The Future Outlook of Desalination in the Gulf:

Challenges & opportunities faced by Qatar & the UAE

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1. Introduction:

When one thinks of a city such as Dubai, the firth thing that may come to mind is the city's sparkling skyscrapers or its vast wealth. However, like many other cities along the Persian or Arabian Gulf (simply referred to as the Gulf in this report), the economic prosperity is largely attributed to the discovery and exploitation of fossil fuels following WWII, along with more recent contributions from the tourism sector (Mansfield & Winckler, 2007). This oil wealth has led to the profound transformation of impoverished small desert principalities to modern wealthy nations (Mansfield & Winckler, 2007). This transformation resulted in major economic, social and environmental changes, which continue to this day. Countries of the Gulf Cooperation Council (GCC) which include; Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates boast some of the highest per capita incomes and the fastest growing economies in the world (The Economist Intelligence Unit, 2009). From 1998 to 2008 real GDP grew at an average rate of 5.2% annually for the GCC, with the population increasing at an average rate of 14% annually for the same time period (Economist Intelligence Unit, 2009). However, to achieve this level of economic development means meeting the ever increasing demand for energy and freshwater (Bachellerie, 2012).

The discovery of oil and gas in GCC countries resulted in them becoming among the world's top fossil fuel exporters (Reiche, 2010), however water remained a major issue (Bachellerie, 2012). The Gulf region is home to some of the most water scarce countries in the world, classified as hot desert climates (BWh) under the Koppen Climate Classification (Institute of Veterinary Public Health, 2011). The limited non-renewable groundwater resources could not sustain the growing population of GCC states and their increasingly water and energy intensive lifestyles (World Bank, 2005). Natural freshwater resources per capita per year range from 60 to 370 cubic meters across GCC countries (World Bank, 2005) and is expected to decrease by 20% in the future due to climate change (Al-Zubari, 2012). As such, desalination has become the backbone of many GCC states, supplying as much as 99% of potable water needs (Al Malki, 2008), and representing 57% of global desalination production (DesalData, 2012). The heavy reliance on desalination in the region coupled with its high energy requirements has led to a strong linkage between the energy and water sector that is unique in the global context (Al-Attiya, 2012).

For this study, Qatar and UAE were chosen as case studies for the GCC countries. Although there are noticeable differences between these countries, they remain similar in many aspects, particularly in their fossil fuel wealth, political landscape, socio-economic state and heavy reliance on desalination (The Economist Intelligence Unit, 2009; World Bank, 2005). Qatar and the UAE, whose country profiles are available in Appendix 2, both demonstrate high levels of economic and population growth. Table 1 below, demonstrates important growth indicators for both countries.

Table 1: Growth indicators for Qatar and the UAE

Indicator	Qatar Growth (%/year)	UAE Growth (%/year)
Population growth rate:	4.93 (2012 estimate)	3.06 (2012 estimate)
GDP real growth rate:	14.1 (2011 estimate)	5.20 (2011 estimate)

Data from CIA World Factbook

The goal of this report is to provide a future outlook for desalination and the water/energy sectors in Qatar and the UAE by illustrating some of the major challenges and opportunities in terms of long-term sustainability and to then provide policy recommendations based on the findings.

The objectives of this report are to:

1) Analyze the current state of the water energy sectors in Qatar and UAE and assess how desalination links the two sectors.
2) Identify current and planned government policies and how they impact the sustainability of the water/energy sectors in Qatar and UAE.
3) Provide recommendations on how desalination can be made more sustainable for Qatar and UAE through policy adjustments to the water and energy sectors.

1.1. Research Methodology

Research for this report was carried out using multiple methodologies, including primary qualitative field research and secondary research involving literature reviews. From April 15th to May 15th 2012, qualitative research through informal interviews was carried out in Qatar and the UAE. Two weeks were spent in Doha, five days in Dubai/Sharjah and nine days in Abu Dhabi. The objective of the qualitative research was to meet with various regional experts who could provide breadth and depth on the future outlook and sustainability of desalination in the two countries from a technical, economic, environmental and political lens. Appendix 1 outlines the major organizations interviewed. Two major conferences were also attended, The 10th Gulf Water Conference and INCONET-GCC Conference. The 10th Gulf Water Conference held in Doha focused on the Water-Energy-Food nexus while the INCONET-GCC Conference focused on GCC research and policy cooperation, particularly in water, environment and climate. In terms of secondary research, the report uses data and information collected from a variety of sources including: academia, government, industry and UN reports, along with international data banks such as DesalData.

