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Present and Future Trend in the Production and Energy Consumption of Desalinated Water in GCC Countries

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Abstract

Water is one of the pressing global challenges facing humanity. In the Gulf Cooperation Council (GCC) countries, it is considered as the most critical challenges and is expected to grow with time. GCC countries have chosen desalination as the strategic water resource option and is, therefore, the world largest desalinated water producing regions. The objective of this study is to explore the current desalination technologies and their respective energy demands in GCC countries with different alternatives to reduce energy consumption. The paper presents and analyzes the present and the future prospective of water production rates and trends as well as the corresponding energy consumptions. The recent and historical desalination operational data have been studied and analysed and the results were presented using forecasted published data, up to the year 2025. Areas of possible efficiency improvements and reduction in the specific power consumption of the main commercially used desalination technologies; thermal (Multi Stage Flash (MSF) and Multiple Effect Distillation (MED)) and membrane (Reverse Osmosis (RO)) including the rehabilitation of present operating plants are presented. In addition, alternative energy sources such as renewable and nuclear as well as new desalination technologies of potential commercialization are also highlighted.

Keywords: *Water desalination, energy, future trends, GCC counties*

1. Introduction

Energy and water are the most pressing global challenges facing humanity. In the Middle East region, especially in Gulf Cooperation Council (GCC) countries, water is scares and desalination is the main sources of fresh water production [1]. Desalination is energy intensive process and many oil producing countries are diverting their natural energy resources (oil and gas) to the local production of electricity, water desalination, and transportation instead of exporting these resources to increase national income.

Faced with these challenges, many countries are reverting to more energy efficiency practices and to alternative energy sources such as renewable and nuclear energy to meet the future energy and water demand. GCC countries (KSA, UAE, Kuwait, Qatar, Oman and Bahrain), as shown in Figure 1, represent a main desalination water producing world region. Figure 2 shows the GCC countries produces about 39 % of the world production, with KSA and UAE as leading countries [2].

Different desalination technologies have been commercially used 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). Although RO currently represents the leading world market technology, mainly due to its lower specific energy consumption [3], however, thermal desalination (MSF and MED) still represents the main technology in the GCC countries, see Figure 3. This is mainly due to the Gulf water poor quality known as 4 H: High salinity, High Turbidity, High temperature and High marine life. In addition, the growing presence of radioactive materials (due to present war ships and planned nuclear power plants) should be taken with serious consideration for health reasons (unsteady flow of ideas, please re-edit). Moreover, the increase of the boron limitation in drinking-water is still debatable from health point of view. The previous value set limit of boron was 0.6 ppm by United Stated Environmental Protection Agency (USEPA) and 0.5 ppm by World Health Organization (WHO) [4], was increased to 2.4 mg/L, Which is questionable and still under investigation from health point of view. The WHO report was claimed to be pushed or supported by RO industry [5]. This will maintain thermal desalination technology as the leading technology in the GCC countries.

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Figure 1. Existing and future desalination plants in the GCC countries

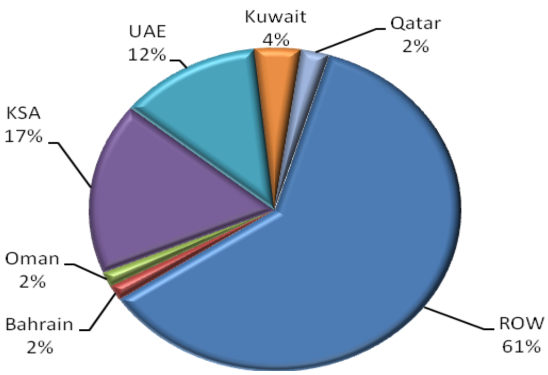

Figure 2. Desalinated water productivity of GCC countries versus rest of the world (2010) [2]

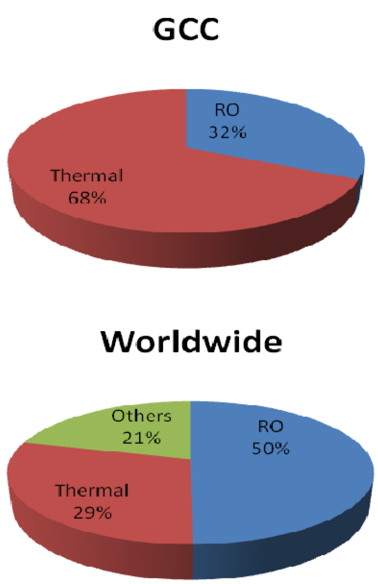

Figure 3. The percentage of thermal and RO desalination technologies application in the GCC countries and the world (2011) [2]

The objective of this study is to explore the current commercial desalination technologies and their respective energy demands in GCC countries and the different alternatives to reduce energy use in desalination.

2. Water Production

Figure 4 shows that KSA, UAE, Kuwait, Qatar, Oman and Bahrain have over 128, 98, 24, 13, 19, and 12 operating plants respectively. The corresponding daily desalinated water production is around 12.5, 9.5, 1.7, 1.9, 1.6, and 1.4 million cubic meters at the end of 2011, respectively.

