

A Review of Desalination Trends in the Gulf Cooperation Council Countries

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Abstract

The Gulf Cooperation Council (GCC) is a sub-region of the Economic and Social Commission for Western Asia economic realm that is located in the Middle-East, and consisting of six members that include Qatar, the Kingdom of Saudi Arabia (KSA), Bahrain, Oman, Kuwait and the United Arabs Emirates. This region is located in an arid ecosystem and one plight that is common to the entire members is the scarcity of renewable water resources. As a result, they have resorted to investing in desalination technologies to suffice the demand of the ever increasing population. Nonetheless, this journey has never been that rosy since there are a number of challenges that have come in their way. Among these challenges is the unit cost of desalination, environmental pollution, and also the number of contracted capacity. However, it is upon the management to frame reliable policies so as to overcome these challenges lest the problems persist. For instance, in Abu Dhabi, in order to realize the 2030 vision, then there is need to recycle wastewater for use in agricultural production instead of using desalinated water that comes directly from the plants. This review paper highlights the desalination trends in the GCC countries.

Keywords: Desalination, Gulf Cooperation Council Countries, Analysis

1. Introduction

The GCC is an economic region consisting of six Middle-East economies including Qatar, KSA, Bahrain, Oman, Kuwait and the United Arab Emirates (UAE). These countries are grouped together since they have a lot in common. Ideally, these nations have comparable socio-economic situation and oil exploration forms the backbone of their economies, spanning four decades back. Importantly, merchandise

in oil-related products dominates their export markets, accounting for more than 90% of their total exports. One major resource that has been impeding the faster development of this region has been the scarcity in natural water resources at the backdrop of increasing demand (Al-Rashidi et al., 2009). The increasing demand is a consequence of population growth, and as such, the surface water resources are now exhausted. In some countries, the aquifers are already drained. To this end, to supplement the declining fresh water resources, the GCC countries have resorted to investing, massively, in desalination plants much to their success. The desalination plants invested in the GCC countries typify a successful project that has lived up to its expectation of serving its population with continuous supply akin to economies that are sufficiently endowed with natural and renewable water resources (Hanbury, 2010).

According to the research conducted by the World Health Organization (WHO), this region, located within an arid ecosystem, has already hit the water scarcity line of less than 1000 m³ per year per capita. In area, this region covers a space of approximately 2.55 million km² and it has a common climate with a few surface water resources. The available surface water resources are localized along the coasts of both KSA and Oman but to the south. In a synopsis, this realm represents the harshest of the entire realms making up the world. This region is endowed with the least fresh water resources around the world, accounting for less than 370 cubic meters. With a growing population, it is projected that these resources will decrease to less than half the current capacity by the year 2030 when the population will be standing at 56 million people. With these facts, it goes without saying that the GCC countries have an uphill task of efficiently managing the limited water resources. This is why they have taken to desalination plants to meet the demand (Mezher et al., 2011).

Desalination plants have been part and parcel of the economies forming up the GCC, supplying both municipalities and industries for the past two to three decades. Overreliance to the same is projected to increase as the population swells. Among the common desalination processes employed include Multi-Stage-Flash (MSF), Multiple-effect Distillation (MED) and Reverse Osmosis (RO). Of the three, the later technology is becoming common to the region owing to the fact that it is cost-efficient and more reliable. While the amount of desalinated water consumed the world over is immaterial, this region accounts for almost 100% of their total needs. According to Global Water Intelligence (GWI) report, “the cumulative capacity of the entire desalination plants contracted in the GCC countries since the year 1994 was 24 million cubic meters per day by 2010” (Al Zawad and Aksakal, 2010).

The energy requirement of any given technology is vital in determining the process economies since any slight variation in the oil prices has a greater effect on the production cost. Moreover, the more intensive a process is in terms of energy requirements the more are the emissions (CO₂ gas) released to the environment. Importantly, the cost of desalinated water is dependent on a myriad of factors that can be grouped as either capital related (CAPEX) or operation related (OPEX).

In the face of all these challenges comes another factor that is the competing demand from various sectors of the economy. For ages, the GCC countries have successfully managed to balance their limited water resources among domestic, animal and agricultural sectors. Nonetheless, in the past 50 years, urbanization, industrialization and population growth have entered the fray. Today, these economies grapple with the rising competing demands, for instance, “urban versus rural and human versus industrial among others” (Hoepner and Lattemann, 2003).

With the background information on the water resource situation of this region, we can objectively analyze the desalination plants in the GCC countries. As such, the rest of the literature in this paper will focus on; the cumulative contracted capacity, number of contracted plants, proportions of different technologies, daily water production volumes, the cost per unit and the future projections in terms of demand/supply. Moreover, this paper will suggest policy initiatives for Abu Dhabi 2030 vision.

2. Cumulative online and contracted desalination plants and capacities

The history of desalination technology stretches way back in history. However, in the modern history, Bahrain and Kuwait represent the first members of the GCC countries to have enjoyed desalination technology in the name of multi-effect distiller (MED). Kuwait is, too, the first member of the GCC countries to launch the MSF in the mid twentieth century. Currently, the number of plants installed in the MENA (Middle East and North Africa) region is a manifestation of the increasing demand of freshwater in this water-scarcity region. The most striking feature, however, is the increasing number of the contracted firms in this region. When you look at the numbers of the contracted firms in the MENA region in Fig.1 below, it goes without saying that this number is relatively high in the GCC countries. Among the first six nations of the MENA region with high numbers of contracted capacity, four hail from the GCC sub-region with the Kingdom of Saudi Arabia leading the pack.

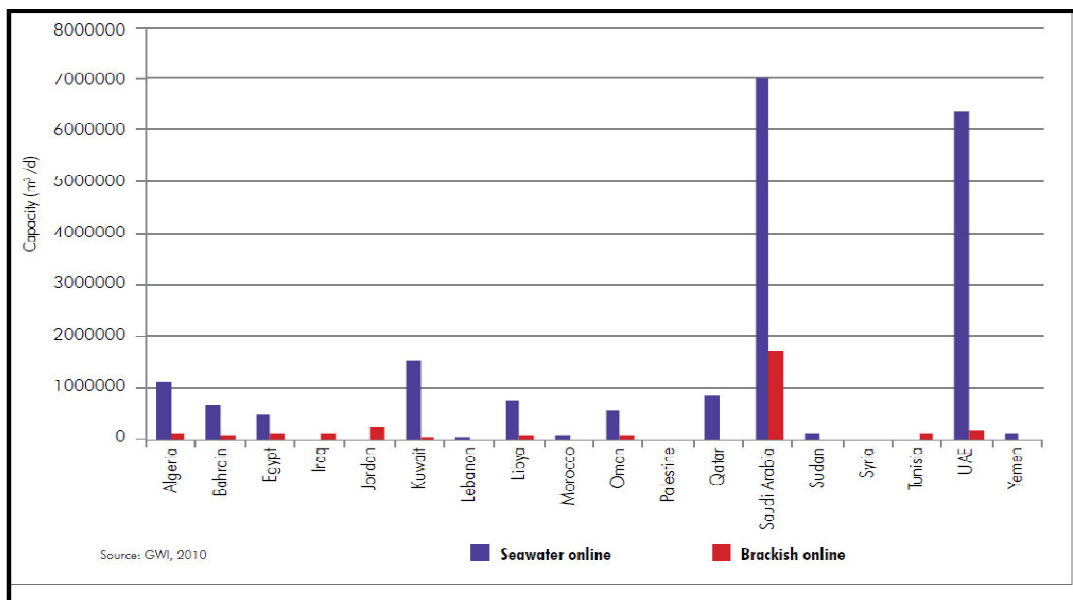


Fig.1: Total cumulative contracted capacity of desalination plants from 1944 to 2010 (Global Water Intelligence, 2010)

As manifested in Fig.2 below, the number of contracted firms in this region is projected to increase in the subsequent decade. This large expansion “requires a review of the present policies and practices including how to increase local capacity, knowledge, and added value to the local economies”(Al-Rashed and Sherif, 2000).

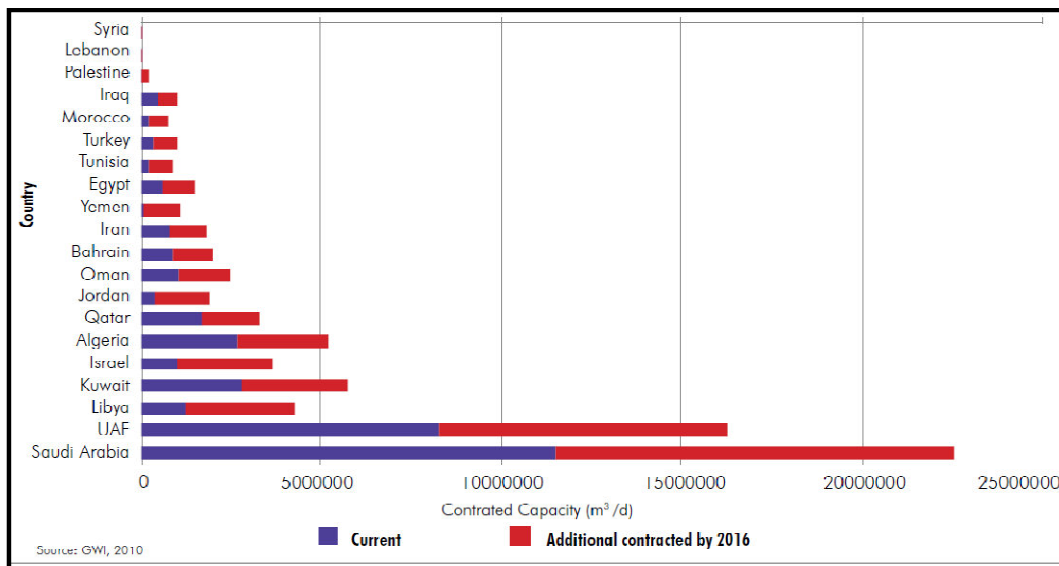


Fig.2: Accumulated (2010) and near term contracted capacities (Global Water Intelligence, 2010)

The local capacity in this realm is biased on only operations and maintenance, assuming manufacturing and design yet this is a region that is highly dependent on the desalination technology to provide freshwater for both domestic and industrial use. Even though there are exceptional local-based engineers in this region, they are not adequate to meet the ever soaring needs of the region. Not unless the governments forming up the GCC region do something to support the local talent, the situation is likely to remain delicate like in other technology-based industries which are dependent on imported talent.