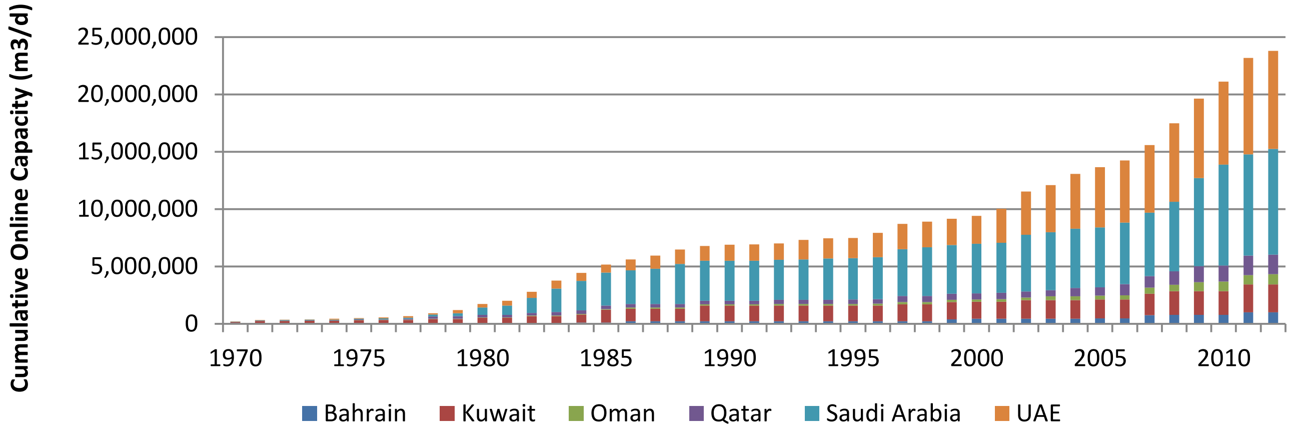
2. Desalination in the Gulf

2.1. History:

The history of desalination in the Gulf is strongly linked to the history of oil. Following the discovery of oil in the Gulf, and particularly after the Second World War, large foreign investments began taking place in oil exploration throughout the Gulf region (Al-Faris, 2002). However, the relatively small population along with limited human capital available prompted GCC countries to open their borders to foreign workers, and hence began the influx of expatriates and the rise of many Gulf cities (Winckler, 1997). Up until that point, the water needs of GCC states were met primarily through existing groundwater; in the mid 1950's, freshwater in Abu Dhabi could be obtained by simply digging down into the sand (IDA, 2012). However, the increasing burden on groundwater along with its increasing quality degradation meant a technical solution was required to meet the growing demand of water (IDA, 2012). It was at this point in time that early thermal desalination technologies such as Multiple Effect Boiling (MEB) were introduced to the Gulf (IDA, 2012), Multi Stage Flash (MSF) being introduced after its invention in 1958 (EAD, 2009). Desalination gained significant traction in GCC states by the 1980's as illustrated by Figure 1 which shows the cumulative installed desalination capacity in GCC states since

1970. The main reason for the sudden boom was the 1973 oil price spike which provided many GCC countries with the funds necessary to make major investments in their water and energy infrastructures (EAD, 2009).

Figure 1: Cumulative Installed Desalination Capacity in GCC States Since 1970



2.2. The Desalination Process:

According to Global Water Intelligence, desalination is defined as “the process of removing salt and other minerals from water”. The primary objective behind the process is to generate potable drinking water from either seawater or brackish water (Elimelech & Phillip, 2011). However, the process can also be used to generate ultrapure water for certain industrial processes (Elimelech & Phillip, 2011).

The greater the salinity of the feedwater is and the greater the desired purity then the greater the energy input required for the process (DesalData, 2012). In the context of desalination, salinity or the measure of the totally dissolved solids (TDS) is most commonly measured in milligrams per litre (mg/L); parts per thousand (ppt) or parts per million (ppm) (DesalData, 2012). Below are the salinity ranges for various water sources (DesalData, 2012).

- Brine water: >50,000 mg/l TDS or >50 ppt
- Seawater: 15,000-50,000 mg/l TDS or 30-50 ppt
- Brackish water: 1,500-15,000 mg/l TDS or 0.50-30 ptt
- Pure water: < 500 mg/l TDS or <0.50 ppt

