GULF COOPERATION COUNCIL (GCC) COUNTRIES 2040 ENERGY SCENARIO FOR ELECTRICITY GENERATION AND WATER DESALINATION

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Abstract

Judicious modelling of an energy system can help provide insights as to how elements of the energy system might be configured in the longer term. In this analysis, current and future electricity and water desalination systems of each GCC country were represented using a full-cost based optimization tool called MESSAGE. Results shows that fossil fuels will continue to play an important role in a least cost future for the region. This is due, in no small part, to the cheap natural gas resources in the GCC. Despite the high renewable energy technologies potential, their penetration – given the study assumptions - proved to be important, but limited in the GCC. On the other hand, nuclear energy – under the same assumptions – appears to show clear economic potential.

Keywords: Energy Modelling, GCC, Renewable Energy, Nuclear Energy, Sustainability and MESSAGE

1 INTRODUCTION

The Gulf Cooperation Council (GCC) consists of six member states of Saudi Arabia, United Arab Emirates, Oman, Kuwait and Bahrain. It contains 29.4% of the total oil reserves in the world and about 25% of the total natural gas reserves [1]. Covers a total area of 2.4 million km2. Since the declaration of the council, the GCC countries have witnessed significant development the last three decades, this can be clearly seen in the GDP growth from has $ 192 million in 1980 to about $ 1372 millions in 2011. Mega projects, modern infrastructure and economical developments increased the immigration rates to this region causing the population jump rapidly from 21 million in 1990 to reach up to 47 million in 2011 [2].

This increase in the population has obviously been reflected in the increase in primary energy consumption in the GCC countries, which have surpassed the total primary energy consumption of Africa although it has only one-twentieth of the population of that continuant. Figure 1 shows the primary energy consumption in different GCC countries between 1971 and 2011 [3]. Saudi Arabia has the largest share then comes the United Arab Emirates and Kuwait. This is expected taking in consideration the population of each country and its economic capabilities. And this growth is expected to continue to reach up to 59 million people by 2025 and 71 million people by 2050, which is a main driver for electricity and water demand in the region [4].

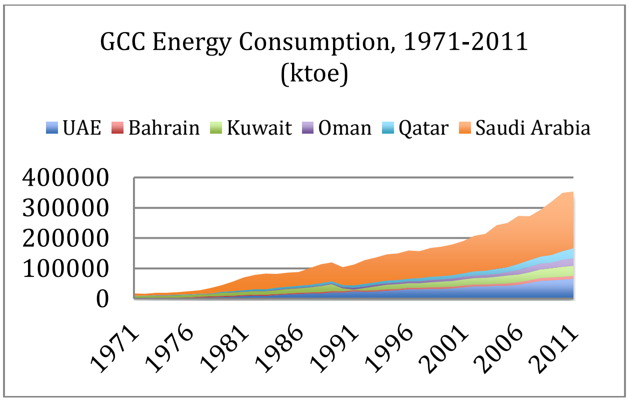
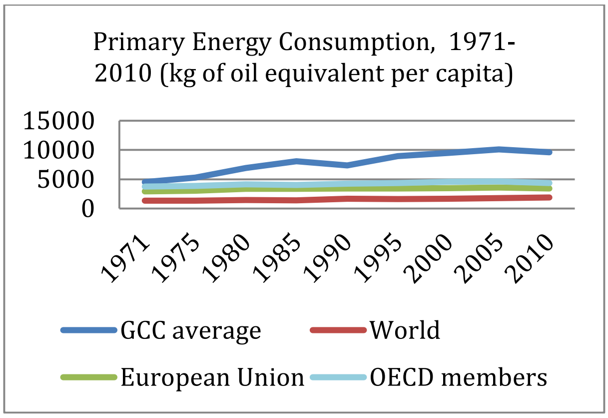


Figure 1: Primary Energy Consumption in the GCC, 1971 – 2011

Accordingly the region's generated electricity has grown from 115 TWh in the year 1990 to almost 436 TWh in the year 2010 [5]. The harsh climate in GCC region causes high cooling demand throughout the year. Moreover, huge energy waste due to the use of low efficiency appliances, high living standards and the energy intensive lifestyle in GCC countries have added more elements that ranked those countries among the highest countries in term of energy consumption per capita according to the world bank as shown in Figure 2 [6].