Among the policies proposed by IWRM (Integrated Water Resource Management) to curb this trend is to seal all the water leakages present in the current facilities before engaging in a white elephant project of contracting more capacity. To this end, IWRM explains that sealing the leakages is relatively cheaper, and it will give a true picture of the actual capacity that is required for addition.

Out of approximately 17,346 contracted and online desalination plants across the globe, the GCC countries hold 7,499 which is 43% of the share. In-terms of capacity, the total global contracted and online capacity as of 2013 is approximately 94,500,000 m³/d, from which 62,340,000 m³/d comes from the GCC countries with a share of almost 70%(Table 1). Amongst all GCC countries KSA has the largest number of plants and total capacity followed by the UAE. This trend can be directly correlated to the populations of these two countries, being the top two in terms of population. On the other hand the country with the lowest population (Bahrain) has the lowest desalination capacity, although it has more desalination plants than Kuwait and Qatar. This highlights the fact that the number of plants is not a good indicator to the desalination activities when compared to capacities. This arises from the wide range of plant capacities present. Plant sizes as small as 1 m³/d are recorded with plants planned for 880,000 m³/d capacity. This short analysis of the GCC countries as a whole shows how important the GCC region is in the global desalination market. Of course, population growth is not the only driver for the desalination capacity growth. In-fact the rapid industrial growth in the GCC countries especially in the last two decades made this region a hub to many global industrial markets and in particular the energy market.

Table 1: Most recent figures of online and contracted plants and capacities of the GCC countries(DesalData, 2013; World Bank Group, 2013)

	Online plants	Contracted plants	Online capacity (m ³ /d)	Contracted capacity (m ³ /d)	Population
UAE	492	497	9,358,492	10,109,057	9,205,651
KSA	2,664	2,688	13,080,497	14,791,660	28,290,000
Qatar	139	141	1,832,762	1,997,218	2,035,106
Oman	184	187	1,094,740	1,350,832	3,869,873
Kuwait	88	89	3,023,369	3,477,969	3,250,500
Bahrain	165	165	1,113,001	1,113,001	1,318,000
Total	3,732	3,767	29,502,861	32,839,737	47,969,130

Analysing the various trends in Fig.3 to 8 (and 30 to 35 in supplementary data), to start with, we observe the general growth of number of desalination plants and capacities of countries with the population growth. In particular, one of the steepest and most rapid growth is taking place in the UAE where within a period of 10 years (2003 to 2013) the population literally tripled (+300%). Consequently, we observe an almost 220% increase in desalination capacity within the same period. This effect demonstrates how population growth and industrial growth are interlinked. If we consider the typical water consumption per capita per day in the UAE, 0.35 m³/d, and calculate the required demand within the years 2003 and 2013 based on the given population growth. The additional demand solely by the population would be approximately 2,050,000 m³/d, while we observe that the additional capacity added in this period to date is approximately 5,800,000 m³/d (i.e. more than double). This observation is obvious due to the requirements which come naturally with population growth, such as amenities, hospitals, job market etc.

The number of desalination plants and capacity figures are much related and show almost exact trends with population. In general, we observe that the start of the rapid growth of desalination in the GCC countries was mostly in the 1970s except for Kuwait which began its desalination take-off during late 1950s. In particular Kuwait suffered the Iraqi invasion in 1990 which severely affected the desalination activity. In fact, it can be observed that during the years preceding the war Kuwait lost almost 23% of its desalination capacity.

In the UAE, the rapid growth of desalination started with the merge of the union of the seven emirates and the birth of the UAE as a country in the early 1970's. At its early stages the desalination capacity was around 29,000 m³/d (Fig. 3) and today it's almost 9,400,000 m³/d. Within a period of 40 years, the UAE became a producer of 10% of the global desalination capacity. It can be seen from Fig.3 and Fig.17 that the year 2003 was the start of a steep rise in both population and desalination in the UAE. Even with the recession in 2009, both trends continued to rise. Fig.17 shows the predicted increase in the UAE population up to 2050, and we notice a reduction in the slope in comparison to the period before 2012.

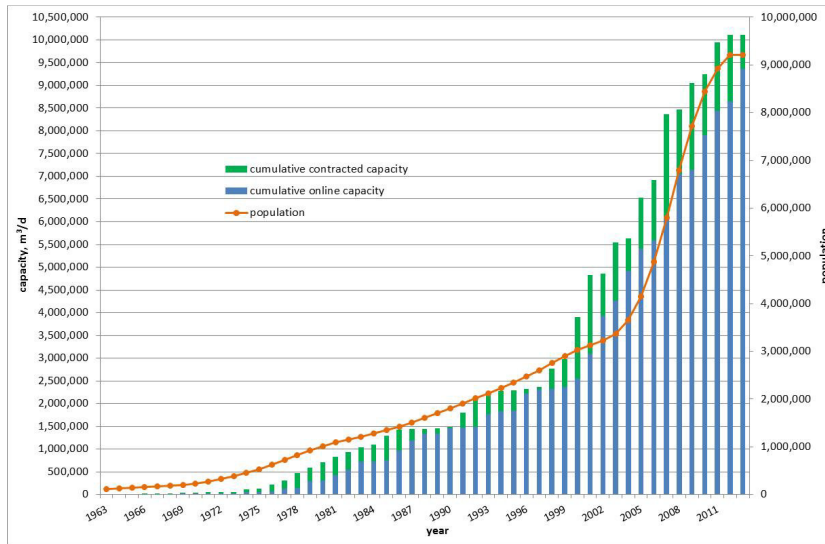


Fig.3: Contracted and online capacities with the population trend in UAE (DesalData, 2013; World Bank Group, 2013)

The desalination and population profile of KSA shows a rather consistent growth in both. Similar to the UAE, in the early 1970s the desalination capacity of KSA started to increase at an accelerated rate. This was a parallel consequence of the industrial and population growth which happened during the same time. Similarly within 40 years, KSA became a very important player in the global desalination market with an almost 14% share in the global desalination capacity.

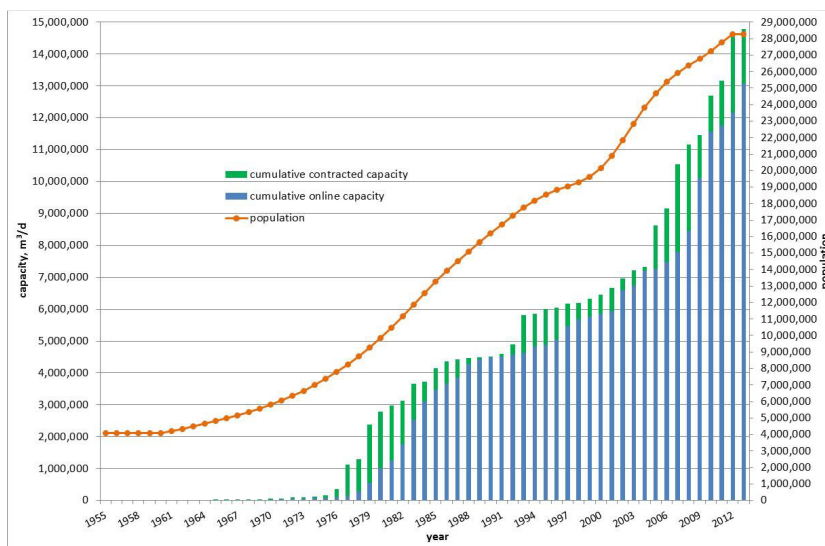


Fig.4: Contracted and online capacities with the population trend in KSA (DesalData, 2013; World Bank Group, 2013)

As one of the smaller GCC countries in terms of population and desalination capacity, Qatar saw the rise in its desalination profile during mid-1970. The growth of desalination and population entered a sharp increasing slope around 2004, with an increase of almost 1,100,000 m³/d in capacity since 2004. Oman experienced a relatively consistent increase in desalination since the 1970. This growth level-off during late 1980s and then went into another period of relatively rapid increase in desalination capacity. Currently

Oman has the lowest desalination capacity between all GCC. Kuwait is one of the first GCC countries to implement desalination technologies. The growth of desalination was consistently growing in Kuwait between the periods early 1960 to 1990 when the Iraq invasion occurred. Then Kuwait started its second recover and rise in desalination in 1998. Today Kuwait is the third top GCC country in terms of desalination capacity. Bahrain has the second lowest desalination capacity after Oman. Desalination started in Bahrain since the early 1960s with an increasing rate of growth from 1970. The growth of desalination continued thereafter until today.

