 450 million imperial gallon per day (MIGD) utilizing MSF technology (reverse osmosis is utilized with negligible production capacity).

In Kuwait, the energy conversion system serves a typical electric load profile as shown in Fig. 1 (2008 load profile as an example). High temperature during summer seasons, during which maximum temperature can reach higher than 50 ºC, is a key driving force for the high electricity demand. This is mainly due to the widespread use of air conditioning (A/C) systems which are the largest consumer of electricity. A/C systems account for nearly 70% of the annual peak load demand and over 45% of the yearly electricity consumption [14]. Fig. 1 shows the load profile at the hours 04:00, 15:00 and 20:00. These hours are selected to illustrate the load fluctuations and transients throughout the year and in a typical day in which the temperature and society work activities at their minimum and maximum. The load level during summer is approximately twice the base load, e.g., in 2008, the base load was around 4,000 MW and the average summer load was 8,000 MW.

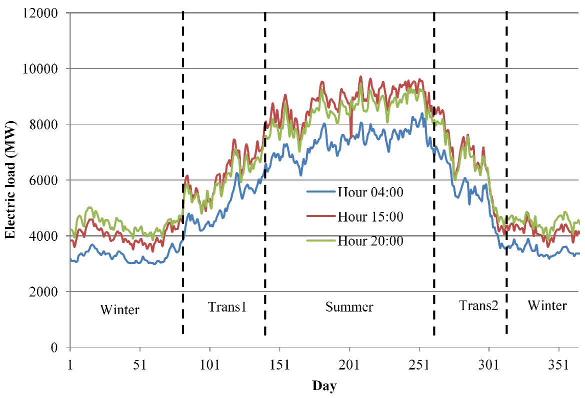

Fig. 1 Typical load profile in Kuwait (2008 electric load)

Currently, the base load is around 4,500 MW which is about 40% of the total installed capacity. The average daily difference between the maximum load (at hour 15:00) and minimum load (at hour 04:00) is around 1,000 MW throughout the year. This difference is about 10% of the total installed capacity. Despite the temperature drop during the evening, the load is close to the maximum load during the afternoon because of the social activities that take place during this period. There are two load transient periods (i.e., Trans1 and Trans2) during which the load rises and drops from winter to summer and summer to winter, respectively.

Currently, the electricity and potable water production consumes about 13% of the Kuwait's oil production, which is around 2.7 million barrel per day, [12], and it is expected to reach 20% by 2020. The country's economy highly depends on oil, i.e., 95% of the country's revenues comes from the oil export. Therefore, considering non-oil electricity generation technologies has become a priority in order to increase revenues, extend the life of the oil and gas resources and lower environmental impact.

III. Future Electricity Generation Technology Options

There are urgent and legitimate motivations that call for the adoption of alternative fuel energy sources and electricity production technologies in Kuwait. These motives include:

- Rapid electricity demand growth,
- Reliance almost entirely on energy intensive sea water desalination for fresh water supply,
- Current fuel consumption for electricity and water has reached 13% of the total oil production. It is expected to reach 20% by 2020,
- Kuwait's current maximum allowed oil production by the Organization of Petroleum Exporting Countries (OPEC) is 3 million barrel/day. Increasing the oil consumption for electricity and water production reduces the revenues and negatively affect the country's economy, and
- The per capita carbon dioxide (CO_2) emissions are among the highest in the world. The current CO_2 emission resulting from the electricity and water production is approximately 40 million tons per day and expected to reach 70 million tons per day in 2030 [15].

Alternative sources that may play a role in substituting part of the oil and gas fuels are renewable energies. Renewable resource assessment study was carried out and showed that solar and wind energies are the most viable in Kuwait [16]. One of the main techno-economic parameters that provides a cost-effect measure of a particular energy source and related technologies is the levelized cost of electricity (LCOE). LCOE is determined for a range of technologies for the purpose of comparison and technology selection.