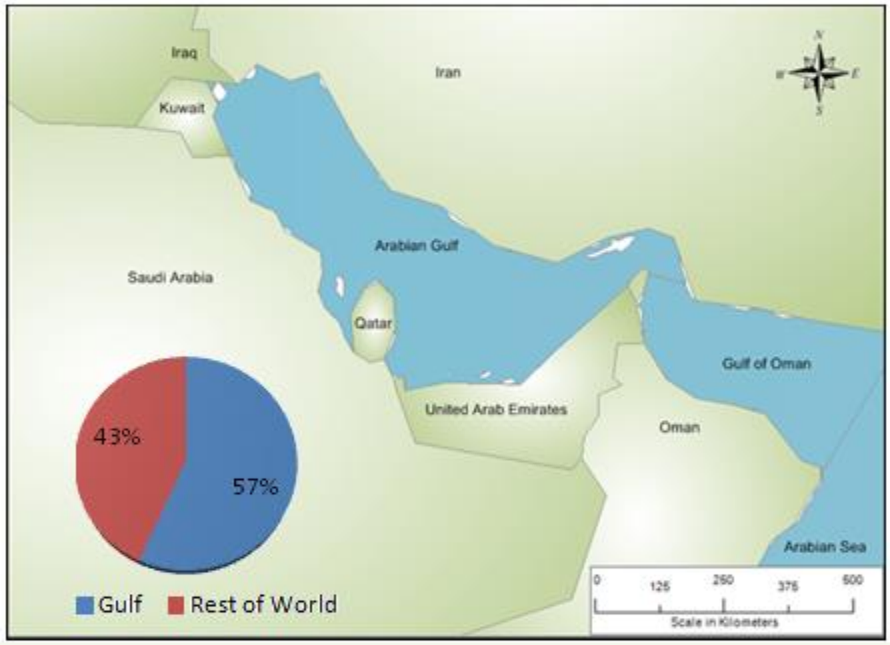
There are numerous desalination processes available, particularly in smaller scale applications (Elimelech & Phillip, 2011), however for large scale seawater desalination they are most often classified into one of two groups, thermal and membrane based (Shannon et al, 2008). Thermal processes such as Multi-Stage-Flash (MSF) and Multiple-Effect-Distillation (MED) evaporate out the water and then re-condense it (Elimelech & Phillip, 2011). Membrane based processes such reverse osmosis (RO) force feedwater through a semi-permeable membrane that blocks out various particulates and dissolved ions (DesalData, 2012). These processes are outlined, explained and compared in Appendix 3. It is worth noting that significant research is currently taking

place into the improvement of existing technologies particularly through hybridization with other technologies such as nano-technology (Shannon et al, 2008).

2.3. Physical characteristics of the Gulf:

The Gulf is a semi-enclosed sea with an area of 240,000 km^2 connected to the Gulf of Oman through the Strait of Hormuz (Purnama et al, 2005). It is fed mainly by the Euphrates and Tigris rivers from Iraq which converge at the Shatt Al-Arab delta (Purnama et Al, 2005). Countries with coastlines on the Gulf include Oman, UAE, Qatar, Saudi Arabia, Kuwait, Iraq, and Iran, as illustrated in Figure 2 (Hopner & Windelberg, 1997). The semi-enclosed nature of the Gulf coupled with an evaporation rate of 1.4-2.1 m/year, river runoff of 0.15-0.46 m/year and precipitation of 0.07-0.1 m/year explains the Gulf's hyper-saline and shallow nature (Nadim, et Al, 2008). Average surface salinity is around 40 ppt (Purnama et Al, 2005). The average depth of the Gulf is 35m, with a maximum depth of around 100m (Nadim, et Al, 2008). Average temperatures range from around 22°C in the winter to 33°C in the summer (Sale et Al, 2010).

Figure 2: Map of Gulf & Share of Global Desalination



Map created by Omar Saif

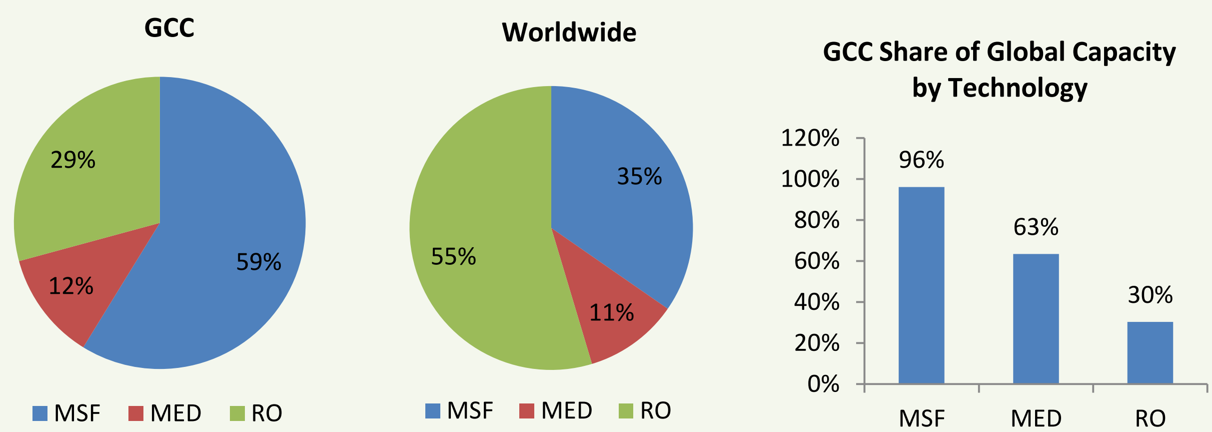
2.4. Desalination Technology in the Gulf