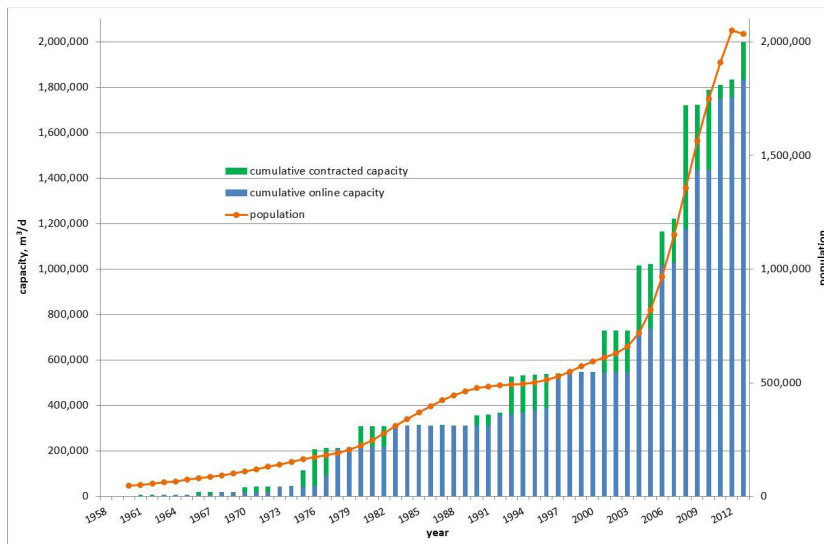


Fig.5: Contracted and online capacities with the population trend in Qatar (DesalData, 2013; World Bank Group, 2013)

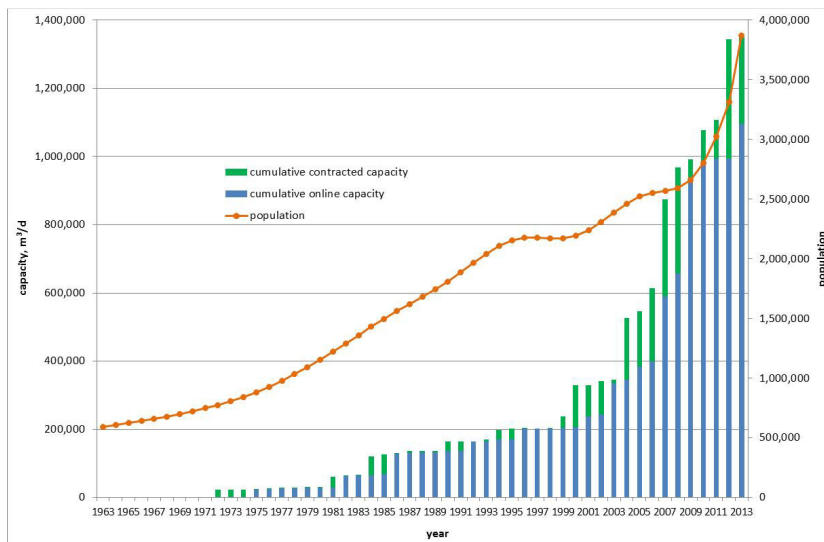


Fig.6: Contracted and online capacities with the population trend in Oman (DesalData, 2013; World Bank Group, 2013)

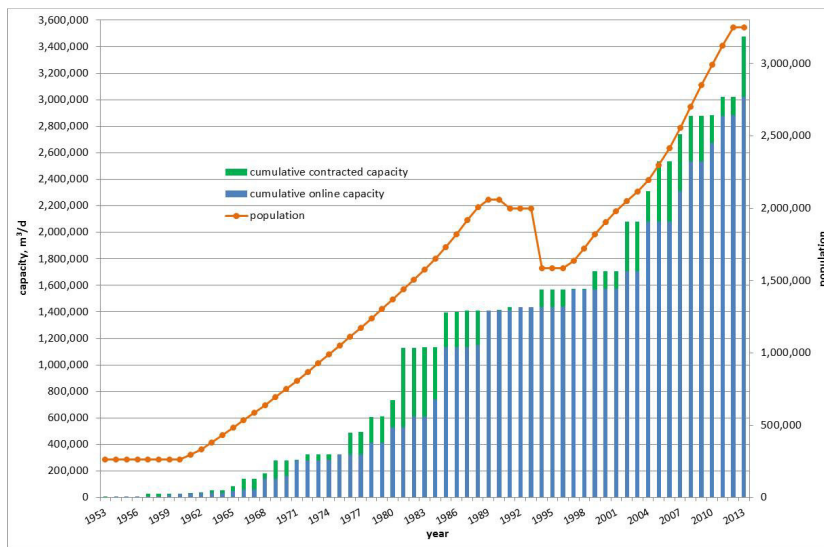


Fig.7: Contracted and online capacities with the population trend in Kuwait (DesalData, 2013; World Bank Group, 2013)

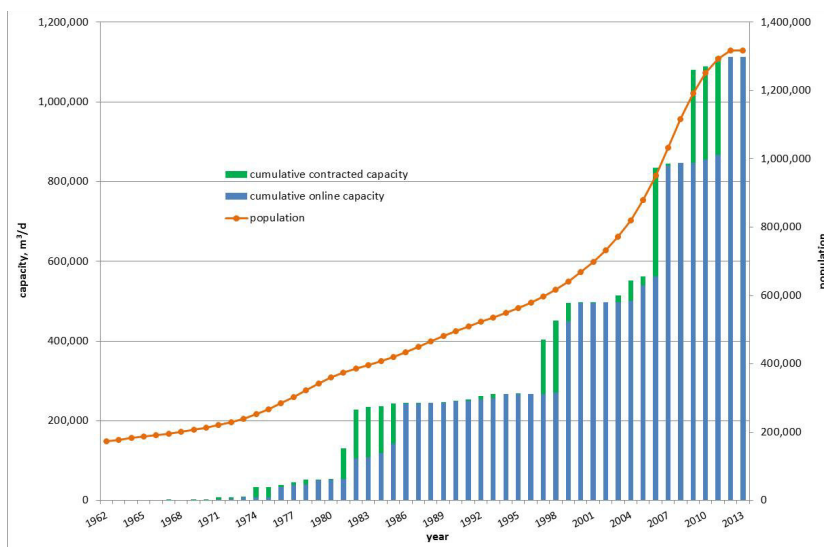


Fig.8: Contracted and online capacities with the population trend in Bahrain (DesalData, 2013; World Bank Group, 2013)

3. Supply and demand: past, present and the future

The daily water production in the GCC countries is dependent on the demand, a function of population growth. Water demand in this region can be grouped into three sectors including domestic, agricultural and industrial sectors. Fig. 9 below is a depiction of the requirements per sector in the Economic and Social Commission for Western Asia (ESCWA) region. Individually, most countries align their specific requirements with the regional demand. An economy in the GCC region that doesn't fit well in the regional sector includes Bahrain which uses only 50% of its requirements to agriculture.

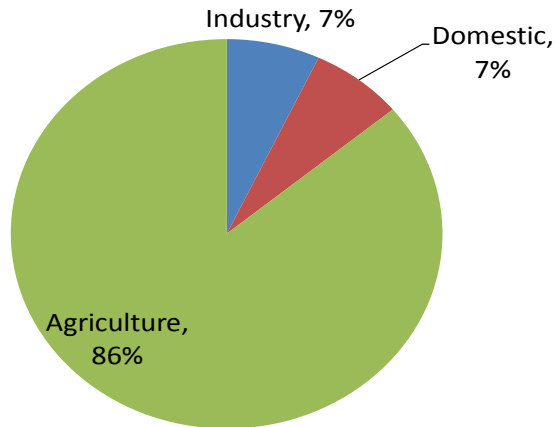


Fig.9: Water demand by sector in ESCWA(ESCWA, 2013)

With sufficient oil resources, the GCC countries have largely invested in desalination plants to meet the increasing demand from various sectors. These sectors include municipality, industrial power, tourist, military, demonstration and irrigation. Of these sectors, demand in municipality dominates in the GCC region (Fig. 10) while demonstration records the least demanded water. The dominance of municipality demand has been replicated in the GCC nations with exception of two states- Bahrain and Qatar (Fig. 2). These two states' consumption is biased towards industrial use. Just like in the entire region, the least demanded water for use per nation is demonstration. The most dominant sectors which consume a lot of water per nation are municipal and industry. However, the demand of water from other sectors (power, tourist, military, demonstration and irrigation) in KSA dwarfs the dominant sectors (municipal and industry) of most nations of the GCC. For instance, military consumption in KSA is more than what is demanded in Qatar, Bahrain, Oman, and Kuwait. This can be attributed to the fact that KSA is large and as such dwarfs the others in population/demand.

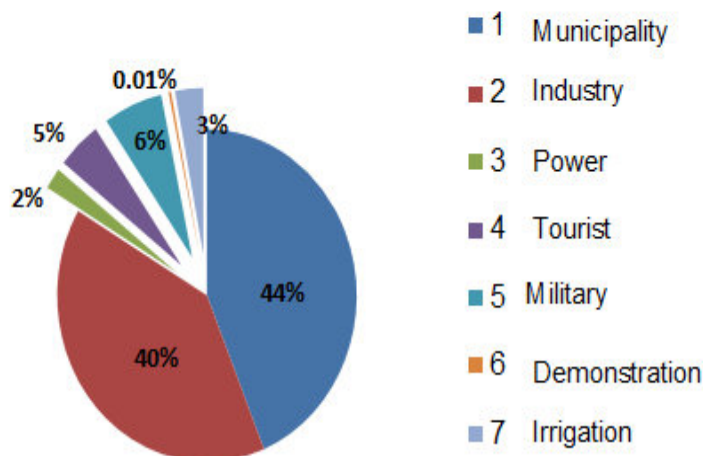


Fig.10: Demand by sector in the GCC (DesalData, 2013)

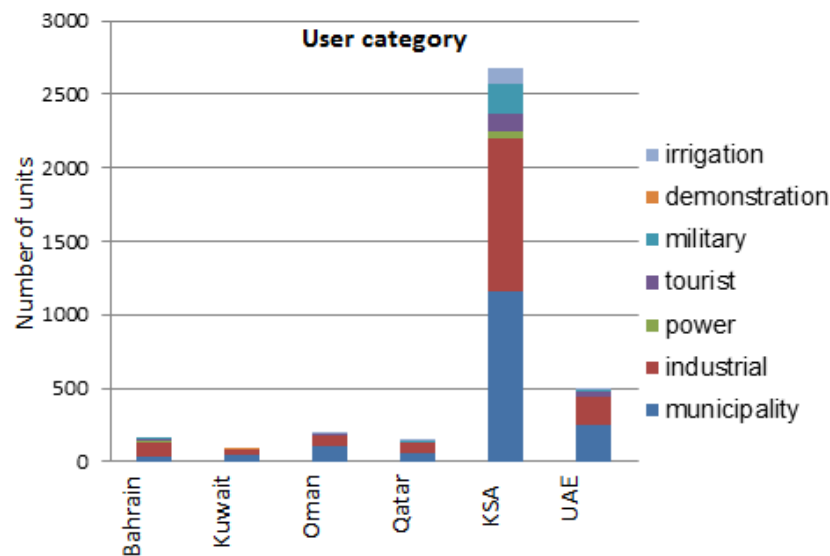


Fig.11: Number of desalination units by user category (DesalData, 2013)

When we consider individual members from the GCC region, it is evident (Fig.12) that both Bahrain and Qatar utilize much of their water for industrial use. The others utilize much of their water within the municipality. While Kuwait and Bahrain have no water demanded for irrigation, the others have significant water demand from this sector with the KSA demanding more for this purpose (United Nations, 2009).