A. Levelized Cost of Electricity Comparison

LCOE basically provides the cost for generating an electric energy unit (i.e., cost to generate Watt hour of electricity) from a particular energy technology system. LCOE is calculated as follows,

$$LCOE = \frac{\sum_{t=1}^{T}(I_t+OM_t+F_t+C_t+D_t)(1+r)^{-t}}{\sum_{t=1}^{T}(E_t)(1+r)^{-t}} \quad (1)$$

where I_t is the initial investment, OM_t is the operation and maintenance cost, F_t is the fuel cost, C_t is the carbon emission cost (or tax), D_t is the decommissioning cost, r is the discount rate, and E_t is the generated electric energy in year t and T is the number of years from commissioning to decommission of the plant or system. The parameters that are used to calculate the LCOE of the different technologies were based on [17]. From Fig. 2, it is observed that by 2015 the wind energy is more cost-effective than the gas fired technology, i.e., closed cycle gas turbine (CCGT), and the oil fired technology, i.e., reheat steam power plant (RHSPP). However, CCGT is expected to be more cost-effective than the central plant solar photovoltaic (PV) and solar tower with storage where the latter two renewable technologies are more cost-effective than RHSPP. The distributed solar PV and solar technologies start to be more competitive with RHSPP by 2020 to 2023. By 2027 to 2030 the distributed solar PV and solar tower with storage will compete with CCGT. Within the analyzed period (2015 to 2030), the solar trough with hybrid gas and with storage, and solar sterling will still be the least cost-effective when compared to the fossil technologies.

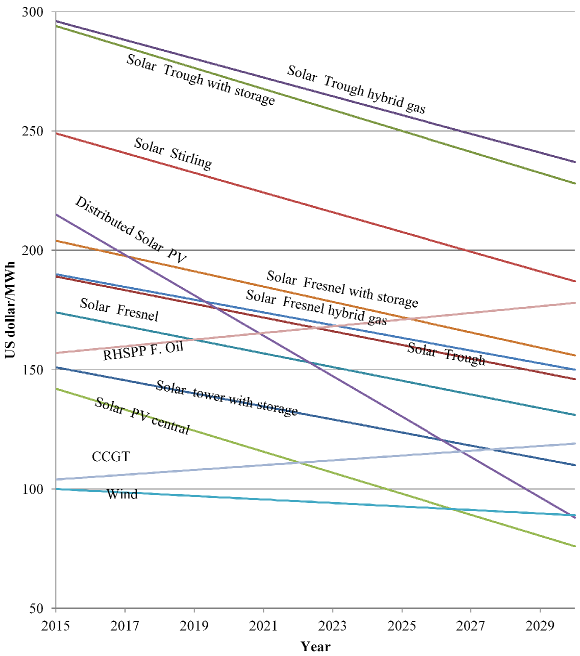

Fig. 2 Levelized cost of electricity

LCOE analysis shows that wind and solar will be competitive with conventional technologies (oil and gas fired systems) by 2015 and 2022, respectively. However, it should be mentioned that the LCOE analysis presented in Fig. 2 is based on peak hours in Kuwait (12:00 to 16:00 during summer seasons) during which the solar radiation and wind intensities are high. Renewables are not base load systems, i.e., they do not provide electric energy 24 hours throughout the year with a stable electric energy. Renewables are complementary systems that can contribute toward saving indigenous primary fuels and lower the impacts on the environment.

Renewables are considered to be an option and included in Kuwait's electricity generation inventory. In addition to the LCOE, further analysis were carried out to examined the renewable energy system's economic performance within the generation inventory, e.g., running costs of generation inventory (with/without renewables), fossil fuel savings, and increase/decrease of oil and gas exporting revenues. The renewables were included in the reference energy system of Kuwait for additional analysis.

B. Reference Energy System Option

A TIMES model is developed based on the reference energy system (RES) shown in Fig. 3, which depicts Kuwait energy system including alternative (solar and wind) and conventional (oil and gas) energy sources.