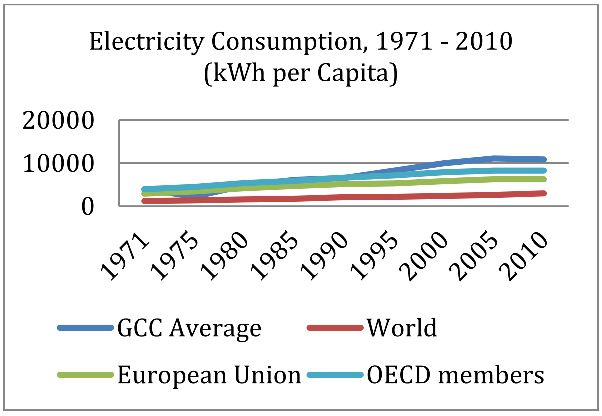


Figure 2: Energy Intensity Trends in the GCC, 1971 – 2010

2 WATER DESALINATION

The GCC countries lie in a geographical location that suffers from short supply of renewable resources of water, notably rainfall and groundwater. The average per capita renewable water supply in the Gulf countries is about 92 cubic meters, with the lowest level found in Kuwait at 7 cubic meters and the highest in Oman at 482 cubic meters, taking in consideration that the globally the per capita renewable water supply threshold is 1000 cubic meters a year [7]. On the other hand, GCC countries consume about 65 % more water than the world average 816 cubic meters pcpa, versus 500 cubic meters pcpa [8]. The gap between the annual consumption and the average renewable resources supply is significant in most GCC countries, only Oman enjoys enough water resources that meets its demand over the year. In such a case, GCC countries rely mainly on desalinating seawater to meet their demand for potable water. This makes water to be more important than hydrocarbons and one ton of water costs more than one ton of oil [9].

Therefore it is the world largest desalinated water-producing region. Figure 3 shows that the GCC produces about 39 % of the global desalination worldwide, with KSA and UAE accounting for 17% and 12% respectively in 2010 [10].

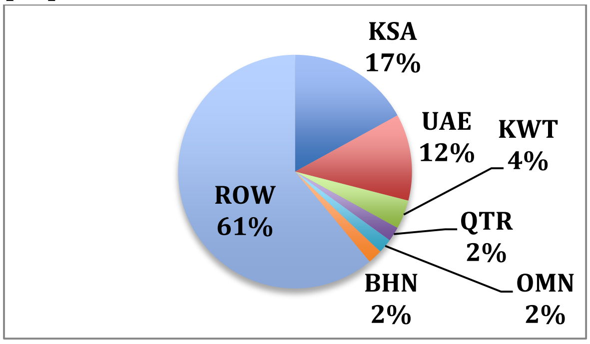


Figure 3: Comparison of desalinated water production in the GCC versus the rest of the world (2010)

In the last four decades the GCC countries have implemented different desalination technologies including: 1) thermal technologies such as Multi Stage Flash (MSF) and Multiple Effect Distillation (MED); and 2) Membrane Technologies such as Sea Water Reverse Osmosis (SWRO), Brackish Water Reverse Osmosis (BWRO) and Electro Dialysis or Electro Dialysis Reverse (ED/EDR). Despite the fact that the Reverse Osmosis (RO) technology is the world leading technology due to it low energy intensity, the thermal desalination (MSF and MED) are still dominating in the GCC and account for 68% of the total desalination units in 2010 leaving the rest 32% for RO See Figure 4 [10]. The main reason behind this is the poor quality of the gulf water, which is known as the "4H": High salinity, High Turbidity, High Temperature and High marine life [11].