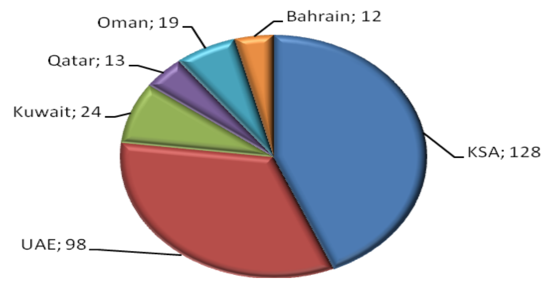

Figure 4. GCC operating desalination plants in 2011, [2]

Figure 5 shows the development of both thermal (MSF and MED) and membrane (RO) as the major technologies used in GCC countries. The Figure shows that thermal technologies are the leading conventional technology in UAE, Kuwait and Qatar. However, in the last few years, RO shows a significant increase in KSA and Oman (as the Red sea and Indian ocean water are more suitable feed water to RO than the Gulf sea water due to the lower and the clear water (compared to the Gulf water). Thermal and membrane are almost shared in Bahrain. The forecasted values in 2016, as depicted in Figure 5 for example, shows 62.6 % of the desalination productions is for RO in KSA and 74.7 % for Oman, while it is still 30.4 % for UAE, 32.3 % for Kuwait, 15.6 % for Qatar, 30.4 % for UAE, and 42 % for Bahrain.

As a leading country in desalination, 42 % of the desalinated water in KSA are produced by 10 companies of the private sector including Marafiq, *ACWA* Power and *ARAMCO* [5] and the rest is produced by Saline Water Conversion Corporation – *SWCC* – KSA' main water governmental utility. The average water production cost is around 3.01 SR/m^3 (0.8 USD/m^3), [6]. With a growing population, KSA is expected to add another 10 Million m^3/day by the year 2025 [2]. Over 100 Billions USD are expected to be the investment of KSA in the next twenty years for both power and desalination plants [5]. KSA has also the largest capacity desalination plants in the world in its facility at Al-Jubail, which produces over one million m^3/day of desalinated water. Another similar capacity plant in Ras Al-Kheir is under construction. The countries are also trying to manage their water consumption to stop the depletion of its brackish water aquifers

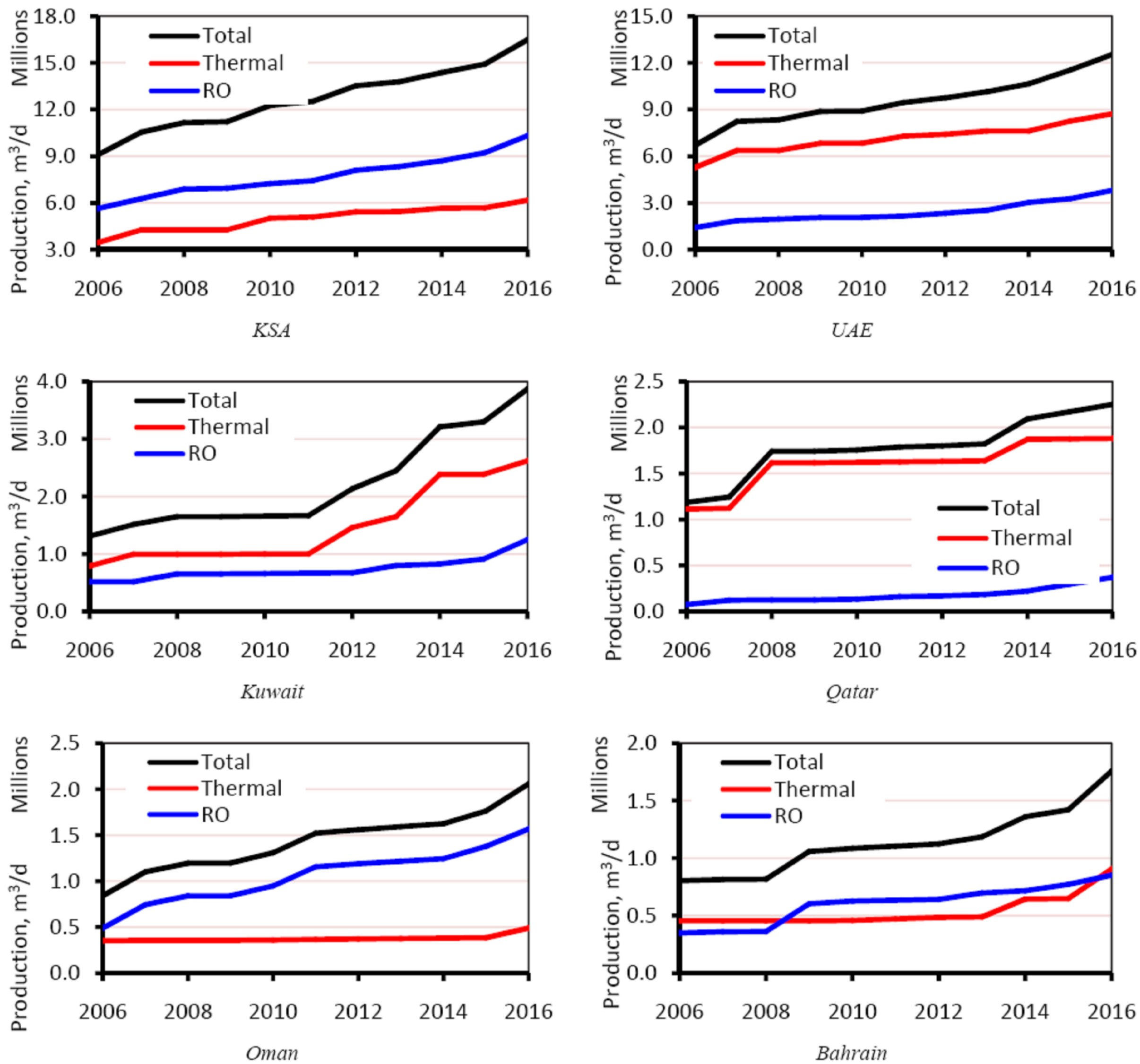

Figure 5. Development of both RO and thermal desalination plants in GCC Countries

The production rates of different desalination technologies up to the year 2016 are shown in Figure 6. These data show very scattered yearly incremental production between 2006 and 2016[2], as large scale plants are built in a batch way, which could not fit any potential forecasting or trend line. Due to this scattered incremental yearly production, the selected assumption is to take the average yearly desalination production and project this same average as a yearly desalination production for years 2017 to 2025. This means that a linear yearly increase is assumed for the cumulative production. The average of yearly production from 2006 to the forecasted 2016 (which is equal to 721,108, 546,230, 232,978, 109,731, 116,734, and 111,583 m^3/d in KSA, UAE, Kuwait, Qatar, Oman and Bahrain, respectively) are used for the average incremental yearly desalination production from years 2017 to 2025.