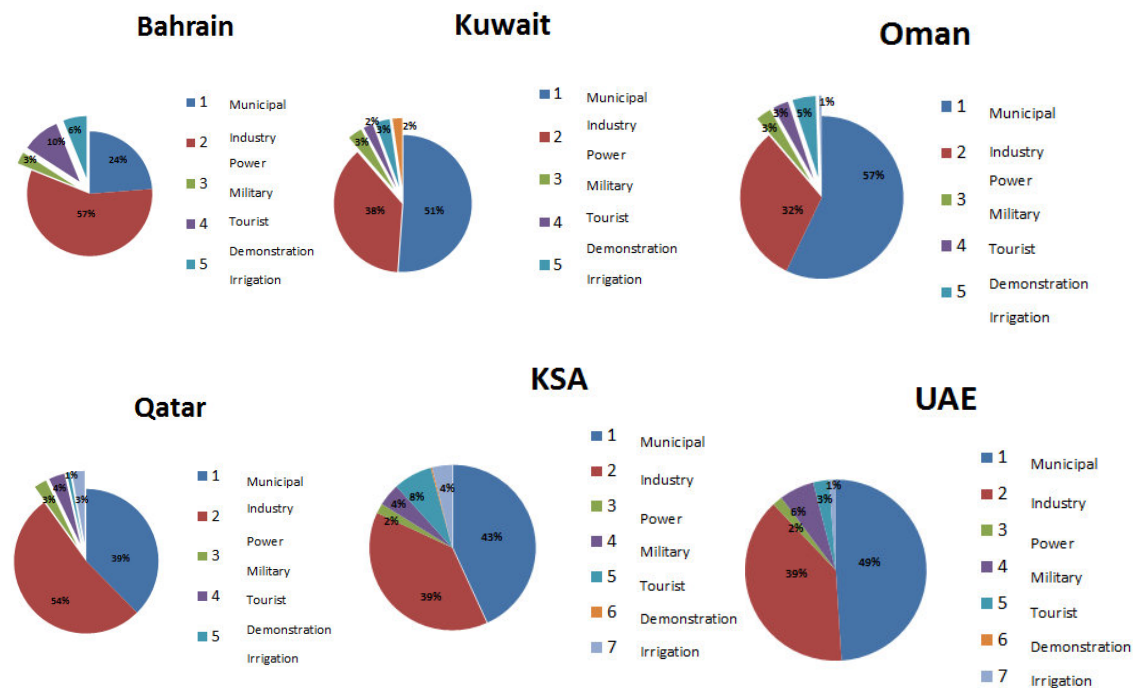


Fig.12: Desalination demand by sector (DesalData, 2013)

Most of the feed-water for desalination plants in the GCC region comes from the sea. In all the nations with an exception of Bahrain and KSA utilize sea water. The exempted two countries utilize brackish water. KSA and UAE reclaim much water from the sea than the other nations (Fig.13). Like it has

been mentioned before, just as expected, the raw water from river would be low in this region with KSA dominating because it has a few rivers. Of the GCC nations, it is only KSA that has substantial wastewater recycling units. When considering individual countries, it is evident (Fig.134) that Bahrain, Kuwait and KSA don't utilize brine as feed water in their respective plants. KSA is the only nation from the GCC that utilizes significant amount of water from the river as feed water (Al-Rashed and Sherif, 2000).

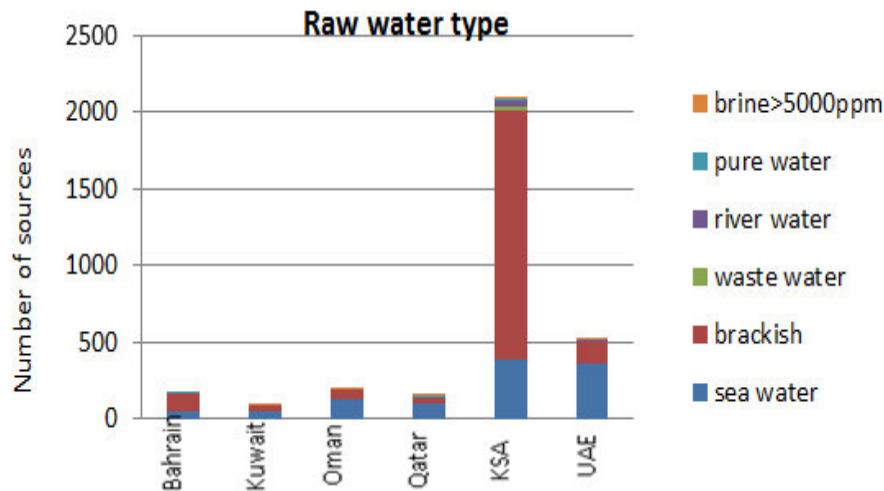


Fig.13: Desalination by raw water type (DesalData, 2013)

In the GCC region, the average consumption rate takes approximately 80% of the total requirements. This figure is forecasted to increase by at least 40% by 2020. However, the agricultural sector accounts for a paltry 10% of the GDP in the entire region. The investors in the agricultural sector have continued to be skeptical about this industry because the ratio of the “agricultural GDP to agricultural the labor force has always been below 1.0 in some GCC countries (Abdulrazzak, 1995). As such, investors in the sector are seeing an investment in the industry as beneficial to labor industry. As for the domestic demand, the consumption rate is dependent on the standard of living (Fig.15). From the Fig. 15 below, it is evident that the most of the GCC nations which have higher standards of living consume a lot of water per day.

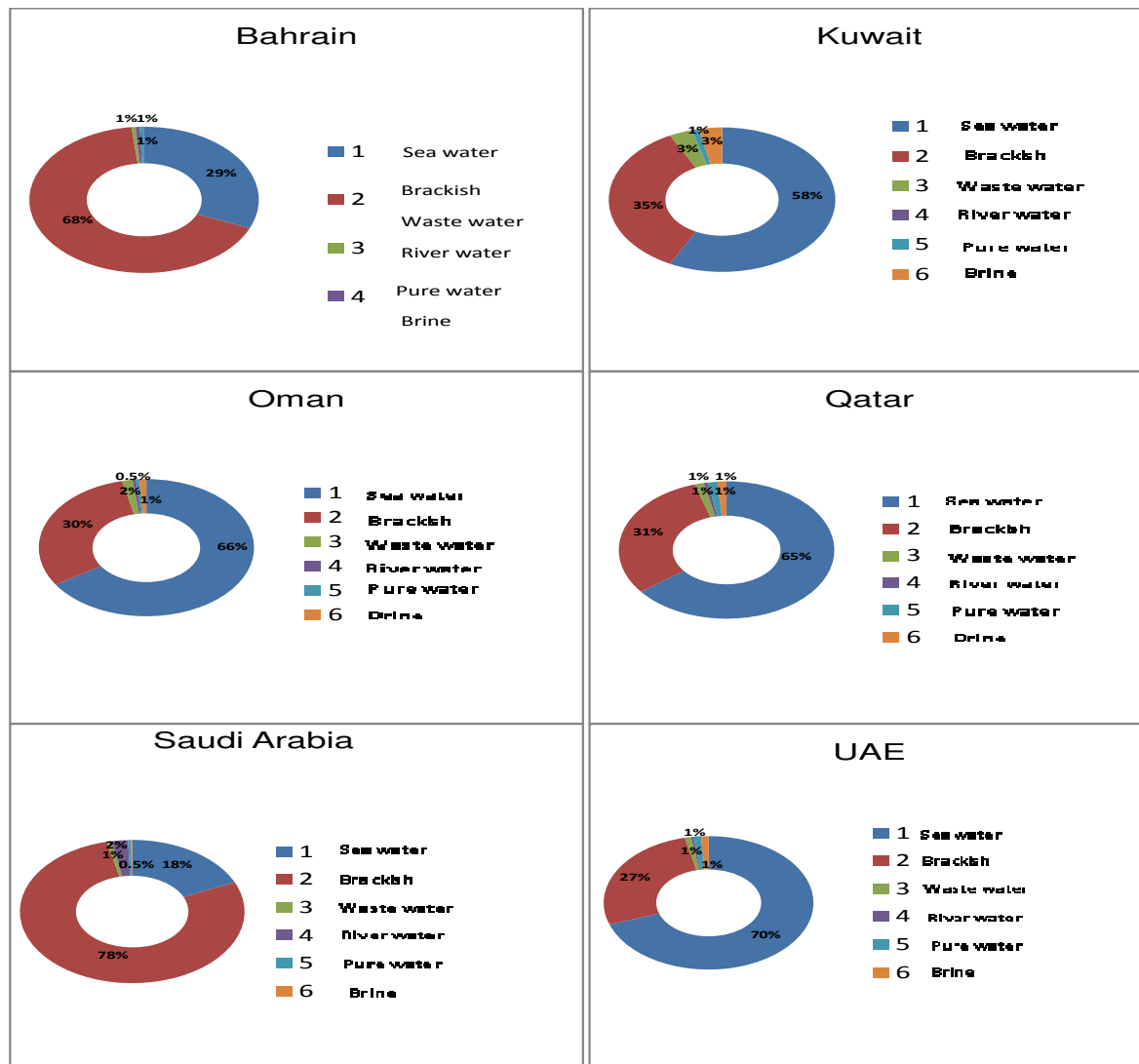


Fig.14: Feed water type for each GCC country (DesalData, 2013)