Historically, the physical characteristics of the Gulf played an important role in determining the choice of desalination technology, particularly for the countries of Kuwait, Qatar and Bahrain which have access only to Gulf waters as feedwater (DesalData, 2012). However, some GCC states such as the UAE, Oman and Saudi Arabia benefit from having access to other water bodies such as the Arabian Sea and Red Sea (Fath, 2012). The harsh conditions of the Gulf make desalination in this region particularly difficult, despite 57% of the world's desalination capacity taking place in this relatively small water body as illustrated in Figure 2 (DesalData, 2012). The high salinity and temperature have particularly influenced the choice of technology used in the Gulf (Fath, 2012).

As Figure 3 illustrates, the majority of the world's thermal use by capacity takes place in the Gulf (roughly 88%) (DesaData, 2012). This is despite RO's greater energy efficiency and dominance outside of the Gulf (Elimelech & Phillip, 2011). The Gulf's high temperatures, salinity, and turbidity, coupled with the presence of marine

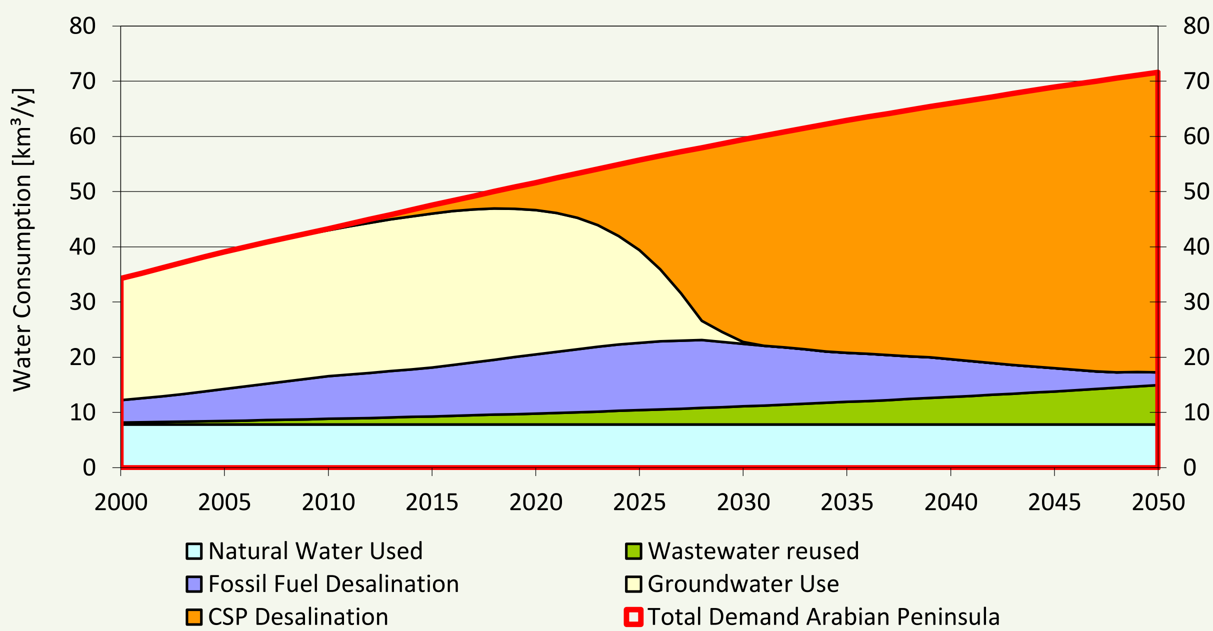
organisms have traditionally contributed to high pre-treatment costs for RO (Fath, 2012). Cheaply available low grade steam from gas-fired power plants also explains the dominance of thermal technologies in the Gulf (DesalData, 2012). However, recent advances in membrane technology along with other technological innovations that reduce or even eliminate pre-treatment have increased the uptake and interest of RO technology in the Gulf (DesalData, 2012). See Appendix 3 for more information on desalination technologies, comparison and trends.