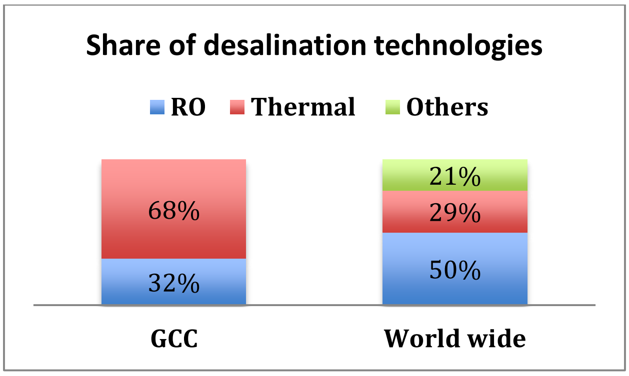


Figure 4 Share of desalination technologies in the GCC and the world.

The GCC is leading the world in desalination capacity, with total 294 operating plants producing over 28 million cubic meters per day of desalinated water distributed as shown in Table

1 [10]. The world largest desalination facility is Al-Jubail-KSA, which produces over one million m3/day of desalinated water. Another similar capacity plant in Ras Al- Kheir is under construction.

Due to the growing population and accordingly water demand, KSA is expected to invest over 100 Billions USD in the next two decades to add another 10 Million m3/day by the year 2025 [11].

Table 1 Summery of the GCC countries desalination capacity in 2010

	Number of Desalination Plants	Capacity (Gl per day)	% Share of the world capacity
KSA	128	12.5	17%
UAE	98	9.5	12%
KWT	24	1.7	4%
QTR	13	1.9	2%
OMN	19	1.6	2%
BHN	12	1.4	2%

3 METHODOLOGY

The aim of this study is to optimize the energy system of the GCC countries for electricity generation and water desalination in a time horizon of 2014 - 2040. The study draws a road map for each country about the necessary investments that should take place.

To achieve this goal, a mathematical model using Model for Energy Supply Strategy Alternatives and their General Environmental Impacts “MESSAGE” software was built. Then various future scenarios were designed to best describe the predicted future and to reflect the desired changes to the energy system.

The MESSAGE model is used to optimize the energy system of a region or a country under certain set of bounds or constraints. These bounds are a representation of the current or future limitations and or restrictions to the energy system of the country. The linear programming of MESSAGE runs simulation to achieve the objective function that contains all the possible solutions of the problem. MESSAGE framework allows flexible and detailed description of energy system of the region, this includes defining the energy forms at each level of the energy chain, then defining the technologies that are producing or consuming the energy forms, reaching up to the available resource at the region of the imported fuels [12].

As mentioned earlier, future scenarios are designed using projections, bound or constrains to best describe the future projections. In MESSAGE the user-defined constraints can be limits on new investments, availability of fuel, limits on the trade, environmental regulations and market penetration rates for new technologies [12].

3.1 Load regions and general parameters:

This project aims to study the future scenarios from 2014 till year 2040, therefore an annual basis model was selected with the base year as 2010, first model year as 2011 and the final year to be 2050. This final year was extended beyond the study time horizon to avoid the edge effect related to the investments made to the new technologies. The investments were allowed in the first half of the first modelled year with the overall discount of 6%.

MESSAGE allows subdividing the year into time slices that has the same electricity requirements or in another word has the same load; these time slices are called “load regions”. In this study the yearly load is divided into 2 winter seasons, one summer and one intermediate season. Moreover, the weekly load is divided into 5 weekdays and 2 weekends.

3.2 Technology Selection

In MESSAGE, technologies represent the transformation of the energy form from one level to another; for example a technology can be a refinery, power plant or a distribution and transformation lines. What this section is focusing on; is the power generation technologies. This is a main criterion in the model setup that will affect the whole energy system performance and therefore it required several trails and enhancements before it was finalized.

The selection of the technologies was based initially on the currently implemented technologies at each GCC country. Due to the very generic information provided by the local authorities about the specific types of power plants and fuel used, PLATTS database was used to integrate it with the local authorities information and give a more segregated classification of technologies based on fuel type.