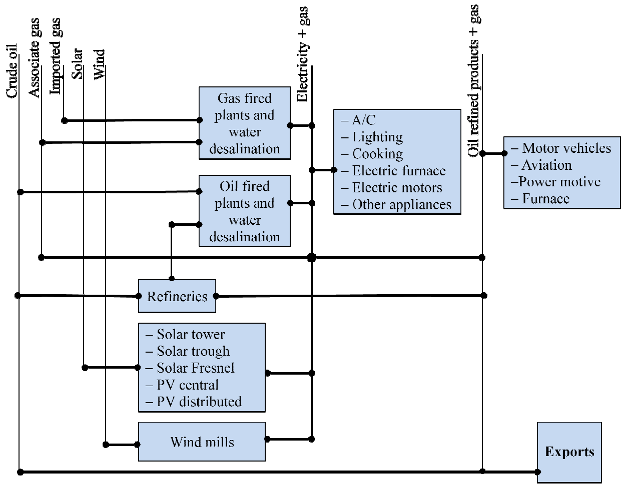

Fig. 3 Reference energy system of Kuwait including conventional and renewable energy systems

Data and information of the current operational and planned conventional energy system (i.e., fuel types and related economic and planning parameters, and energy conversion technologies and related efficiency and economic parameters) as well as the optional renewable energy systems parameters were assembled into a database that represents the underlying RES. This database depicts how commodities (energy carriers) are used by processes (technologies) to meet the demand for energy services. TIMES model minimizes the total cost of an energy system. All cost elements are appropriately discounted to a selected year. The discount rate was selected to be 7.5% to reflect the trend toward private-sector development of conventional power plants. For each year of the planning horizon, the total energy system cost is comprised of:

- Capital costs incurred building and/or dismantling power plants,
- Fixed and variable annual operating and maintenance (O&M) costs associated with each power plant, and other annual costs occurring during the construction and dismantling of power plants,
- Costs incurred for domestic resources and imports consumed for the production of electricity and/or potable water,

- Revenues from exports. It is assumed that oil price in 2010 is \$86/barrel and it is linearly increasing to \$108/barrel in 2030,
- Delivery costs where appropriate, and
- Optionally, taxes and subsidies associated with commodity flows and process activities or investments.

More details of Kuwait's RES is discussed in [15].

IV. Electricity Generation Inventory Options: Analysis Results

In this work, the analysis is carried out on KEW model with respect to two main scenario cases, namely, Reference and Renewable cases. The Reference case includes a generation inventory without renewable systems. The Renewable case includes both the conventional and renewable generation systems. The analysis results of each case are presented with respect to generation technology type and its calculated economic outcome for comparison purposes.

A. Reference Case

The reference case is based on demand projections for electricity and desalinated water from 2010 to 2030 (demands in 2010 are 57 TWh and 151 BIG growing to 159 TWh and 385 BIG in 2030) [15], [17], oil and gas prices are assumed to be \$86/barrel in 2010 and linearly increasing to \$108/barrel in 2030 (assuming gas price parity with oil price), and the availability of natural gas for power generation, which is based on the gas resource case, 2.7 BSCFD [15], [17]. The scenario uses a discount rate of 7.5% to reflect the trend toward private-sector development of conventional power plants. No air-pollution constraints or CO_2 tax is imposed. The KEW model under the Reference case parameters was solved for most economic optimum generation technology mix through 2030. The generation capacity mix result is shown in Fig. 4.