Figure 3: Online desalination capacity by technology in GCC and worldwide 2012



2.5. Growing demand for water & electricity in the Gulf

Figure 4: AQUASTAT 2004 Water Demand Projection for GCC Countries & Yemen

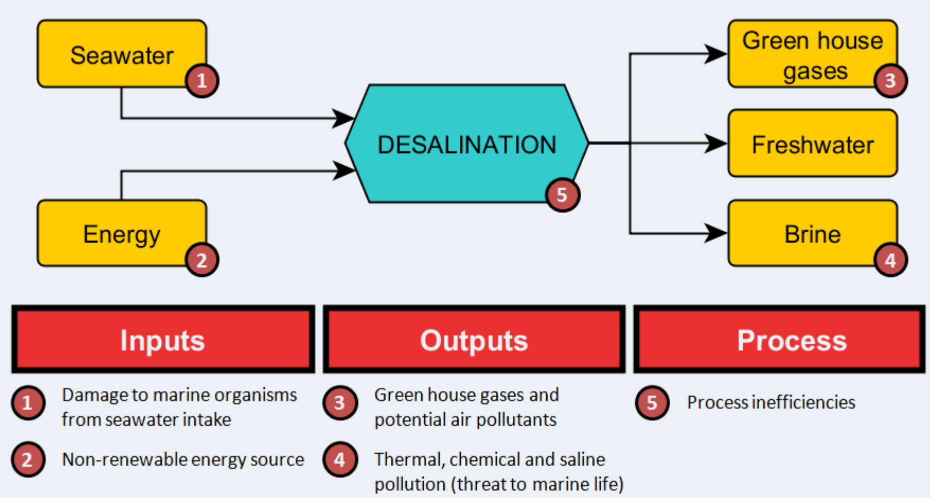


For many GCC states, the demand for water and electricity is seemingly ever increasing, with a proliferation of investment in supply capacity to meet growing demands. While most GCC countries including Qatar and the UAE are currently reporting surplus water and energy production, future forecasts suggests that trend will likely change. Figure 4 is a projection by Aquastat for GCC countries and Yemen that forecasts expected water demand until 2050 (Trieb, & Mullersteinhagen, 2008). The projection is a scenario in which water needs are met through a combination of fossil fuel desalination, concentrated solar power desalination and wastewater reuse. Based on the projection, by 2050 - desalination irrespective of its fuel source, would account for 76% of all water needs for the region for all sectors (Trieb, & Mullersteinhagen, 2008).

3. Environmental impacts associated with desalination:

There are numerous environmental concerns associated with current desalination practices in the Gulf. Figure 5 below highlights the primary areas of concern. They can be categorized as input concerns, output concerns, and process concerns.

Figure 5: Desalination Inputs, Outputs & Concerns



Adapted from Medeazza, 2005

In terms of inputs, the current use of non-renewable energy, mainly natural gas is problematic for both its output, as well as the sustainability of the energy source (Medeazza, 2005). Given the heavy reliance on desalination for the freshwater needs of GCC countries, a sustainable source of energy for desalination would ensure that the water produced is also renewable (Trieb & Mullersteinhagen, 2008). Furthermore, it is estimated that when desalination is coupled with renewable energy sources, the environmental load can be reduced by 80-85% (Medeazza, 2005).

An addition input concern is the seawater intake water pipes for desalination plants (Lattemann & Hopner, 2008). Organisms living with in the vicinity of the desalination plant's intake pipe can collide with the intake screens (impingement) or be sucked in with the feedwater in to the plant (entrainment) (Lattemann & Hopner, 2008). Due to lack of data and ability to quantify the rates of impingement and entrainment, the associated environmental impacts are often overlooked even though they may represent the most significant and direct effects from desalination (Pankratz, 2004). The threat of intake pipes on the marine environment is highly variable and dependent on the technology employed for seawater intake; how far the intake pipe is from the shore as well whether the intake pipes are open sea or subsurface (Pankratz, 2004; Reynolds & Maley, 2008).

In terms of outputs, the use of fossil fuels, mainly natural gas as the energy input presents an environmental concern from a climatic perspective (Medeazza, 2008). This is due to the greenhouse gases that are spewed into the atmosphere resultant from the gas-fired power plants that supply desalination plants with the required steam and electricity (Trieb & Mullersteinhagen, 2008). Based on current production, desalination plants in Qatar consume around 1.54 billion kWh of electricity annually, which roughly translates to around 680,000 metric tons of CO_2 equivalents per year (Sovacool, 2008). This value excludes steam consumption for thermal desalination plants, which if accounted for would significantly increase the estimated value. The percentage of energy used for the desalination process from cogeneration facilities is also staggering. Energy used for water production from cogeneration plants stands between 20 to 45% in Abu Dhabi (EAD, 2009). This translates roughly into 4 to 9 million tonnes of CO_2 equivalent per year for the emirate of Abu Dhabi alone (EAD, 2009).