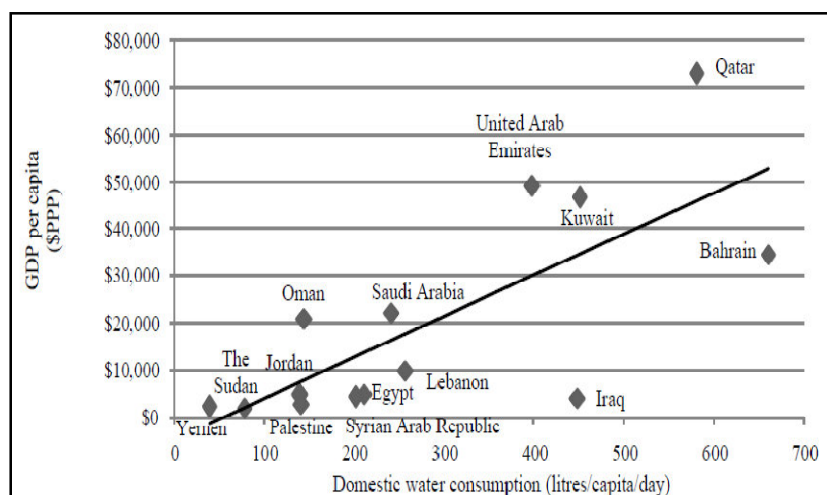


Fig.15: Domestic water consumption vs GDP per capita (Abdulrazzak, 1995)

By comparison, the industrial demand in the ESCWA region vis-a-vis other regions continues to hit a low (United Nations, 2009). Nonetheless, it has continued to grow gradually. The industrial demand is specifically meant for cooling purposes. Population is one factor that has led to increased water demand. As typified in the Fig.17 to Fig.22, the population in the GCC sub-region continues to soar. As such, the water demand is projected to increase as the population swells. With these projections, the pressure is directed to the governments making up this region to ensure a regular and constant supply of water to its citizens. As shown in Figs 1 to 6 (supplementary data), the numbers of the contracted plants continue to increase to meet the rising demand. The desalination plants in the GCC region are meant to meet the current and the future water demand due to increasing population. Of the GCC countries, Kuwait and KSA are first nations to launch the modern desalination plants back in the 1950s. Among the desalination plants gracing the world today, almost 70% hail from this region. The desalination plants with their unique technologies are expected to increase in this realm in the future owing to increasing demand. The ever increasing population coupled with the scarcity of non-renewable water resources are the reasons that is an increase in desalination plants. Fig.16 below depicts the trend of the total capacities per day of desalination plants since 1950 until the year 2000 in the region.

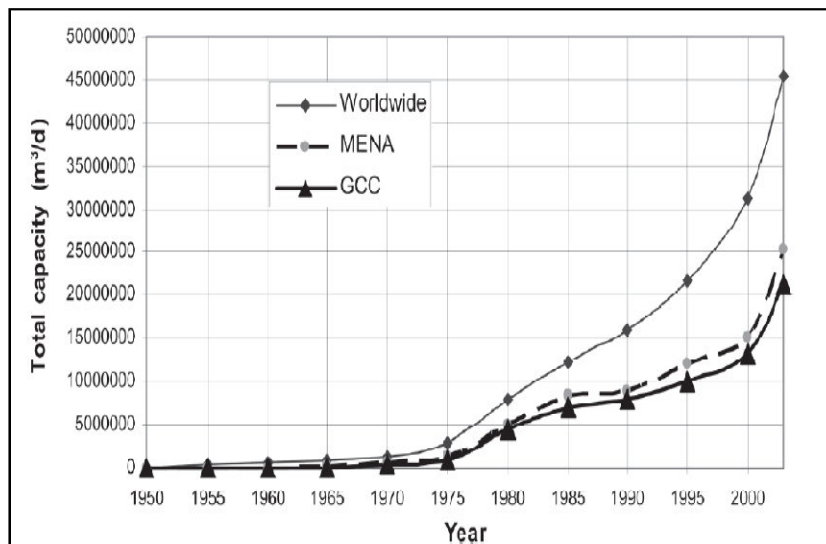


Fig.16: Desalination capacity trend 1950 – 2000 (AlRukaibi, 2010)

Even as investors struggle to meet the ever increasing water demand, with the above projections there seem to be a looming battle between stakeholders-investors versus environmentalists (Dawoud, 2012). While desalination plants offer socio-economic benefits by providing potable water devoid of affecting the freshwater ecosystem, the niche that faces potential destruction is the marine ecosystem. The desalinated water demand and supply trend over the years and the forecast of these is a very important strategic factor for all countries in general and for the GCC countries in particular since they heavily rely on desalinated water. Fig.17 to Fig.22 depict the supply and demand trends and forecasts for the GCC countries. In particular the forecasted supply is based on announced desalination plant projects which are under contraction. Similarly the forecasted demand is based on population growth as well as other important factors such as industrial growth, agricultural activities and others. The general trend in Fig.17 to Fig.22 is that the demand and supply grow with population with the exception of the UAE and Qatar which show a slightly decreasing demand. Also, it can be seen that in general supply overtakes demand in most present and forecasted cases with some exceptions which will be highlighted here. KSA, Qatar and Bahrain maintained a good supply which always over-met the demand in the past years. On the other hand the UAE,

Oman and Kuwait had a shortage in this respect during the year 2000 for the UAE and Oman and 1978-1980 for Kuwait. All the GCC countries maintained a good supply for most of the years in general. When we look at the forecast we observe that the UAE, Qatar, Kuwait and Bahrain have already secured their water needs up to 2050 based on the predicted demand. On the other hand, KSA and Oman will face a shortage if they rely only on the so far announced desalination projects. In fact both countries will face this shortage during the period 2020 and 2030 as predicted by the demand forecast.

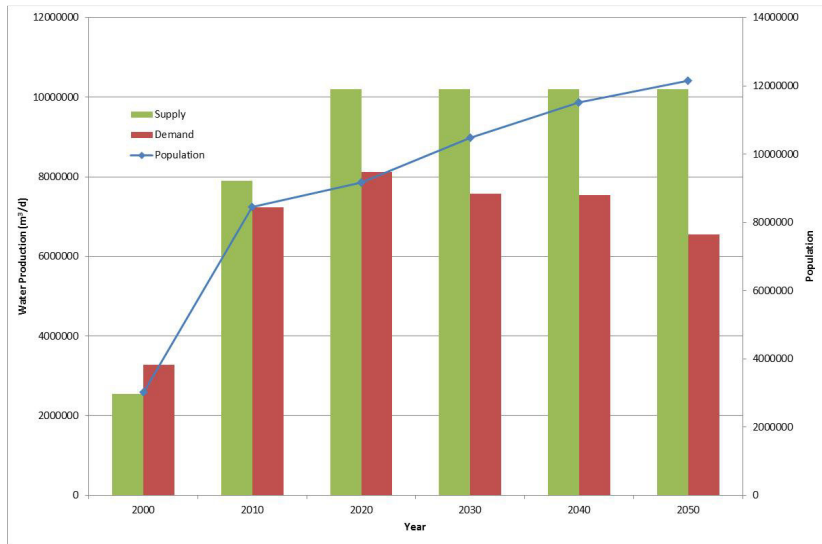


Fig.17: Supply and demand of desalinated water with the population trend in the UAE (DesalData, 2013; ESCWA, 2013; World Bank Group, 2013; Verdier, 2011)

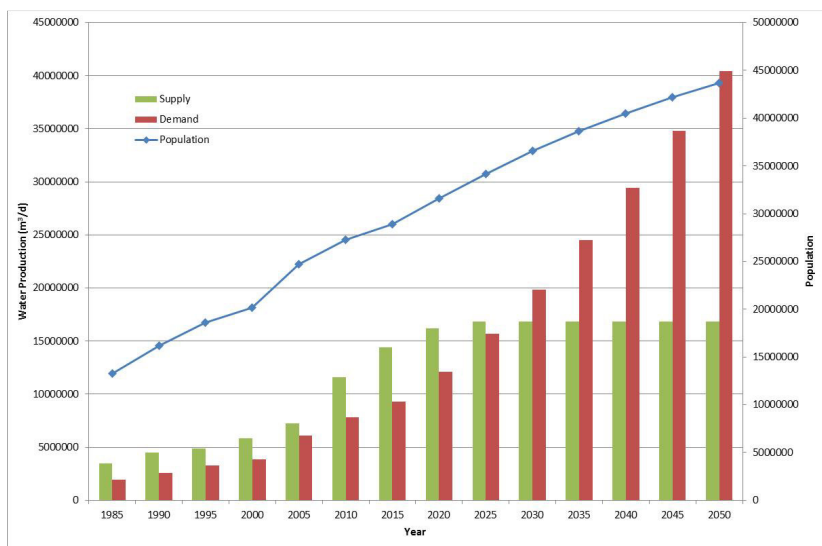


Fig.18: Supply and demand of desalinated water with the population trend in KSA (DesalData, 2013; ESCWA, 2013; World Bank Group, 2013; Verdier, 2011)