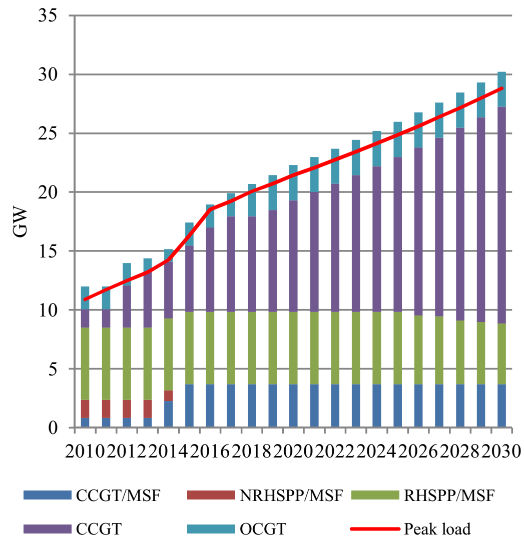

Fig. 4 Installed generation capacity under Reference case

B. Renewable Case

The Reference scenario case (discussed above) was run with the addition of the renewable energy technologies to the portfolio of future power plant options to examine the cost-effective share of renewables. The main scenarios run were as follow. The "Ref-RE" scenario which is the KEW model's optimum solution for the generation technology mix. The "Ref-RE20" scenario is the KEW model's solution under the constraint of including renewables so that they produce 20% of the generated electric energy. The purpose of the forced 20% RE scenario is to examine the economic feasibility for increasing/decreasing renewables within the generation system mix. The generation capacity mix results for the Ref-RE and Ref-RE20 scenarios are shown in Fig. 5 and Fig. 6, respectively.

The increase of the installed capacity of the renewable systems does not necessarily imply that the generated electric energy is increased. The quantity of the generated electric energy by renewables is subject to the availability of renewable energy sources. Consequently, in the renewable cases the total installed capacities reach about 35 and 40 GW compared to about 30 GW in the Reference case due to intermittent nature and lower availability of the renewable technologies. The optimum solution of the Ref-RE case of KEW model results in 11% of generated electric energy from renewables by 2030 (Fig. 5). Fig. 6 shows the generation mix result when enforcing 20% of the generated energy to be produced by renewables. Although, the parameters of other renewable technologies, such as, solar sterling engine and solar cooling, were included in the modeling procedure. The model solution excluded them (at least for the coming 20 years) due to their cost-ineffective compared to solar PV, solar thermal trough, tower and Fresnel.