Lastly, one of the most significant areas of environmental concern when it comes to desalination plants is brine management (Ahmed et al, 2001). Brine discharge is often a mixture of saline concentrate, along with thermal and chemically added pollutants (Medeazza, 2005). The solution's salinity concentration is largely dependent on the technology employed; though often double the ambient seawater salinity (DesalData, 2012). In addition to the added salinity, the brine mixture often contains numerous chemicals employed in pre-treatment such as: antiscaling additives, antifouling additives, halogenated organic compounds formed after chlorine addition, antifoaming additives, anticorrosion additives, and oxygen scavengers (Hopner & Windelberg, 1997). Furthermore, if thermal desalination is the predominant technology employed, as the case with the Gulf, the temperature of the brine mixture will often be above the average sea temperature (Sale et al, 2010). All the aforementioned by-products can negatively impact the Gulf's native biota; be they mangroves, corals or other aquatic species (Sale et al, 2010); particularly given the brine's density which sinks it to the bottom of the seabed where most ecological activity takes place in the Gulf (Medeazza, 2005).

Coral and mangrove species survive within a narrow set of environmental parameters that if exceeded can lead to ecological stress on the marine populations (Namin et Al., 2009). Coral and mangroves species in the Gulf are unique as they are among the most versatile corals and mangroves, being able to tolerate both high temperatures and salinity (Namin et Al., 2009). Despite the high tolerance of mangroves and coral to this harsh environment, these habitats are still vulnerable to brine discharge (Purnama et al, 2005). Mangroves in both Qatar and the UAE have often been cleared in the process of coastal development (Peter et al, 2010). Mangroves rely on a delicate balance of inland freshwater and seawater, if the seawater becomes too saline or concentrated due to brine discharge, then their growth can become stunted or they may die all together (Burchett et al, 1989). Similarly, corals exposed to high temperatures will undergo a process called coral bleaching, which effectively destroys the coral (Brown, 1997). There is clear evidence to suggest that brine discharge negatively affects marine fauna (Dupavillon & Gillander, 2009); however there remain few studies that assess the direct impacts of desalination on marine organisms (Purnama et al. 2005).

It is also worth mentioning the potential cumulative effects of desalination on the Gulf. The semi-enclosed nature of the water body along with the high desalination rates present a unique case in which the effect of brine discharge by desalination plants must be looked at collectively and cumulatively opposed to singular environmental impact studies (Sheppard et al, 2010). Long term environmental studies on the cumulative impacts of desalination discharge in the Gulf are largely unknown (Purnama et al. 2005).

4. Energy & Water Sectors in Qatar & the UAE:

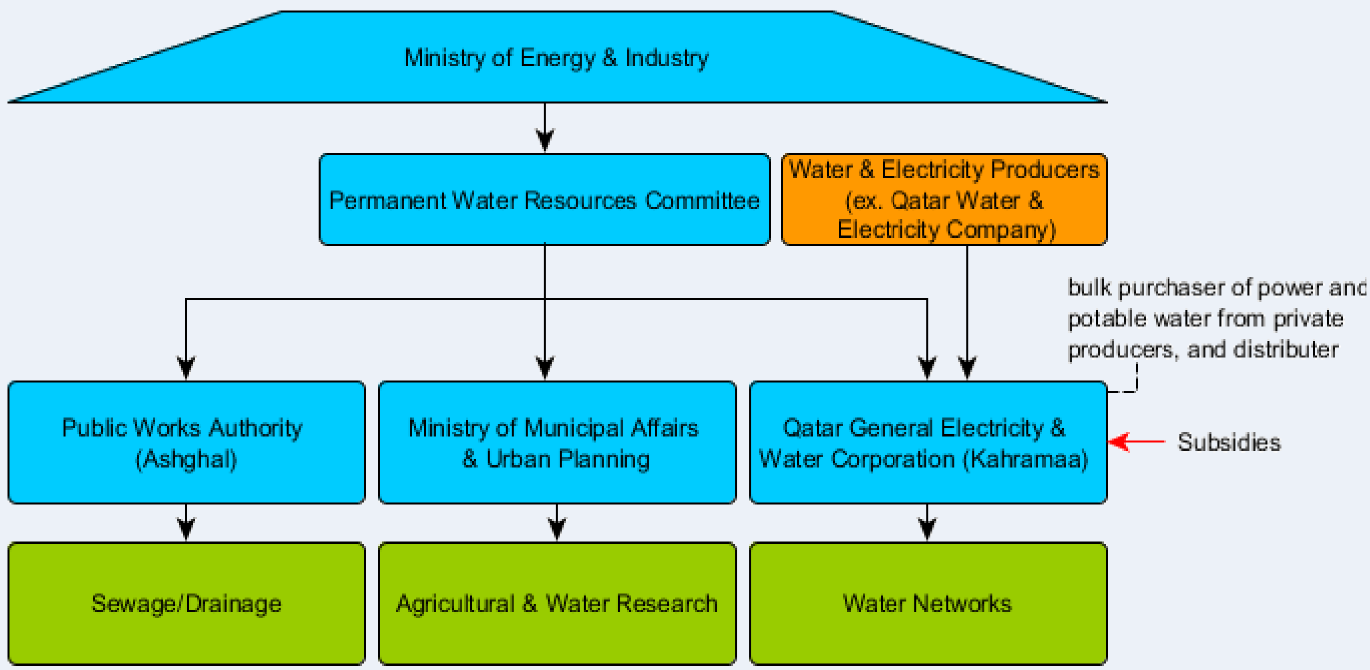
A common characteristic amongst GCC countries is the nexus that exists between water and energy sectors (Al-Attiya, 2012). This relationship is the result of two main factors, the first being the heavy reliance and use of desalination, and the second being the high use of thermal technologies as illustrated in Figure 3. The use of MSF and MED in the Gulf is widespread not only due to the limitations of RO in the region outlined in section 2, but also due to the predominant method of electricity generation, which is through gas fired power plants (DesalData, 2012) . A by-product of the electricity generation process is steam, which can be utilized by MSF and MED desalination plants, for their energy needs (World Bank, 2005). The two plants need to be co-located in order for the desalination plant to capitalize on the generated stream by-product (Elnashar, 2001). This arrangement of power and desalination plants is what is referred to as a co-generation (Elnashar, 2001). Roughly 60% of MSF plants in the UAE are co-generation while that percentage stands at 70% in Qatar (DesalData, 2012).