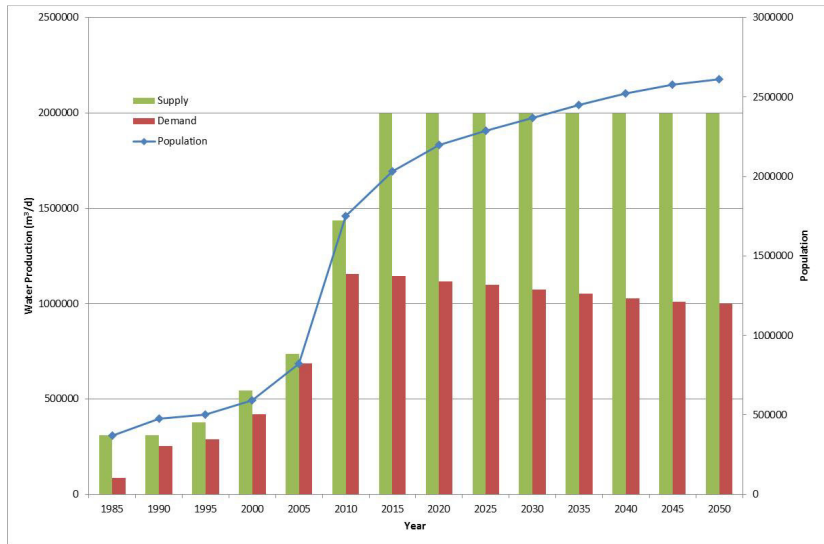


Fig.19: Supply and demand of desalinated water with the population trend in Qatar (DesalData, 2013;ESCWA, 2013; World Bank Group, 2013; Verdier, 2011)

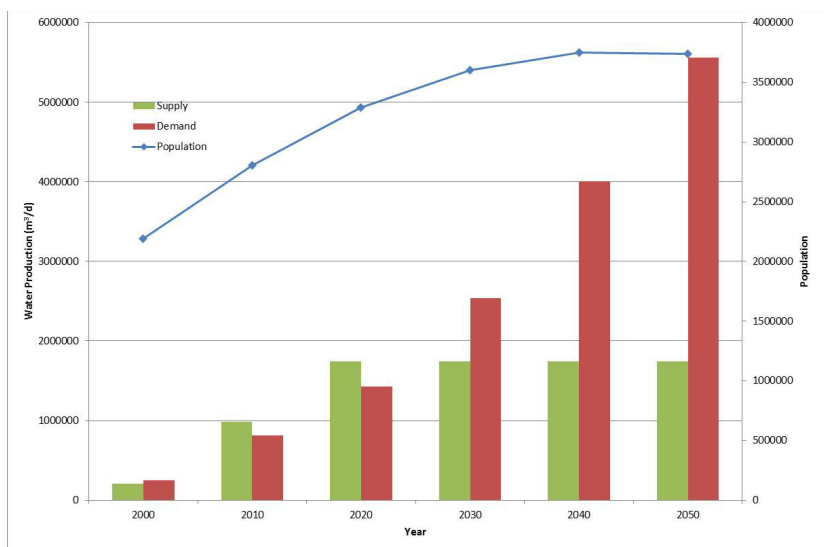


Fig.20: Supply and demand of desalinated water with the population trend in Oman (DesalData, 2013;ESCWA, 2013; World Bank Group, 2013; Verdier, 2011)

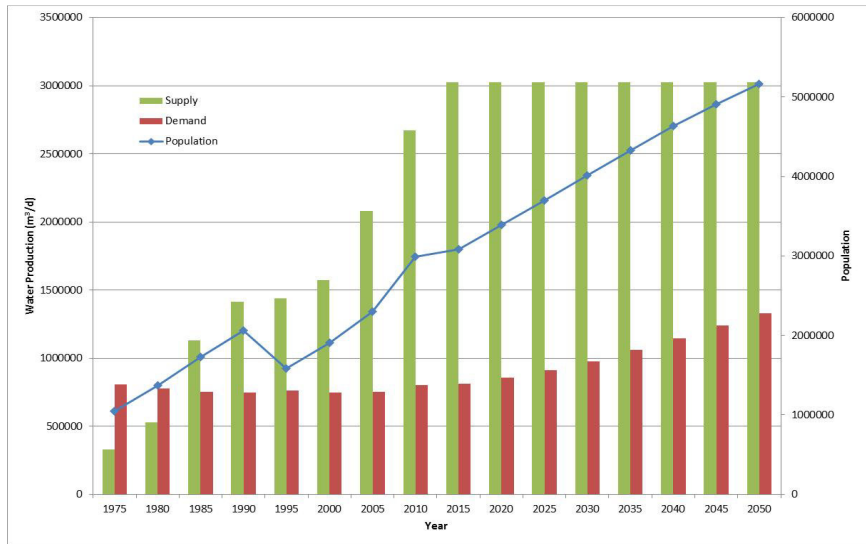


Fig.21: Supply and demand of desalinated water with the population trend in Kuwait (DesalData, 2013;ESCWA, 2013; World Bank Group, 2013; Verdier, 2011)

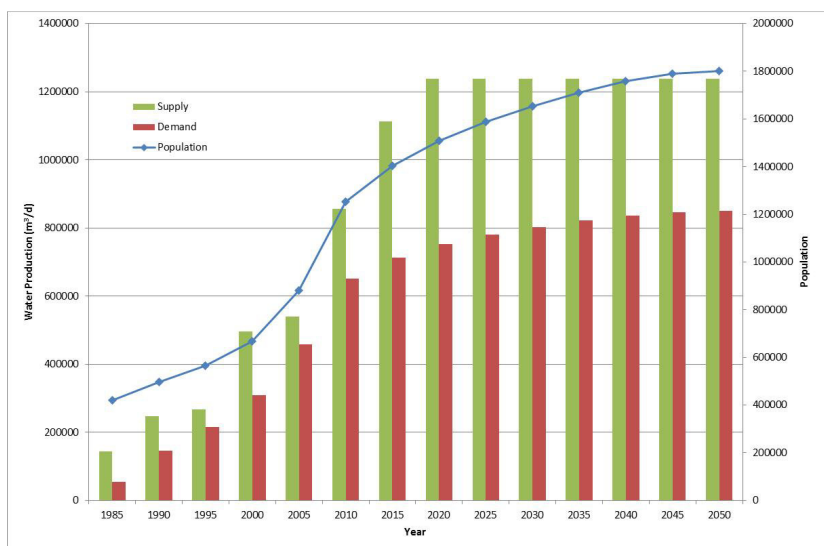


Fig.22: Supply and demand of desalinated water with the population trend in Bahrain (DesalData, 2013;ESCWA, 2013; World Bank Group, 2013; Verdier, 2011)

4. Technologies implemented in the GCC countries

Reverse Osmosis, a membrane technology, has dominated the world desalination industry over the past three decades as manifested in Fig.23. Nonetheless, in the ESCWA region, and more so in the GCC economies, thermal technologies are dominant. This is exhibited in the Fig.23 below (Sommariva, 2010).

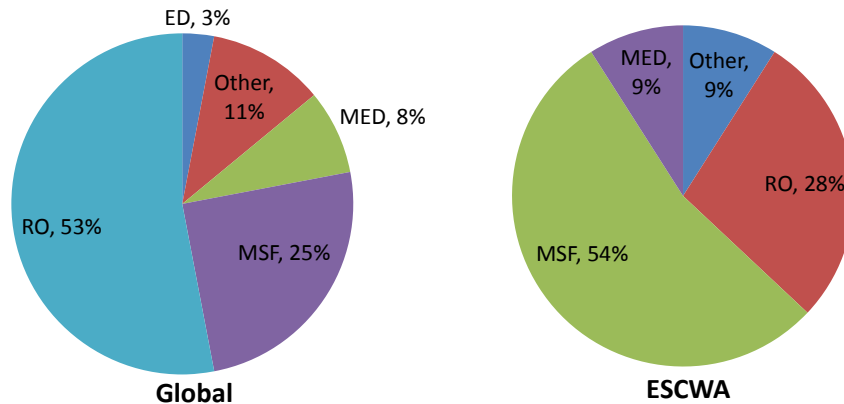


Fig.23: Global and ESCWA desalination capacity by process (Sommariva, 2010)

Thermal technologies are a common place in the GCC region owing to the fact that many of the firms in this region optimize on the fuel to co-generate both water and electricity. However, in the regions where electricity is available and the feed water is brackish, membrane technology comes in handy. Ideally, contemporary commercial technologies in place today can be classed as either thermal or membrane technologies. The thermal technologies include MSF, MED and VC (Vapor Compression). On the other hand, the membrane technologies include SWRO (Seawater Reverse Osmosis), BWRO (Brackish Water Reverse Osmosis), ED (Electro-dialysis) and NF (Nano-Filtration). The membrane technology to be adopted is dependent on the degree of salinity in the brackish water. While ED is more efficient for low salinity brackish water, RO is more efficient for higher salt concentration feed-water. In the MENA region, the MSF technology is the dominant technology. Fig.24 shows proportions of a diversity of technologies applied in this region but cumulatively since the year 1965. However, over the years, RO has been slowly gaining dominance.

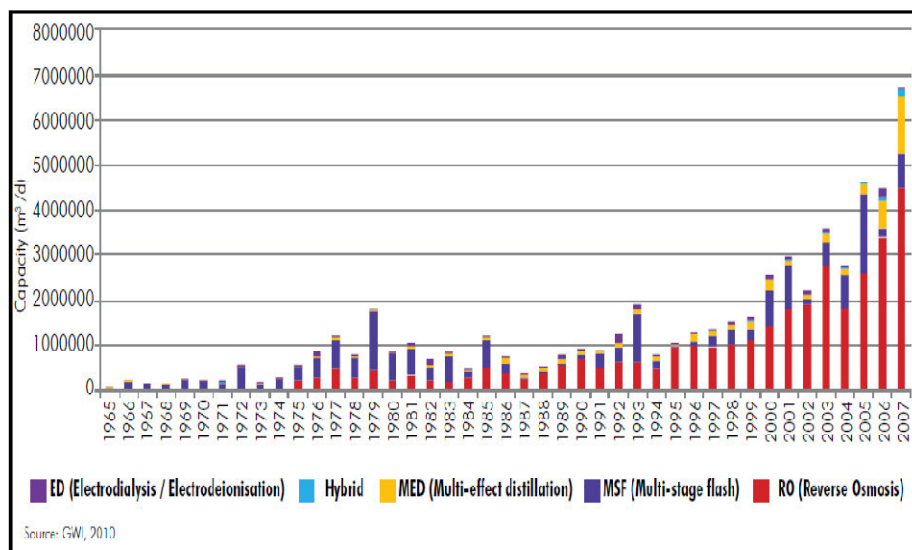


Fig.24: Global contracted capacity by technology in 2010 (Global Water Intelligence, 2010)

RO is slowly gaining dominance owing to the fact that it is cost-efficient, and of late, there has been an improvement in the membrane technology to enhance its efficiency. Contemporary applications adopt hybrid technologies which combine both thermal and membrane technologies to achieve efficiency, low-cost operations and to co-generate electricity. Some of the hybrid combinations include MED/RO and MSF/RO.