Figure 7 shows the cumulative capacity increases, with linear increase for desalinated water production trends, from 2017 to 2025. For KSA the cumulative water production from 9.1 Mm^3/day (in 2006) to 23.0 Mm^3/day (in 2025) with percentage increases of 253 %. For UAE, it is increased from 6.7 Mm^3/day (in 2006) to 17.4 Mm^3/day (in 2025) with percentage increases of 260 %. For Kuwait, it is increased from 1.3 Mm^3/day (in 2006) to 6.0 Mm^3/day (in 2025) with percentage increases of 456 %. For Qatar it is increased from 1.3 Mm^3/day (in 2006) to 3.4 Mm^3/day (in 2025) with percentage increases of 254 %. For Oman it is increased from 0.9 Mm^3/day (in 2006) to 3.2 Mm^3/day (in 2025) with percentage increases of 349 % and for Bahrain it is increased from 1.1 Mm^3/day (in 2006) to 3.0 Mm^3/day (in 2025) with percentage increases of 282 %. This large increase in desalinated water production will be associated with a similar large increase in energy requirement. These present and extrapolated water production data are then used to calculate the energy consumption till the year 2025

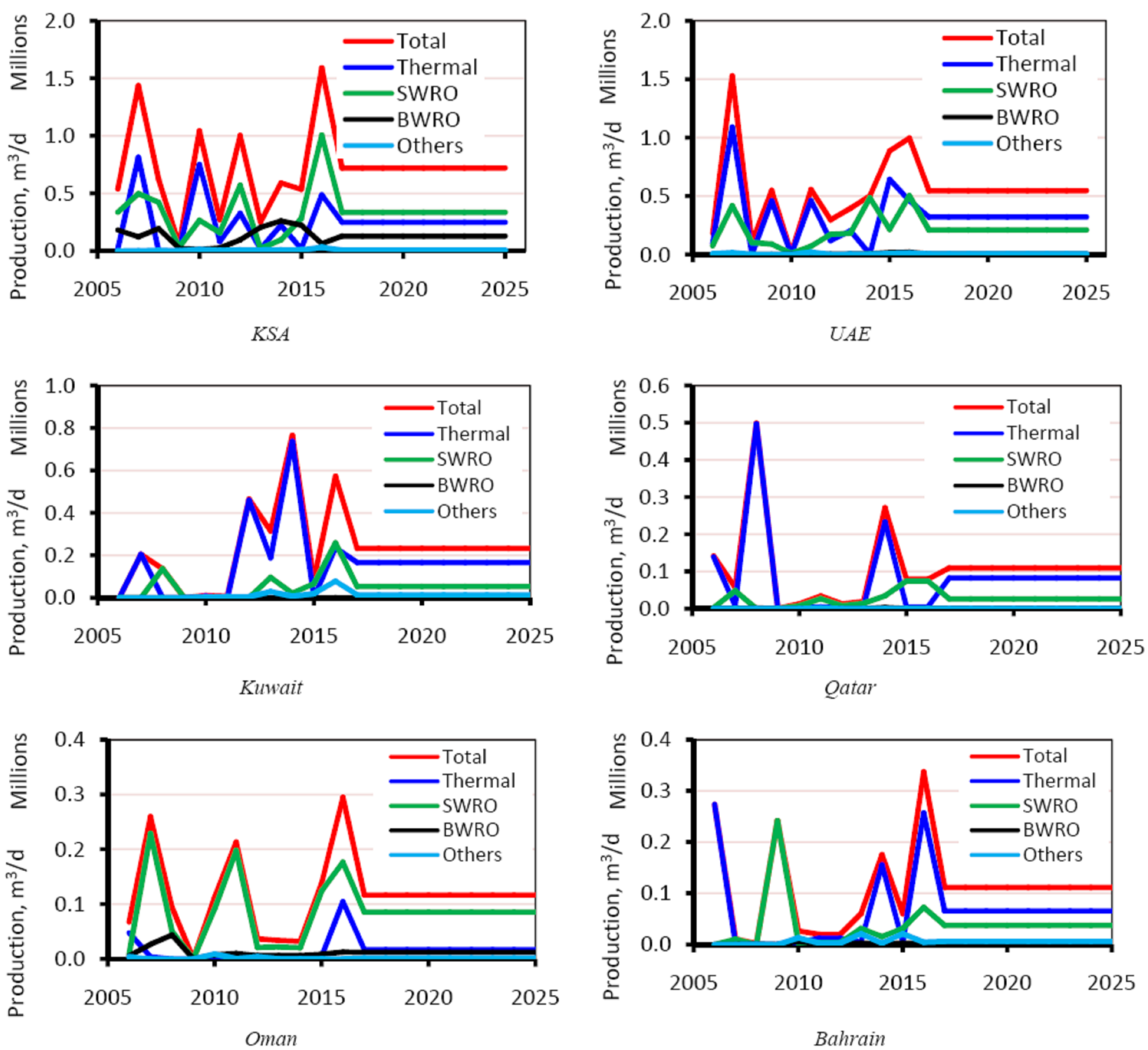

Figure 6. Incremental changes of desalinated water production per technology

3. Energy Consumption by Desalination

Both thermal and electrical energy are required to drive thermal desalination plants. Electrical energy (pumps, etc) and usually measured in the form of "Specific Electrical Energy Consumption - SEEC", which is the amount of electrical energy per m3 of product water. Thermal (steam) energy and usually measured in the form of "Gain Output Ratio –GOR- which is equal to mass of water production per mass of heating steam used. In general, almost all thermal desalination plant are linked to electrical power plant (in co-generation configuration) to get the steam required from the power plant. Low pressure steam is transferred from the power plant steam turbine (either back pressure or extracted steam). In membrane technology, however, there is no heat required and only electrical energy is needed. Therefore RO plants can be built at any site and get electricity directly from the electrical grid. In some cases, both thermal (MSF & MED) and membrane (RO) plants are built side by side (Hybrid plant) to share a common inflow feed water and outfall brine channels, and to blend the production of both plants to reduce the salts and boron contents of the RO product water.

To calculate the total energy consumption of the produced (and forecasted) desalinated water, for different technologies, different rule of thumb assumptions are made from operational plant data [3]. Table 1 summarizes the values of the desalination plant performance parameter used for energy (power) calculation, and their justification. Thermal energy is calculated from the efficiency term GOR and Water production.