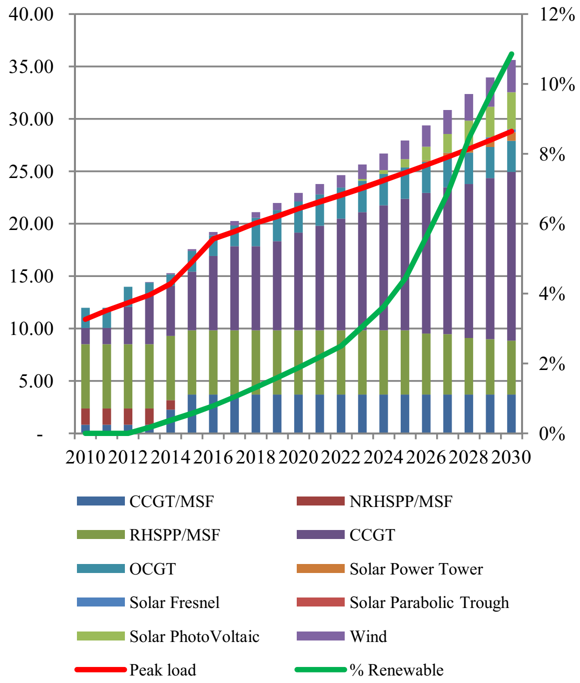

Fig. 5 Installed generation capacity under the Ref-RE scenario case

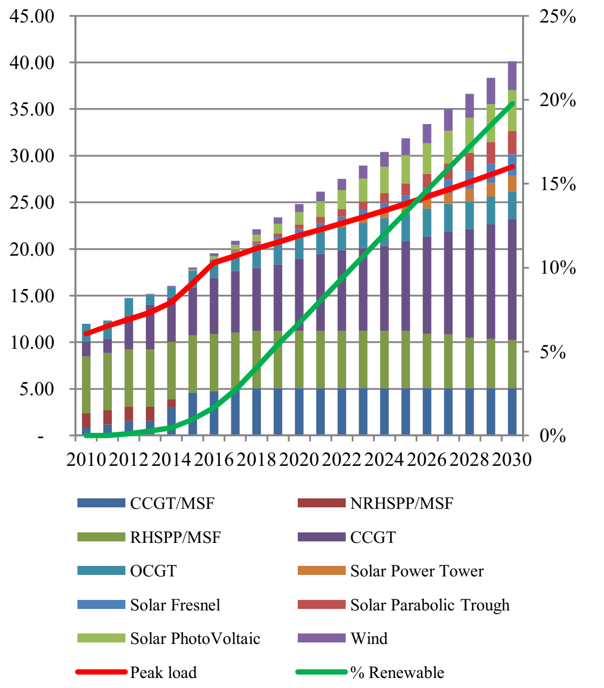

Fig. 6 Installed generation capacity under the Ref-RE20 scenario case

C. *Analysis Results*

As part of the build out in the Reference case, non-reheat steam power plants with multistage flash desalination (NRHSPP/MSF) are retired and replaced by CCGT/MSF plants by 2014. Most electricity demand growth is met by new CCGT plants. Through 2016, new CCGT/MSF plants are built to meet desalination demand, but after that period, the growth in desalination demand is met by reverse osmoses (RO) plants. Domestic heavy fuel oil and natural gas supplies are augmented with significant imports of natural gas, which grow to slightly more than 600 BSCF per year in 2030 [17]. The energy system cost, which is dominated by fuel costs, reaches almost $24 billion annually in 2030 [17]. Air pollutants, which largely come from fuel oil combustion, remain constant as new capacity is fired by natural gas. The CO_2 emissions grow from 40 million tons per year to 72 million tons per year [17].

In the Ref-RE case, the cost-effective renewable uptake in 2030 is 11% of total electric energy generation. By the 2030 the total installed capacity of oil/gas and renewable systems are 27.9 and 6.8 GW, respectively. Fig. 7 shows the development of the generation inventory under the Ref-RE scenario. In this figure, the installed generation capacity in Reference case is subtracted from Ref-RE case. The purpose of the subtraction was to observe the replacement of oil and gas energy generation capacity with renewable systems. Wind energy is the first renewable to enter the generation inventory starting with 50 MW in 2013 and reaching 190 MW in 2015 replacing part of the CCGT (–40 MW). By 2023, PV enters the generation inventory with capacity of 190 MW and its contribution, in addition to wind with 1350 MW, further replace more the CCGT (-340 MW). In 2027, solar Fresnel gets into the generation system with 30 MW. By 2030, the wind, PV, and solar Fresnel reach 3000, 3500 and 300 MW, respectively, replacing more than 2000 MW of CCGT. In 2030, the annual energy system cost reaches almost $10 billion and the CO_2 emissions is expected to be brought down from 72 (Reference case) to 60 million tons per year [17].

In the Ref-RE20 case, renewables are forced into the model to uptake 20% of total electric energy generation by 2030 in which the total installed capacity of oil/gas and renewable systems are 26 and 14 GW, respectively. Fig. 8 shows the development of the generation inventory under the Ref-RE20 scenario. In this figure, the installed generation capacity in Reference case is subtracted from Ref-RE20 case. The purpose of the subtraction was to observe the replacement of oil and gas energy generation capacity with renewable systems. Wind enters the generation inventory by 2012 with 30 MW. By 2015, PV, solar thermal tower and Fresnel start operating with 100, 30 and 10 MW, respectively. In that year the wind capacity is 220 MW and the total renewable installed capacity 360 MW. Moreover, the CCGT/MSF capacity is increased to reach 4600 MW. The addition of above renewables and CCGT/MSF replace part of the OCGT (–160 MW) and CCGT (–500 MW). In 2017, the solar thermal parabolic trough enters the service with 100 MW and additional CCGT/MSF capacity to reach 4900 MW and replacing more of CCGT (–1500 MW). In 2030, the total installed wind, PV, solar tower, solar Fresnel, and solar parabolic trough reach 3100, 4400, 1700, 2300, and 2500 MW, respectively. These systems with the CCGT/MSF (5000 MW) replace more than 5000 MW of CCGT. By 2030 the annual energy system cost reaches almost $14 billion [17]. The CO_2 emissions is expected to decrease from 72 (Reference case) to 55 million tons per year.