In the meantime, there is a pilot project to determine the competitiveness of NF/MSF/MED/RO combination which is set to revolutionize the desalination technology. The world over, there are a number of novel desalination technologies that are slowly being developed. These technologies include “membrane distillation, carbon nanotube membranes, aquaporin (biomimetic) membrane, forward osmosis, and electro-dialysis/deionization”. Nonetheless, skeptics doubt whether these technologies would have a significant effect in the desalination industry.

The GCC sub-region has the highest concentration of desalination plants worldwide. The Arabian Gulf Coast is shared among seven ECSWA economies. Of these members, it is only one member who does not belong to the GCC sub-region. As a matter of fact, for most of the GCC members, the Arabian Gulf is the only source of their feed-water. To these nations, most of the plants are stationed near the major cities which are always located at the coastal line (Fig.25). For instance, in Saudi Arabia, they are located in Al-Jubail and Al-Taweelah among other coastal cities. Fig.25 shows the locations of different plants by technologies located along the coastal strip of the Arabian Gulf.

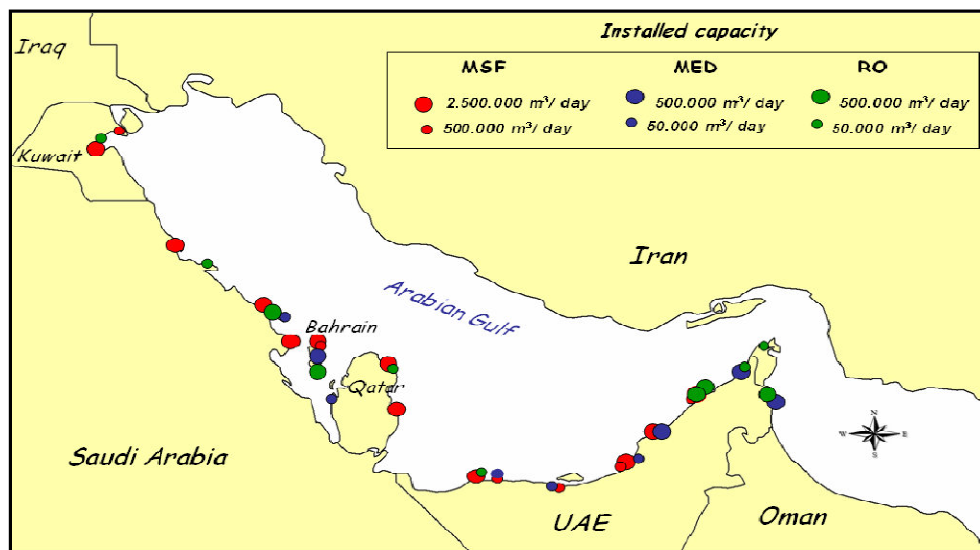


Fig.25: Major desalination plants in the Arabian Gulf region(Dawoud, 2012)

The GCC countries produces about 70% of the world production, with KSA and UAE as leading countries. Although RO is the dominant desalination technology of the world (about 60%), thermal processes like MSF and MED continue to dominate in the GCC countries. This is due to the poor quality of Gulf waters known as 4 H: High salinity, High Turbidity, High temperature and High marine life and the large base of thermal desalination units which has proven high operational reliability and can be conveniently integrated with power plants. Commercial desalination plants started making their appearance in 1960 and most of these were based on thermal processes. MSF became popular and many commercial plants were set up using this technique, especially in the Arabian Gulf. Membranes entered the desalination market in the late 1960s and were initially used for brackish water treatment. The next decade saw the use of reverse osmosis (RO) membranes in seawater desalination.

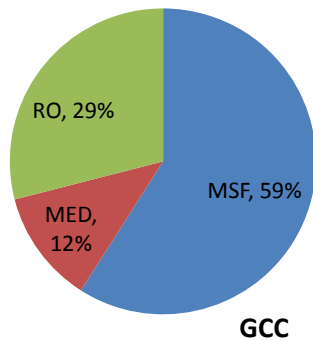


Fig.26: Desalination capacity by technology in the GCC countries (DesalData, 2013)

The charts in Fig.27 show 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 waters of the Red sea and Indian Ocean are more suitable as feed water to RO than the Gulf sea water due to low salinity and clarity).

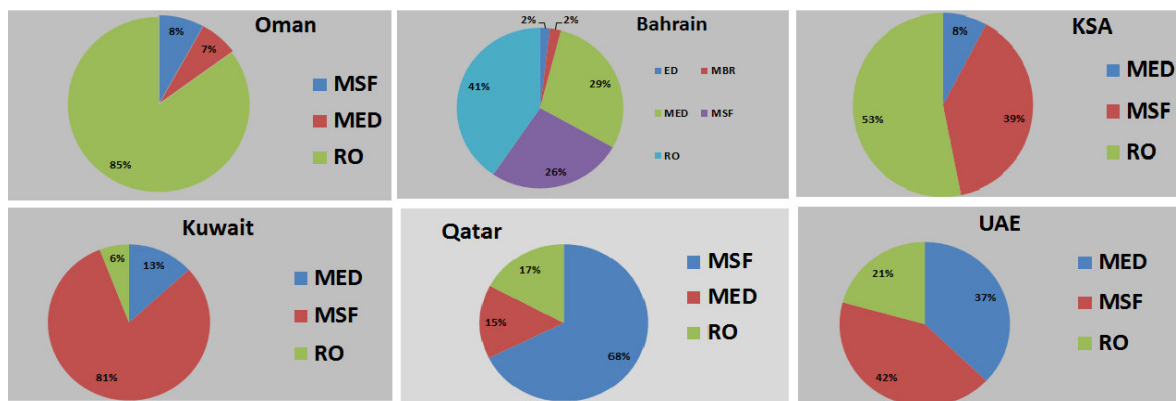


Fig.27: Desalination capacity by technology (DesalData, 2013)

5. Cost of desalination

Desalination industry is a capital intensive project that requires optimization of factors to limit on the cost of the product. Those technologies with lower operation cost (OPEX) options always tend to be responsive to both the operating skills and the quality of the raw material (feed water). The CAPEX is a function of the quality of the raw material, “production capacity, required infrastructure, plant efficiency, material selection and other location factors”(Dawoud et al., 2006). For majority plants, the CAPEX always ranges between \$1000 and \$2000 per cubic meters. Both the CAPEX and OPEX are vital in determining the final cost of water. Also, as typified in the Fig.28 below, the unit cost is dependent on the technology which is proportional to the cost of oil.

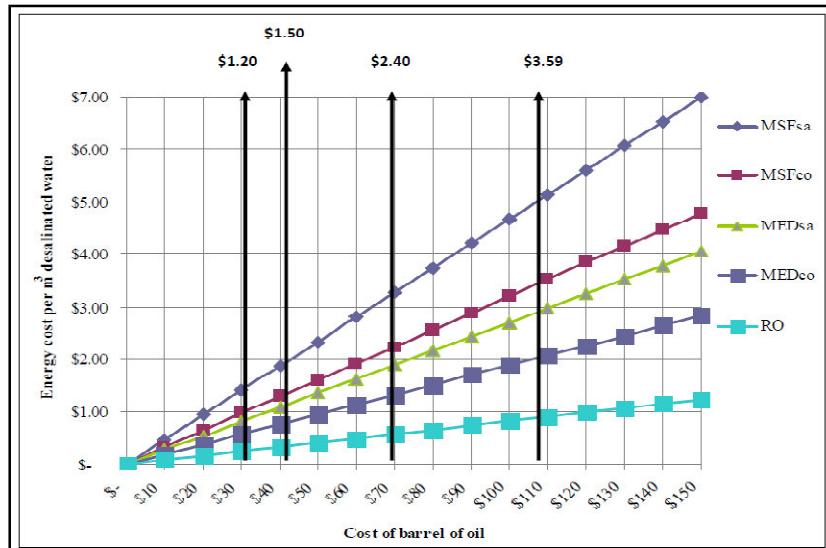


Fig.28: The energy cost of desalination in relation to the cost of oil(Dawoud et al., 2006)

Also, as typified in Fig.29, OPEX is a function of the technology. To this end, the RO technology attracts the least operation cost.

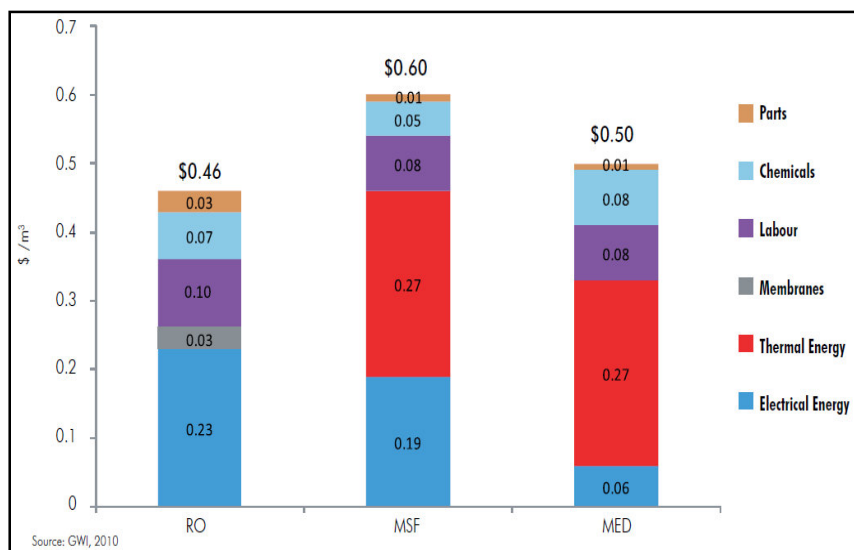


Fig.29: Relative operating costs of desalination processes in cogeneration plants (Global Water Intelligence, 2010)

As outlined above, cost management is very sensitive in determining the final cost of the product. A “different policy discourse can have a massive effect on the unit cost”(Global Water Intelligence, 2010). For instance, government agencies need to shift focus to being purchasers of the product (water) rather than procurers of plants. This will enhance the establishment of most efficient technologies. Furthermore, this would shift the government roles from being an operator to a regulator.