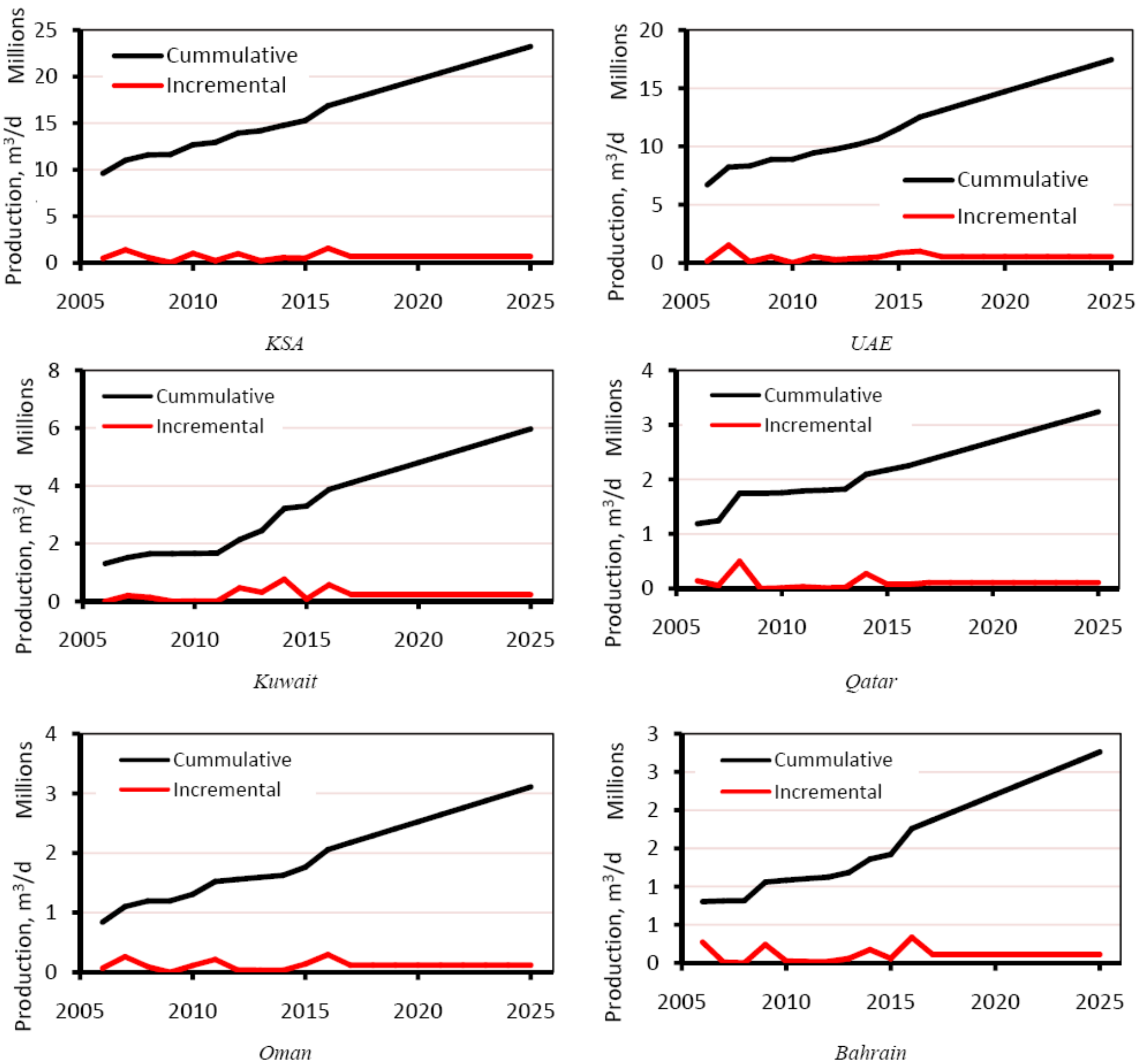

Figure 7. Yearly Incremental and Cumulative Water production

The Cumulative Energy Consumption (CEC) up to 2025 is shown in Figure 8 as the base line scenario versus the conservative and high possible scenarios. In KSA, the results show that the CEC up to 2006 was 48,391 GWhr will almost triple by the year 2025 to be 119,111 GWhr. Similarly, in UAE, the results show that the CEC up to 2006 was 64,761 GWhr and will almost triple by the year 2025 to be 145,412 GWhr, respectively. It should be noted that although in 2025, the desalination water production in UAE is less than in KSA, the CEC in UAE is higher than in KSA because thermal processes (of higher specific power consumption) are a dominated processes in UAE, while, KSA depends on larger percentage of RO processes, Figure 5, of lower specific power consumption. In Kuwait, the results show that the CEC up to 2006 was 10,143 GWhr will increase almost five times by the year 2025 to be 50,604 GWhr. In Qatar, the CEC up to 2006 was 14,516 GWhr will increase almost 2.24 times by the year 2025 to be 31,625 GWhr. In Oman, the CEC up to 2006 was 5,471 GWhr will increase almost 2.22 times by the year 2025 to be 12,150 GWhr, while in Bahrain, the CEC up to 2006 was 8,772 GWhr will increase almost 2.53 times by the year 2025 to be 22,225 GWhr.

Table 1. Assumed performance parameters, [3]

Item	Value	Justification
Thermal Plants (MSF & MED)		
GOR	8	• Large cumulative water was produced by relatively old plants with GOR = < 8 • New plants with lower cumulative and GOR = 8-10
SEEC, kWh/m^3	3.5	• MSF Specific power consumption is 4-5 (say 4.5 kWh/m^3) • MED Specific power consumption is 2-3 (say 2.5) kWh/m^3
Electrical power plant Efficiency, %	35	• Conventional thermal power plant efficiency = 35 % (higher efficiency of small number of combined cycle power plants balance the lower efficiency of older steam power plants)