V. Conclusion

The objective of this work was to compare the economic performances of conventional (oil and gas fired) electric generation plants and alternative (oil, gas and renewables) electric generation inventory. The ETSAP-TIMES modeling framework was used to perform the economic analysis and a TIMES model of Kuwait's electricity sector was constructed based on data provided by MEW and KPC that characterizes the projected demand for electricity and water and supply of primary fuel to meet the demands. Consequently, the option of including renewables within the generation inventory was addressed with respect to their viability in Kuwait, type of technologies up to 2030, and energy generation capacities.

The viability of including renewables can be deduced when comparing the running costs of the conventional electric generation inventory (Reference case), which is $24 billion annually by 2030, and the generation inventory with renewables. In 2030, the running cost of the renewable cases, Ref-RE and Ref-RE20 are $10 and $14 billion, respectively. The difference ranges between $10 and $14 billion. The reason for such relatively high difference is contributed to the cost of oil and gas fuels. In the renewable cases, oil and gas fuel saving increase the oil export revenues, augment the life of indigenous natural resource, e.g., oil, and lower the impact on the environment.

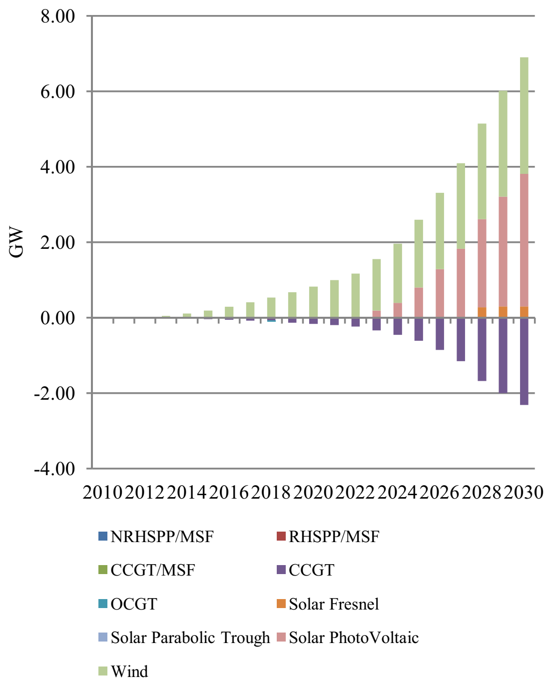

Fig. 7 Development of generation capacity under Ref-RE scenario (difference between Reference and Ref-RE)

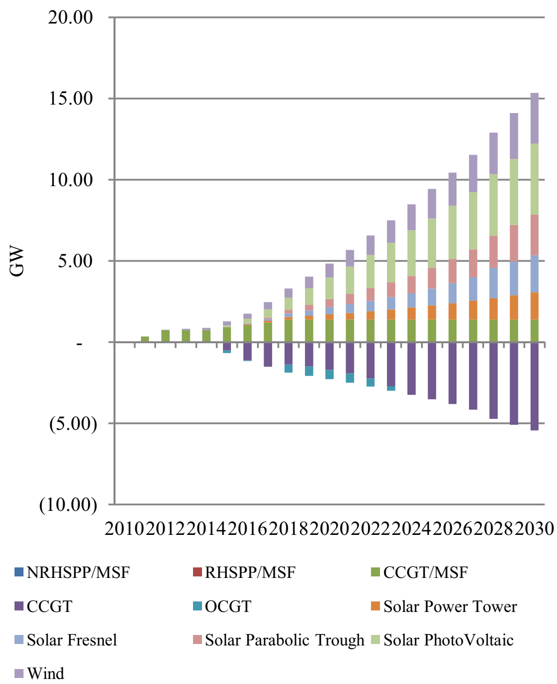

Fig. 8 Development of generation capacity under Ref-RE20 scenario (difference between Reference and Ref-RE20)

Results show that wind, PV, solar thermal tower, trough and Fresnel are the most cost-effective technologies which are to be adopted within the coming 20 years. It is found that the optimum total installed renewable capacity of 6.9 GW, which contributes 11% of the generated electric energy, is the most cost-effective. Such inventory (Ref-RE) mix costs $4 billion less than the an inventory with higher renewable installation, i.e., Ref-RE20.

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