Since future renewable alternatives are to be studied for each country, a list of potential renewable technologies was selected based on the available potential and the feasibility of the options to be considered. The same list of technologies was used to model all of the six countries.

3.3 Performance and technology cost data

These data were extracted from the International Energy Agency (IEA) [3], the International Renewable Energy Agency reports [13][14][15][16][17], the IEA-Energy Technology Systems Analysis Program, technology briefs [E01, E02, E03 and P06] [18][19][20][21] and IEA-Energy Technology Perspectives (ETP) [22].

The thermal desalination units in the GCC are operating mainly in cogeneration mode with electricity generation, therefore the same characteristics of the single cycle steam turbine (SCST) and the gas turbines (SCGT, CCGT) were assumed [22]. However, for the energy intensity of the thermal desalination units and Reverse Osmosis units the values obtained from literature were back-calculated to be consistent with statistical data [23][24][25][26].

4 SCENARIO DESCRIPTION

The following scenarios were examined:

- **The business as usual scenario (BAU)**: current energy system is extended into the future without any changes. The energy system structure and characteristics are kept the same. The fuel prices are also kept at the current subsidized levels.
- **The netback-pricing scenario (NB)**: all fuel costs are increased to the international market price. The freed amount of fuel is assumed to be available for export to the international market. Moreover, this scenario examines different carbon tax options of 0, 20, 30, 40 and 50 dollars per kilo tons of CO2 emissions.
- **The Nuclear hub scenario (NucHub)**: examines the idea of a "nuclear hub" state for the GCC region that can have all the "know-how" and logistics to provide sufficient nuclear energy for the GCC through the Interconnection Grid "GCCIG".

5 RESULTS

5.1 Business As Usual scenario (Baseline)

The GCC Countries are expected to witness high growth in the coming decades. The total population of the GCC is expected to grow from 44 million in 2010 to about 55 million in the year 2020 and 67.5 million by the year 2040 [27]. Along with the ambitious mega projects in the region like the Expo 2020 in Dubai and world cup 2022 in Qatar, all these energy intensive activities are expected to boost the demand for electricity from 466 TWh in 2011 to 1397 TWh by 2030 and 1979 TWh by 2040, and the total installed capacity to increase from 127 GW in 2011 to 293 GW in 2030 and 417 GW in 2040. Making about fourfold increase over the study period as shown in Figure 5.

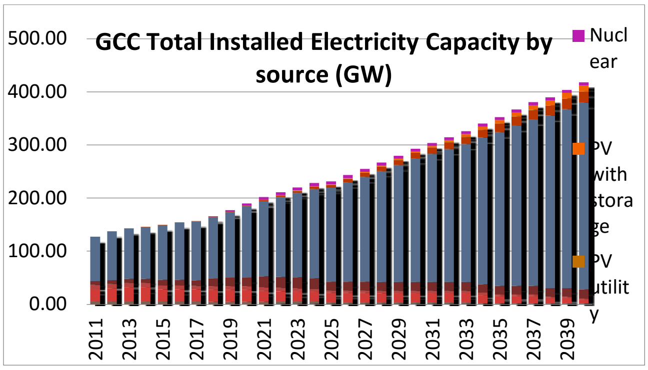


Figure 5: GCC total installed capacity under the BAU scenario 2011-2040.

Due to the available fossil fuels resources in the region and low prices, the total installed capacity of electricity in 2011 is about 127.2 GW of which 65% comes from natural gas, 18% from crude oil and the rest is splatted between light oil, heavy fuel oil and diesel. In terms of energy generation, natural gas accounts for 75% then comes crude oil with 14.4% of the total energy generation mix of the GCC in 2011 and the rest 10% comes from light oil, heavy fuel oil and diesel. In the coming decades Natural gas is going to play vital role in the GCC. Its share of the installed capacity is going to increase to 79.5% in 2030 and about 84% in 2040. Its expected to supply the GCC with about 90% of the total electricity generation and replacing crude oil, which will decrease to only 2% of the total installed capacity by 2040 and less than 1% of the total electricity generation. The rest should be met by solar (PV and CSP) and nuclear power, as shown in Figure 6.