Membrane (RO) Technologies		
SWRO, SEEC, kWh/m^3	5	• 5 and 2.5 kWh/m^3 are typical specific electrical power consumption of SWRO and BWRO plants respectively • Other technologies (indicated in [1]) are assumed to be SWRO.
BWRO, SEEC, kWh/ m^3	2.5	
Others, SEEC, kWh/m^3	5	
EDR		
SEEC, kWh/m^3	5	• ED/EDR is very limited process and is only limited to very Brackish Water. In fact it is rarely uses

Table 2. Potential Energy Efficiency Improvements in Desalination Technologies

Technology	Parameter	Baseline Scenario	Conservative Scenario			Highest Possible Scenario		
			Current 2012	2013-2020	2021-2025	Current 2012	2013-2020	2021-2025
MSF	*GOR*	8	8	9.5	11	10	13	18
	SEEC	4.50	4.50	4	3.5	4.00	3.50	3
MED	*GOR*	8	8	11	13	10	15	20
	SEEC	3	3	2.0	1.5	2.50	2.00	1.50
MSF/MED	*PPE*	35	35	40	50	35	45	55
SWRO	*SEEC*	5	5	4	3	4	3.5	2.50
BWRO	*SEEC*	2.50	2.50	2.0	1.5	2.0	1.5	1.25
Others	*SEEC*	5	5	4	3	4	3.5	2.50

- *SEEC ≡ Specific Electrical Energy Consumption (kWh/m^3).*
- *PPE ≡ Power Plant Efficiency (%).*

Table 3. Key data summary of RE-desalination technologies, [18]

Renewable Water Desalination								
Technology Variants	Solar Stills	Solar MED	Solar Membrane Distillation	Solar CSP/MED	PV/RO	PV/ED	Wind/RO	Wind/MVC
Development Status	Applic.	Applic./ R&D	R&D	R&D	Applic./ R&D	R&D	Applic./ R&D	Basic R&D
Energy Input (Kwhe/m^3+kjt/kg)	Solar passive	1.5 + 100	0 +<200	1.5-2.0 +60-70	0.5–1.5 BW 4.0-5.0 SW +0	3.0–4.0 BW +0	0.5–1.5 BW 4.0-5.0 SW +0	11–14 SW +0
Typical current capacity (m^3/day)	0,1	1-100	0.1-10	>5,000	<100	<100	50-2000	<100
Market share of renewable desalination	<1% of the global desalination capacity (62% based on RO, 43% powered by PV)							
Production cost, USD/m^3	1.3-6.5	2.6-6.5	10.4-19.5	2.3-2.9	6.5–9.1 BW 11.7–15.6 SW	10.4–11.7	3.9–6.5 BW 6.5–9.1SW	5.2–7.8