This technological arrangement is mirrored in how the energy and water sector is set up at the institutional level. As shown in Figures 6, 7 & 8, public sector agencies in both the UAE and Qatar oversee water and electricity transmission, distribution and regulation jointly.

4.1. Energy & Water Sectors in Qatar:

In Qatar water and electricity producers are for the most part private entities, though the government often having sizeable shares of those facilities through independent water and power projects (IWPP) discussed further in 4.3.1 (GWI, 2011). The Qatar General Electricity & Water Corporation, also known as Kahramaa, is the public sector utilities company and the bulk purchaser of power and desalinated water from private producers such as the Qatar Electricity & Water Company (QEWC) (Kahramaa, 2011) through Power & Water Purchasing Agreements (PWPAs) set at 25 year term cycles (DesalData, 2012). Kahramaa buys the electricity and water from the producers at production price then resells it to the population at a subsidized rate (Sunna, 2012). Kahramaa's production cost of desalinated water stands at \$1.64/m^3 while distribution costs \$1.10/m^3, a total of \$2.74/m^3 USD (DesalData, 2012). Qatari nationals receive the electricity and water for free while non-Qatari expats pay for the services at a subsidized rate; roughly 70% of production and distribution cost (Sunna, 2012). Table 2 below outlines the production cost of water and electricity in Qatar while Table 3 summarizes current tariffs for water and electricity for various customer categories. Table 3 also provides the percentage of the cost subsidized for the various customer categories. The permanent Water Resources Committee, under the Ministry of Energy and Industry (shown in Figure 6), is the legal body that oversees water management within the country (GWI, 2011). Legally, Kahramaa is only required to provide potable water to households, however in practice it also supplies freshwater to industry (Sunna, Kahramaa). The Ministry of Municipal Affairs & Urban Planning is in charge of supplying water for agricultural and research purposes while the Public Works Authority, commonly known as Ashghal is in charge of sewage and drainage (DesalData, 2012).

Figure 6: Water & Electricity Production, Transmission & Distribution in the Qatar



Adapted from DesalData

Table 2: Production cost of water and electricity in Qatar

Product	Cost (QAR, before subsidies)	Cost (USD, before subsidies)
Electricity	~0.24/KWh (commercial, residential)	~0.07/KWh
Water	10/m^3	2.74/m^3

Data from DesalData

Table 3: Water & electricity tariffs in Qatar according to various customer categories