In this scenario the penetration of nuclear and renewable energy like solar PV and CSP is mainly due to planned capacities in the UAE, non of the other GCC members will be utilizing any of the other resources due to the relatively high cost of these technologies in comparison to the low cost fossil fuel based power plants with subsidized prices of fuels. Moreover, the low capacity factor of renewables in comparison to the fossil fuels based technologies, makes it more challenging to shift to renewables under the current scenario conditions. The concentrated solar power (CSP) with storage is the planned technology option to be implemented in this scenario. Its share in the total GCC electricity generation mix will grow from less than 1% in 2020 to about 2.8 % (42.44 TWh) in 2030 and 3.8% (81.91 TWh) in 2040. In this scenario nuclear power capacity in each country is allowed to the maximum capacity of the UAE's nuclear capacity of 5.6 GW, though the model shows that its share will not exceed 42 TWh which is about 2.5% of the total electricity generation mix in GCC in 2030.

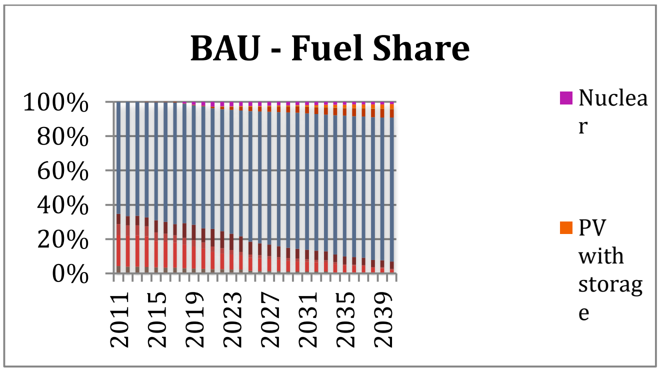


Figure 6: BAU fuels share in the total electricity capacity (%)

In the BAU scenario thermal desalination plants are the dominating technology in the GCC for the coming decades. Thanks to the cheap natural gas supplies, which according to the BAU scenario will fuel up to 80 % of the total desalination plants by 2020, growing to 90 % by 2030 and 99 % by the end of the study period. Natural gas will not only take the place of crude oil and heavy fuel oil in total desalination share but it will also take the share of reverse osmosis plants which will phase out gradually under the conditions of the current scenario.

5.2 Comparison with alternative scenarios

Netback Scenario (NB)

The Netback scenario changes the pricing system in the GCC from the current subsidized prices for fossil fuels to the high level international market prices with carbon taxes of zero, 20, 30, 40, 50 US dollar per kilo ton of CO_2 (As shown in Table 2). Assuming that all the amount of crude, light oil, heavy fuel oil and natural gas that is saved and not being used to generate power is available for export. Which will increase the export revenues and allow GCC governments to spend on new high efficiency, high cost technologies. Moreover, this transition is expected to make renewables and nuclear power more attractive since the fossil fuels used for power and water generation are now put on a competitive level with the exports revenues

Table 2 Assumed local fuel cost and netbacks

	\$/boe	\$/boe
Fuel	Local Costs	Netback
Crude	7.5	109 - 128
Light Oil	6.5	120.63
HFO	3.8	98.83
Diesel	9.3	11.3 - 100
NG	7.5	15 - 37.74
Uranium (\$/KWyr)	10	10

Similar to the business as usual scenario, the model indicates that Qatar, Oman and Bahrain will rely totally on natural gas to meet their electricity demand. In the case of Kuwait the shift toward natural gas is faster than the previous scenario. It's noticed that under the conditions of the netback scenario, Kuwait will rely 100% on natural gas to meet its electricity demand throughout the study period. Similar trend can be noticed in Saudi Arabia where natural gas share in the total energy generation will increase from 73% in 2011 to 96% in 2020 and 98% in 2030. The rest come from light oil, heavy oil and diesel collectively. Natural gas is also a major player in the energy generation mix of the UAE, however, it share decrease from 99% in 2011 to 84% in 2020 and 74% in 2030. This decrease is due to the penetration of planned solar (PV and CSP), nuclear power and clean coal power plants.