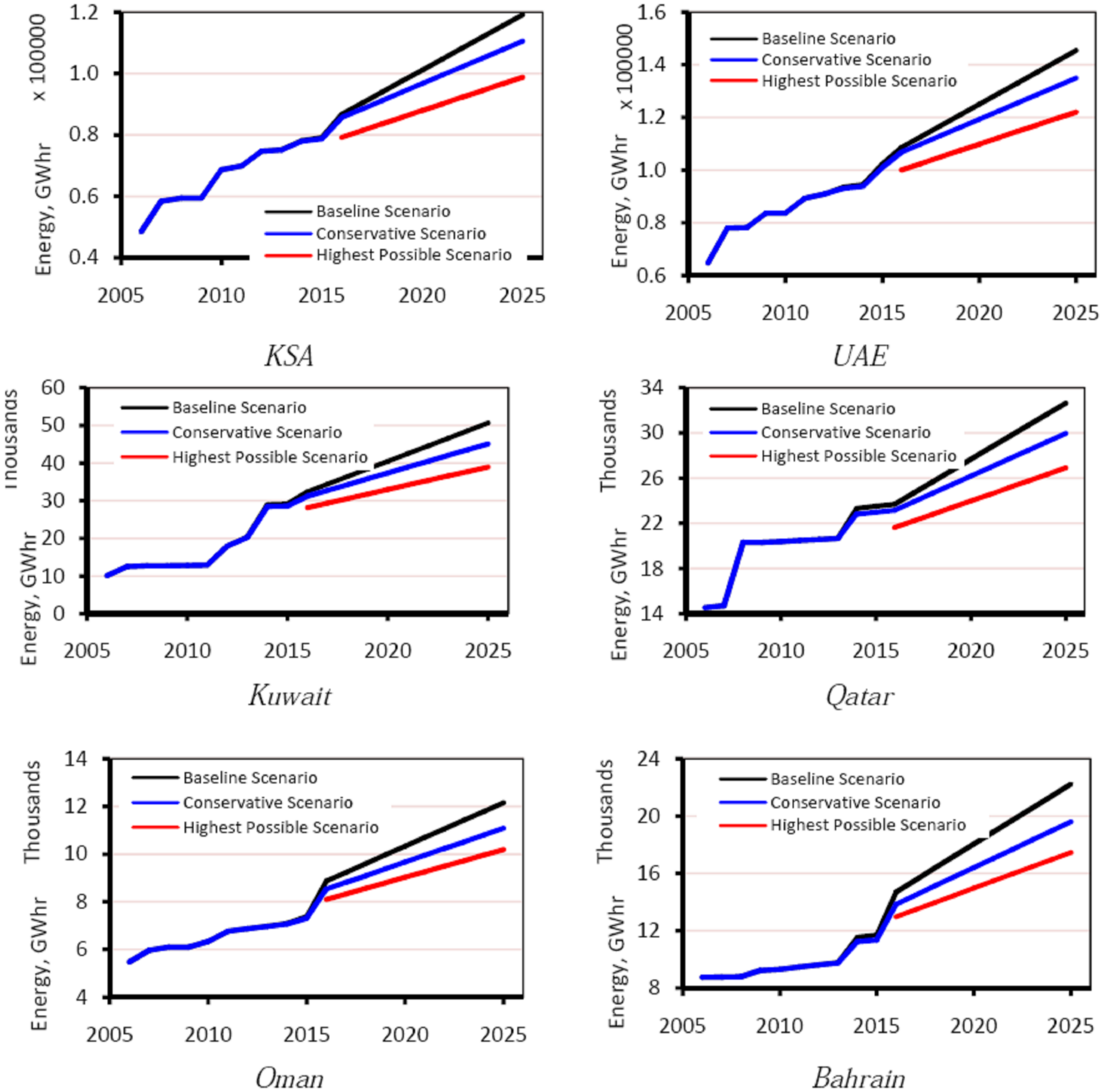

Fig. 8. CEC Base line vs. improved scenarios

4. Areas of Reducing Energy Consumptions

Figure 9 presents the specific water cost of MSF technology as function of fuel (energy) cost [7] where the authors indicated that the MSF specific water cost estimates made by other published studies significantly vary due to inconsistent methodologies in cost calculation and market variation in fuel and material costs. For subsidized fuel cost of 20 \$/Barrel, the water cost is 1.0 \$/m^3, however, for IWPP project with international fuel cost of 100 \$/Barrel, the water cost may reach 4 \$/m^3 [18]. Also, for natural gas energy, especially in co-generation, the approximate cost is around \$6 per MMBtu (about \$36 per barrel of oil on an energy equivalent basis), the water cost is 1.5-2.0 \$/m3. It should be noted that these results are only given for a typical 16.2 MIGD MSF plant located at the Red sea. For other technologies as MED and RO, the specific water cost will be different. Reduction of desalinated water specific energy consumption, kWh/m^3 is, therefore, needed for reducing the water cost (as energy is becoming a main contributor to water production cost) and reducing the CO_2 emission and footprint.

The possible areas of reducing specific energy consumptions for different thermal and membrane technologies can be addressed as follows:-

4.1. Thermal Technologies

Although many authors indicated that MSF is a mature technology as it is the main leading technology in GCC countries for over fifty years, however, margin is still available for future technical and economical improvement. The direction is to increase processes efficiency (GOR) from conventional 8-9 to 12-13 and even 15-20 [8, 9]. Novel ideas and patents [10, 11], are under testing by different desalination institutes, companies and utilities. For example, the increase in Top Brine Temperature (TBT) using Nano Filtration (NF) [12, 13] and other pre-treatment technologies (as high TBT anti scalant) [14] is a well known method of improving GOR and reducing energy consumption. Similarly, increase the number of stages and the partial recycle (using TVC/MVC) of the low pressure vapor can also add to the improvements of MSF performance and reduction of driving thermal and electrical energies. On the other hand, MED, at present, uses low TBT of <= 66 ^{o}C to prevent tubes scaling. However, with the use of NF as pre-treatment (or high TBT anti scalant), TBT could be as much as 130 ^{o}C [12, 13]. The cost of introducing NF on the overall CAPEX & OPEX was presented by [15] and shows the techno-economic - favours NF-MSF. However, the experience of UAE (Sharjah) NF-MSF plant was stopped due to some operational problem. On the other hand, the introduction of large (Giant) capacity units allows the reduction in the specific thermal and electrical power consumption of both MSF and MED. Large MSF units of 22 MIGD (At Ras Al-Khair – KSA) and MED of 15 MIGD (at Yanbu – KSA) are now under construction and plans for larger units (30 MIGD MSF and 20 MIGD MED) are in pipeline.