Since MSF is an energy-intensive process, integrating it with power generation helps to reduce the cost. RO processes have also been integrated with MSF/power cogeneration systems. When RO and MSF are in parallel operation, capital savings result from the use of common intake–outfall facilities. This kind of a plant is in operation at Fujairah, UAE and is one of the largest desalination plants in the world. It has a

production capacity of 500MW of electricity and 54,200m³/d of water. A solar–MED plant built in Umm Al Nar, Abu Dhabi has a desalination capacity of 120m³/d. The Layyah plant in Sharjah integrates RO with MSF and MED thermal systems. Using nuclear power for desalination is a challenging option to reduce the cost of desalinated water for GCC countries. Wind or solar energy could be used to power the desalination plants but these sources are subject to variable intensities while desalination processes are designed for continuous operation. To reduce environmental impacts and enhance sustainability, there is ongoing research to integrate membrane processes like RO, NF with crystallization methods to achieve zero liquid discharge.

Table 2: Desalination costs and revenue(Akber, Kuwait Institute for Scientific Research Water Resources Center)

Country	Cost (US\$/m ³)
Bahrain	0.65
Kuwait	1.98
Oman	1.34
Qatar	1.31
KSA	1.35
UAE	1.16

6. Policy initiatives for Abu Dhabi Vision 2030

In order for Abu Dhabi to realize Vision 2030 of establishing a sustainable economy, then availability of water, a sector vital to its economy need to be effectively managed. Since the dominant technology in this region is thermal-related, there is need to limit on the over-reliance on fossil fuel (a non-renewable energy). This can be minimized through recycling of wastewater. The product (water) can be useful for both agriculture and landscaping. Also, this vision can be realized when initiatives are in place to minimize losses emanating from leakages and wasteful usage. Control of wasteful usage of water can be realized through public awareness. Finally, the government ought to encourage potential investors to employ renewable energy-based technologies in desalination plants, an environmentally sound technology(Dawoud et al., 2006).The initiatives towards a more sustainable water economy in Abu Dhabi by 2030, can be summarized under five categories:

6.1. Water demand reduction

To have a sustainable economy, demand management should be prioritized over supply enhancement strategies to be able to balance between the current/futuristic increase in the demand of water and the limited resources for supply. Managing the demand is not only influenced by the behavior of consumers, but technical efficiency also affects the input/output ratio of the system. Some recommended policies to decrease the water demand are:

1. Creating a holistic water management strategy through Integrated Water Resource Management (IWRM) approach. This could be developed by research and building national master water plans to assess the current state of water, identify its inefficiencies, optimize through initiatives and adopting new policies that should be then circulated among organizations for implementation. Singapore is an exemplary example of a country that developed a successful IWRM system(Onn, 2005). Singapore have figured out their main five challenges and faced them; they have protected their water resources through turning half of its limited land area into water catchments, reclaimed water called

“NEWater” became a source of safe drinking water in a cost effect manner, they also minimized wastage in water supply system by implementing leakage control and accurate metering policy, a community driven program called Water Efficient Homes was implemented to conserve water by fitting water saving devices into taps, and finally closing the water loop through their NEWater initiative.

2. Increasing public awareness through campaigns that are led by relevant governmental authorities.
3. Variation of water tariffs depending on the level of consumption can influence the demand. The implementation should start on industries and agriculture, as they will respond swiftly to small price changes due to them being the highest consumers in UAE. Bahrain is one of the GCC countries that already executed this policy where the tariff increases when the consumption is more than 450 m³/day.
4. Technical efficiency improvement through installation of accurate meters for water, replacement of old piping to avoid leakages, and encouragement to use new efficient technologies through regulations or incentives(Saif, 2012).
5. Efficient water consumption in the agricultural sector is vital due to the arid climate of the UAE. Therefore, planting crops with the least water demand is favorable method to reduce irrigation, banning irrigation during the afternoon period due to the high evaporation rate, and adopting new technologies that would serve longer water retention in soil.

6.2. Energy supply from clean/renewable energy sources

As Abu-Dhabi vision 2030 includes the goal of diversifying the sources of energy instead of the domination of fossil fuels and natural gas, the leadership of Abu-Dhabi has committed to secure 7% of its total energy needs from renewable sources by 2020. Due to the importance of the desalination industry in the region, renewable energy can be integrated into the desalination plants energy supply system. But such transition requires a renewable energy road map at the emirate and national based level. Additionally, there will be the need to decouple the water and energy production, as co-generation plants are the main method used nowadays. There will also be a need for many policy changes to create this transition because the current prices of fossil fuels are cheaper than some renewable energy sources (ex. solar and wind energy), such polices could be: 1) phasing out fossil fuel subsidies, 2) promotion of small and medium scale developments (ex. rooftop PV panels), and 3) tax incentives to businesses and rebate program for consumers. However, nuclear might have a high chance of dominating the industry in the future (Saif, 2012).

6.3. Water supply augmentation

Enhancing the water supply system sustainably is very essential for the country to be able to meet the future demand of the exponentially increasing population. This could be achieved through the following policies:

1. Increasing the rate of reclaimed water utilization through treating the wastewater at high levels depending on the intended end-use of the treated water. The country can start with using reclaimed water for irrigation, landscape decorations (ex. fountains), and gradually improve the level of treatments to be used domestically. Singapore produced the first drinkable reclaimed water in 2010 after their research since 1974. From advanced dual membrane to ultraviolet technologies are used to produce NEWater and it is projected to meet 50% of Singapore’s future water demand in 2060.
2. Increasing desalination capacity comes as an option after demand management and reclaimed measures exhaustion. Additionally, relevant authorities should set rules mandated to regularly refer

to their country's IWRM strategy before asking for tenders on any new desalination project (Saif, 2012).

3. Increasing system capacity by reservoir investments and conservation on existing groundwater. Abu-Dhabi is currently implementing the aquifer storage and recharge (ASR) technology; EAD in collaboration with ADEWA have conducted a feasibility study in 2002 and started a pilot study in 2003 on Artificial Recharge for Aquifer Storage and Recovery to save the surplus desalinated water production for future water needs in case of high seasonal demands and emergencies (Dawoud, 2012). The completion of this project in 2014 will also increase the storage water capacity from 2 days in the time being to 90 days continuous supply to Abu-Dhabi's population.

6.4. Increase environmental management

All of the previous points mentioned above decreases the environmental impacts of desalination whether directly or indirectly. However, there are certain mechanisms, specifically related to desalination process, that directly influences the environment and setting mitigation measures can hugely reduce the impacts.

1. After selecting the site of the desalination plant, the most suitable intake pipes should be chosen to reduce impingement and entrainment level of marine organisms at intake pipes. This could be accomplished through installation of subsurface intake pipes such as vertical wells, horizontal collector wells, slant wells and engineered infiltration gallery (Reynolds and Maley, 2008). On the other hand, open water intake could be utilized with velocity caps to reduce impingement and travelling water screens to reduce entrainment when coupled with velocity caps (Reynolds and Maley, 2008).
2. Saving the seawater's ecosystem through controlling the brine discharge by desalination plants. In the current situation, the country may implement a better way of discharging which is brine dilution and dispersion through discharge diffuser away from the coast to reduce the thermal pollution. A regulation should be enforced for the brine temperature to be maximum 3 degrees higher than the intake water.
3. Setting a regulating for the concentration of greenhouse gases produced, which is hugely dependent on the source of energy used.

6.5. Institutional

Enhancing the opportunities for research and development by integrating research into private sector jobs as well and governmental. Declaring the need for more research in the areas of new desalination technologies, membranes, hybrid systems there is a need for water demand management and it should become a driving force in all the GCC countries. The GCC countries are the world's leaders in desalination technology but they should also thrive to be the leaders in demand management too. There should be policy initiatives based on ingenuity and creativity to curb the ever rising demand for water, creating site-specific studies for choosing the water intake pipes, and encouraging and supporting the population to work on that (Saif, 2012).

7. Conclusions

The GCC countries are the world's leaders in desalination technology but they should also thrive to be the leaders in demand management too. With the rapid increase in population and standard of living, the demands for water is rising at an alarming rate. If this demand is not controlled, it might lead to a substantial investment to augment the desalination capacity. There is an urgent need to implement a new set of legislation targeting the rationalization of water use, and increase the level of public awareness of water

scarcity and the need for the downscaling water demand to yield positive results. Installation of water-saving equipment within residential homes, public utility buildings, and commercial centers, introduction of drip irrigation and sprinklers for irrigation of private and public gardens, and limiting the timings of irrigation should save a large volume of water. Implementation of measures to protect the available water resources from environmental degradation both from natural and man-made causes and overuse will maximize the utility of the available water resources. With very vulnerable groundwater resources and delicate marine environment, the GCC countries should adopt a friendly-ecosystem approach in integrated water resources management. Groundwater should be adequately protected by using the best of practices, examples and experiences. Environmental education should be given due prominence in school curricula.

Abbreviations

ASR	Aquifer Storage and Recharge
ESCWA	Economic and Social Commission for Western Asia
GCC	Gulf Cooperation Council
GWI	Global Water Intelligence
IWRM	Integrated Water Resource Management
KSA	Kingdom of Saudi Arabia
MED	Multi-Effect Distillation
MENA	Middle East and North Africa
MSF	Multi-Stage Flash
NF	Nanofiltration
RO	Reverse Osmosis
UAE	United Arab Emirates

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