The Arabian Peninsula is located in a region that has rich solar resources with daily average solar radiation exceeding 6 kWh/m2 and 80-90% clear sky days throughout the year [28]. Which makes the expectation for the penetration of renewables, especially solar, very high. However, results prove that renewables or solar technologies are still more expensive than the conventional fossil fuel based technologies in the region, even if the fossil fuels prices has been increased to the international standards. The planned capacities of solar PV and CSP in the UAE are the only renewable options that shown in the results, other countries will shift to the cheap natural gas option rather than renewables or nuclear. One of the main reasons for such trend is the low capacity factor for solar technologies. Even if the area receives high solar radiation throughout the year, high humidity and high concentration of airborne dust particles tend to diffuse and attenuate the intensity of solar irradiance. Experiments shows that 20-30% of the energy output is reduced due to the high level of dust in the region [29].

To enhance solar energy's competitiveness in the GCC energy system, new scenarios with more favourable conditions were considered. Carbon tax was introduced of zero, 20, 30, 40 and 50 dollars per kilo tons of CO2. This was added as constant value starting from year 2020 to 2040. Obviously all CO2 tax scenarios were tried with the netback-pricing scheme. It is worth mentioning that in those scenarios the model was set free to increase the capacity of nuclear in order to meet the demand, unlike the BAU scenario where the maximum capacity of 5.6 GW was set to each country.

Figure 7 indicated that as the carbon tax increase; the system would prefer nuclear energy to renewables and fossil fuel based technologies. By the year 2040 the share of nuclear power in the total electricity generation mix will reach to 29.25 % with US 50 dollars carbon tax in compare to 23.3 % and 13.5 % with 40 and 30 US dollars carbon tax respectively. The high capacity factor of nuclear power plants makes this option more economically viable to replace fossil fuel based technologies in the GCC region in the long run.

Under US 50 dollars carbon tax, it is noticed that Oman would take the lead to shift from fossil fuels to nuclear. With the first reactor of 1000 MW coming online in 2024 and constantly growing this capacity to reach 14000 MW by 2040. This should accordingly increase the share of nuclear energy in the total Omani electricity generation mix from 13% (7.5 TWh) in 2024 to about 86% (105 TWh) in 2040. The second country of highest nuclear power share is Bahrain, which will start the first nuclear power plant in 2029 with 890 MWh or 2% of the total electricity generation and will grow to reach about 47.6 TWh in 2040 or 72% of the total electricity generation. The same trend can be noticed in the other countries as well under the conditions of this scenario and the total GCC electricity generation from nuclear power will reach 638.5 TWh in 2040 which about one third of the total electricity demand.

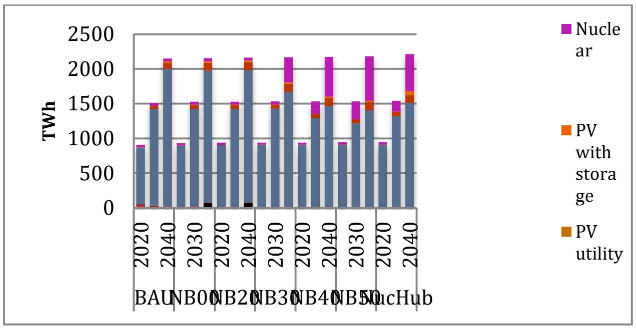


Figure 7: Electricity generation between 2020 and 2040 under the seven scenarios

Nuclear Hub Scenario

The nuclear hub scenario takes the UAE as the GCC hub for nuclear power and uses the GCC interconnection grid to transmit electricity to other countries. This scenario should takes the advantage of having all the required human resources, technical "know how" and other logistics in one central location which should reduce the complexity of introducing nuclear energy to the region.