4.1.2 Membrane Technologies

RO has a dominating presence in the brackish water desalination and increase towards the use of RO for seawater desalination. The trend of growth in RO will continue to be strengthened by the growth in water demand and the development of low pressure membranes (including enhanced membranes with Carbon Nano Tubes - CNT), [16]. Integration of NF for pre-treatment, partial preheating of feed water, improves pressure recovery efficiency, use of DAF and development of larger size membranes improves the RO recovery, performance and specific energy consumption. With the present SEEC of 5.0 kWh/m^3, the short term target is to reduce it to 3.5 kWh/m^3 and the longer term to 2.5 kWh/m^3.

4.1.3. Energy Saving With Improved Efficiency

Based on the energy efficiency improvement discussed above, Table 2 summarizes the possible improvements in the energy efficiency values in different technologies. The assumption that the energy efficiency for all the desalination technologies will remain the same until the year 2025, business as usual is considered to be the baseline scenario. In addition, the table and figure show two additional energy savings scenarios; 1- conservative scenario potential of improvements in energy efficiency for the desalination technologies from 2013 to 2025 and 2- the highest (maximum) possible improvements scenario, including overhaul and replacement of major equipment due to wear and tear.

Figure 9 shows the energy requirements in the baseline scenario and the two new improved efficiency scenarios. In KSA, with the conservative scenario (1), the CEC could be reduced from 119,111 GWhr to 110,535 GWhr (7.2 %). With the maximum possible efficient improvement scenario (2), the CEC could be reduced from 119,661 GWhr to 98,809 GWhr (17.4 %). Similarly, in UAE, with the conservative scenario (1), the *SEEC*?? could be reduced from 145,412 GWhr to 134,918 GWhr (7.2 %). With the maximum possible efficient improvement scenario (2), the energy consumption could be reduced from 145,412 GWhr to 122,028 GWhr (16.1 %). In Kuwait, with the conservative scenario, the CEC could be reduced from 50,604 GWhr to 45,082 GWhr (10.9 %) in 2025. With the maximum possible efficient improvement scenario (2), the CEC could be reduced from 50,604 GWhr to 38,966 GWhr (23.0 %). In Qatar, with the conservative scenario, the CEC could be reduced from 32,625 GWhr to 29,952 GWhr (8.2 %). With the maximum possible efficient improvement scenario, the energy consumption could be reduced from 32,625 GWhr to 26,897 GWhr (17.6 %). In Oman, with the conservative scenario, the CEC could be reduced from 12,150 GWhr to 11,077 GWhr (8.8 %). With the maximum possible efficient improvement scenario, the energy consumption could be reduced from 12,150 GWhr to 10,185 GWhr (16.2 %). Finally in Bahrain, with the conservative scenario, the CEC could be reduced from 22,225 GWhr to 19,600 GWhr (11.8 %). With the maximum possible efficient improvement scenario, the energy consumption could be reduced from 22,225 GWhr to 17,466 GWhr (21.4 %).

5. The potential use of New Desalination Technologies and Renewable Energies

Different new technologies are now emerging under pilot test units or small commercial unit sizes with the claims of reduced specific energy consumption and water cost. These include; Membrane Distillation (MD), Forward Osmosis (FO), [17], Humidification De- Humidification (HDH) and Capacitance De Ionization (CDI). However, the techno-economical feasibility of these new technologies is not proven to suit large scale commercialized plants. The authors believe that it will be a while before these new technologies will be able to commercially compete with the present MSF, MED and RO technologies.

On the other hand, Renewable Energies (RE) and Nuclear Energy (NE) are two alternatives energies for driving desalination technologies with zero CO_2 emission. Almost all GCC countries have announced their interest and plans to use RE as future driver of desalination technologies. Both solar and wind power appear to be mature options for these applications. Wind power exhibits lower energy costs than solar photovoltaic energy and might be suitable for islands as in and Sultanate of Oman where wind speed tends to be very suitable. However, the most important challenge regarding the application of RE is the intermittent power output generated, compared to the steady energy demanded by desalination processes. Combining RE technologies of intermittent power output and desalination processes, which require a constant energy supply, involve technical, economic and organizational issues. Technical developments include a large availability of low-cost RE and energy storage technologies to face the variable nature of RE. In addition to energy efficiency and desalination technology advancement, RE can to play an important role in desalination. This can be partially met with the use of hybrid (Solar/Wind) RE resource units and reduce the costly energy storage systems. Table 3 shows a key data summary of RE-desalination technologies [18].

In the GCC region, solar is the most abundant source of energy. Solar energy – in particular heat from concentrated solar power (CSP) for thermal desalination and electricity from solar photovoltaic (PV) and Concentrated PV for membrane desalination – is a key solution in arid regions with extensive solar energy potentials, whilst wind energy is of interest for membrane desalination projects in coastal and islands communities, [19-25]. There are many barriers that can impede the implementation of the renewable energy technologies in GCC countries. Some of these barriers include not having a clear RE policy by the governments, lack of the relevant institutions to implement and monitor existing policies, old and badly damaged infrastructure, and finally, not building the critical human capacity to build and manage renewable energy projects, [26].

In spite of intensive research on the application of RE to drive desalination plants, practical application is still minimal. After the de-commissioning of UAE-Umm-Elnaar Solar-MED plant (about 100 m^3/day) in 2004, no solar thermal desalination plants exist in *GCC* countries. However, many in small scale desalination water production (50 m^3/day) using solar PV-BWRO plants are built in UAE, [27]. UAE also announced that 7% of the countries power generated by 2030 will be RE. Recently, an ambitious RE-desalination program of building 100 MIGD RE-desalination plants by 2020. Masdar announced the starting of this program by building 3-5 pilot plants (100 – 1000 m^3/day) to test high performance modified conventional plants (MED and RO) or new technologies (MD, FO, EDI) in 2013. The proven technology(s) in 2016 will be chosen for the 100 MIGD utility plants, [28]. KSA, on the other hand, looks towards solar energy to sustain its growing water and energy demand. An ambitious initiative was recently announced, to convert KSA desalination plants to solar driven ones in 10 years. The first large scale solar energy driven (CPV-SWRO) desalination plant is being developed by IBM in joint venture with King Abdulaziz City for Science and Technology (KACST) in the city of Al-Khafji. The plant will be 30,000 m^3/d capacities to provide drinking water to 100,000 people. The plant, will use Ultra-High Concentrator Photovoltaic (UHCPV) technology with application of nanotechnology techniques in the production of solar energy systems and water desalination membranes and would allow for a cost of less than 0.40 \$/m^3 (1.5 SAR/m^3). No indication of the project' CAPEX or the payback period as it is a pilot test for future solar-desalination systems. This project is expected to start running in 2013 and is part of a national initiative for building several water desalination plants that use solar energy, [19]. Qatar is facing a soaring demand for electricity and water amid population growth and large-scale commercial and residential projects. Qatar's demand for electricity is estimated to grow at 17 % per annum, the highest in the region. Although Qatar owns huge natural gas reserves, much of the current production is scheduled for liquid natural gas (LNG) exports and industrial use. Solar energy is expected to generate at least 2 % of electric power in the country by the end 2020

On the other hand, UAE started the construction of two 1400 MWe nuclear power plant near Abu Dhabi. The two units are under construction and operation is expected to start in 2017,. Two other nuclear plants are also in plan at the same site. KSA announced also its interest in nuclear energy and a new (King Abdullah) city for nuclear and solar energy was established. In both countries, nuclear power plants are expected to only be of single purpose power plants to produce electricity and use RO to desalinate saline water via the electrical network. Due to the lack of experience, no direct linkage between nuclear power & desalination plants (as in conventional fuel co-generation plants) is announced. Kuwait has launched a feasibility study into nuclear power development with the aim of having one or two atomic plants in operation by 2020. The study, undertaken by the French government's Agency France Nuclear International and the US nuclear consultant and fuel developer Lightbridge, will assess potential project sites in southern Kuwait, where water from the Gulf could be used to cool reactors. The country's interest in NPPs began in earnest in September 2010 when Kuwait's National Nuclear Energy Committee told the media that it was considering options for four planned 1,000 MWe NPP reactors, [29].

6. Conclusions

The present and future prospective desalinated water production rates and trends by different commercial desalination technologies as well as the corresponding power consumptions are presented and analyzed for the GCC countries. The data and results are presented using existing published data and for the extrapolated up to the year 2025.

- For KSA, the cumulative water production increased from 9.1 Mm^3/day (in 2006) to 23 Mm^3/day (in 2025). This large increase in water production will be associated with a similar large increase in energy requirement. The results show that the annual total energy consumption in 2006 was 48,391 GWhr and will almost triple by the year 2025 to be 119,111 GWhr.
- For UAE, the cumulative water production increased from 6.7 Mm^3/day (in 2006) to 17.5 Mm^3/day (in 2025). This large increase in water production will be associated with a similar large increase in energy requirement. The results show that the annual total energy consumption in 2006 was 64,762 GWhr and will almost triple by the year 2025 to be 145,412 GWhr.
- For Kuwait, th[e] cumulative water produc[t]ion increased from 1.3 Mm^3/day (in 2006) to 6.0 Mm^3/day (in 2025). This large increase in water production will be associated with a similar large increase in energy requirement. The results show that the annual total energy consumption in 2006 was 10,143 GWhr and will increase almost five times by the year 2025 to be 50,604 GWhr.
- For Qatar, the cumulative water production increased from 1.2 Mm^3/day (in 2006) to 3.2 Mm^3/day (in 2025). This large increase in water production will be associated with a similar large increase in energy requirement. The results show that the annual total energy consumption in 2006 was 14,516 GWhr and will increase almost triple by the year 2025 to be 32,625 GWhr.
- For Oman, the cumulative water production increased from 0.8 Mm^3/day (in 2006) to 3.1 Mm^3/day (in 2025). This large increase in water production will be associated with a similar large increase in energy requirement. The results show that the annual total energy consumption in 2006 was 5,471 GWhr and will increase almost triple by the year 2025 to be 12,150 GWhr.
- For Bahrain, the cumulative water production increased from 0.8 Mm^3/day (in 2006) to 2.8 Mm^3/day (in 2025). This large increase in water production will be associated with a similar large increase in energy requirement. The results show that the annual total energy consumption in 2006 was 8,772 GWhr and will increase almost triple by the year 2025 to be 22,225 GWhr.

In terms of thermal desalination energy saving, a very conservative measured indicated that about 7 % of the energy can be saved by the year 2025. With more ambitious efficiency improvements and ambitious energy reduction (including present operating plants rehabilitation) indicated that up to 23 % in energy consumption can be reduced.

Future promising technologies (as FO, MD, HDH and CDI), and alternative energies (as solar and nuclear) are also highlighted. A large scale CPV-SWRO desalination plant in the city of Al-Khafji (KSA) for the production of 30,000 m^3/d capacities is now under construction to provide drinking water to 100,000 people. This is the first large pilot CPV-RO build to be used as a learning plant. Similarly, thirty small scale desalination water production (50 m^3/day) using solar PV-BWRO plants are built in UAE with ambitious plan to build 100 MIGD RE driven desalination plants by 2020. No thermal solar desalination plants are built since the decommissioning of UAE Umm El-Naar Solar-MED plant. Renewable and possibly nuclear energy have been announced by several gulf states to partially operates new desalination projects.

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