This scenario is set to the netback prices and zero CO_2 tax level for all fossil fuels used in electricity generation; also the nuclear capacity in the hub (UAE) was freed to allow for the installation of as much capacity as required to meet the demand of the region.

The first nuclear reactor should come online late 2017 with 1400 MW capacity and will gradually increase to reach 20 GW in 2030 and about 70 GW by 2040. In terms of electricity generation share in UAE, nuclear energy will grow from 13% (31.45 TWh) in 2020 to reach 34.7% (154.4 TWh) in 2030 and 71% (528 TWh) in 2040. On regional scale these values represents 3%, 10% and 24% of the total GCC electricity generation mix in the years 2020, 2030 and 2040 respectively. Natural gas will still be the main contributor to the total electricity generation in the region even under the conditions of this scenario. Its share will drop from 95% in 2020 to

85% in 2030 and 67.7% in 2040. Bearing in mind that this scenario uses netback pricing, the contribution of solar power to the total electricity generation mix is slightly higher in this scenario in comparison to the BAU scenario and almost the same as the netback scenarios.

With regards to desalination under the different alternative scenarios, GCC countries will show significant shift into the fossil fuel based Cogeneration water instead of the stand-alone thermal desalination. The new desalination plants are mainly driven by natural gas, which should fuel up to 90 – 100% of the thermal desalination plants under different scenarios. It's also noticed in this analysis that as the system moves toward more nuclear and renewables sources in electricity generation cycle, desalination cycle prefers more membrane RO technology as shown in Figure 8. Under Nuclear hub scenario, the share of RO in the total water desalination will reach 38% (8660 Gl), which is the highest share among all scenarios. The BAU and netback NB00 shows decrease in the share of RO between 2020 and 2040, which can be related to the increase installation of gas fired plants for electricity generation that will operate in Cogeneration mode to supply water demand as well. This trend is changed as carbon tax scheme increased in the NB20, NB30, NB40 and NB50 scenarios, which will reduce the installation of gas power plants and substitute it with RO membrane desalination units. The average share of the RO in the total desalination reaches about 9-10% under these scenarios.

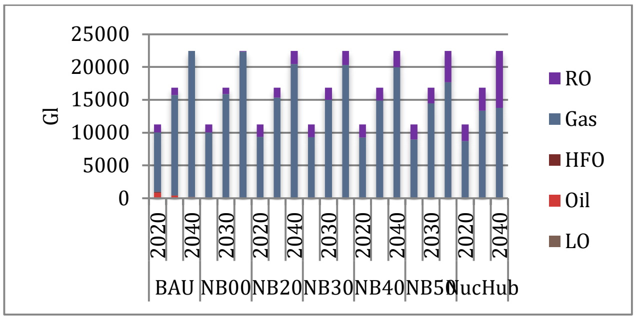


Figure 8: Water production between 2020 and 2040 under the seven scenarios

As shown in Table 3, comparing the total system cost of different alternative scenarios (NB00, NB20, NB30, NB40, NB50 and NucHub) the difference between these scenarios is low. The highest system cost (undiscounted) is in the NB50 scenario, which is 11% higher than the NB00. While the nuclear hub scenario is about 9% higher than NB00 total system cost. This indicates that all the alternative scenarios are almost within the same cost level in the time frame of the study period.

On the other hand if the alternative scenarios are compared to the reference BAU scenario, it's noticed that the differences are significant. The total system cost of NB00 scenario is 70% higher than the BAU, which considered the least difference. While the NB50 total system cost is 88% higher than the BAU. The nuclear hub scenario is 85.7% higher than the BAU scenario. These values indicates that the new technologies are expensive in the GCC region if compared to the current low cost fossil fuel based technologies for electricity generation and water desalination. Taking into consideration that carbon taxes have been introduced are as high as \$50 per kilo ton of CO_2, which is obviously very high values since currently there is no carbon tax scheme in any of the GCC countries, even though the new alternatives are not economically viable.

Table 3 Cumulative system costs during 2011 – 2040 in Billion USD under the seven scenarios

Scenario		Inv. (Gen)[1]	Fuel costs	O&M costs	Fuel Export Revenue	Total System Costs
BAU	Un-disc[2]	536	311	183	0	1029
	Disc[3]	87	75	44	0	206
NB 00	Un-disc	578	1206	201	-232	1754
	disc	186	237	52	-79	396
NB 20	Un-disc	587	1195	201	-227	1757
	disc	189	235	52	-77	399
NB 30	Un-disc	625	1155	214	-144	1849
	disc	196	232	53	-58	424
NB 40	Un-disc	698	1074	244	-127	1890
	disc	216	224	56	-44	452
NB 50	Un-disc	742	1037	262	-105	1936
	disc	228	218	59	-33	473
Nuc Hub	Un-disc	691	1084	240	-104	1912
	disc	214	225	56	-39	455

1.Investment Cost (Generation)
2.Un-Discounted.
3.Discounted.

Looking into another criteria to evaluate the proposed scenarios, the system cost per unit of energy consumed (See Figure 9) gives a clear indication that the BAU scenario is the least cost pathway in the long run. The GCC system cost of generating electricity in this scenario averages at about 33.3 USD/MWh by 2040 in comparison to 66 USD/MWh in the NB00 scenario and 67 USD/MWh in the nuclear hub scenario for the same year. It is noticed that all the alternative scenarios will lead to almost the same system cost per unit of energy of about 66 USD/MWh, which is almost double the cost in the BAU scenario.

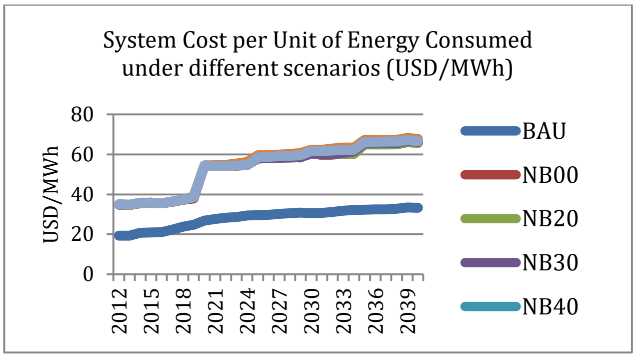


Figure 9: Total system cost per unit of energy consumption under the seven scenarios.

6 CONCLUSIONS

Much scope exists to explore the role of renewables and nuclear in the GCC's future energy mix. Significantly increasing demand for electricity and water desalination in the region makes exploring new economical alternatives solutions of importance to decision makers.
Considering the limitations and the boundaries in this study, the scenarios analysed indicate that the GCC shift into renewables will still be expensive and challenging in comparison to the fossil fuel based technologies. The current costs and learning rate of renewable technologies like solar PV, solar thermal and wind technology is not enough to compete with the low price and high intensity fossil fuel energy sources. This can be more challenging with the current sharp drop of the oil market price, which declined below $ 50 per barrel, or almost half the international price assumed when this study was done.
However, nuclear power has shown that it can be an integral part of the GCC future energy mix for electricity generation and water desalination. The low fuel cost and the high capacity factor of nuclear energy lends it to be an alternative source for electricity generation and water desalination in the longer term. The first key element in the competitiveness of non-fossil fuel deployment, is to shift from the current pricing scheme to netback pricing for all types of fossil fuels used in electricity generation and water desalination in the region. Another key element would be the ability to export all the saved amount of fossil fuels at the netback prices – offsetting the revenue lost by consumers who will experience a higher electricity cost. UAE initiatives in this field will likely see nuclear energy enter the region by 2017. The growth of this technology, and other non-fossils - will depend on the technical, economic, social and political circumstances of the GCC and its development.

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