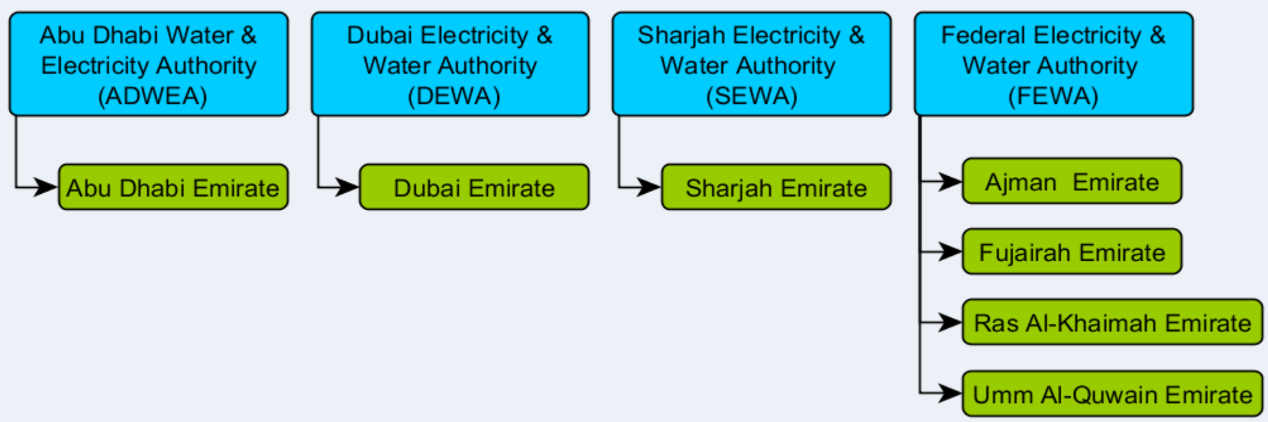
Product	Customer Category	Tariffs (QAR)	Tariffs (USD)	% subsidized
Electricity	Residential Flat	0.08 – 0.1/KWh	0.02 – 0.03/KWh	58.3% - 66.7%
	Residential Villa	0.08 – 0.1/KWh	0.02 – 0.03/KWh	58.3% - 66.7%
	Commercial	0.09 – 0.14/KWh	0.02 – 0.04/KWh	41.7% - 62.5%
	Industrial	0.07/KWh	0.02/KWh	70.8%
	Government	0.15/KWh	0.04/KWh	37.5%
Water	Residential Flat	4.4/m^3	1.21/m^3	55.8%
	Residential Villa	4.4/m^3	1.21/m^3	55.8%
	Commercial	5.2/m^3	1.43/m^3	47.8%
	Industrial	4.4/m^3	1.21/m^3	55.8%
	Government	7.0/m^3	1.92/m^3	29.9%

Data from Kahramaa website

4.2. Energy & Water Sector in the UAE:

The water and energy sectors in the UAE share commonalities with those in Qatar. However, due to the larger population size of the UAE along with decentralization of the country's federal power according to each emirate, the structure of the sectors varies within the country according to the emirate. Figure 7 demonstrates the division of the public sector electricity and water authorities in the UAE according to the recipient emirate(s). The water and electricity authorities of Abu Dhabi, Dubai and Sharjah service their own emirates, while FEWA, the federal agency, services the four northern emirates (DesalData, 2012). Given the varying agencies and respective structures, this section will focus primarily on the emirate of Abu Dhabi which also happens to be the largest emirate in the UAE both geographically and demographically (Emirates 24/7, 2012).

Figure 7: Water & Electricity Authorities in the UAE



Adapted from water & electricity authority websites

4.2.1. Energy & water sector in Abu Dhabi Emirate:

Similar to Qatar, water and electricity producers in the Abu Dhabi emirate are largely private entities, though with sizeable government shares (Al-Omar, 2012). However, unlike Qatar, producers do not sell water and electricity directly to the distributers (RSB, 2012). Rather, water and electricity is purchased exclusively by the Abu Dhabi Water & Electricity Company (ADWEC) under PWPAs, and the water and electricity is transmitted by an intermediary agency TRANSCO, to the distributing agencies (RSB, 2012). The two distributing agencies in the emirate are the Abu Dhabi Distribution Company (ADDC) and the Al Ain Distribution (AADC) Company, servicing the municipalities of Abu Dhabi and Al Ain respectively (ADWEA, 2012). The Abu Dhabi Water & Electricity Authority, ADWEA, is the primary regulatory agency responsible for the implementation of government water policies (ADWEA, 2012).

In Abu Dhabi, along with the other emirates, Emirati nationals receive water and electricity at heavily subsidized rates. Table 4 below outlines the production cost of water and electricity in the Abu Dhabi Emirate while Table 5 summarizes current tariffs for water and electricity for various customer categories in the Emirate. Table 5 also provides the percentage of the cost subsidized for the various customer categories. The average Emirati-national being subsidized by around 89% for water and electricity combined while non-nationals are subsidized by

around 59% for the two services (Zawya ,2012). As Figure 8 illustrates, government support is provided through The Abu Dhabi Water & Electricity Company financially compensate ADDC and AADC who sell the water and electricity to consumers below production cost (RSB, 2012). It is also worth noting that ADWEC subsidizes the water and electricity production process by purchasing the gas fuel from fuel suppliers and supplying it to the water & electricity producers (RSB, 2012).

Figure 8: Water & Electricity Production, Transmission & Distribution in the Abu Dhabi Emirate

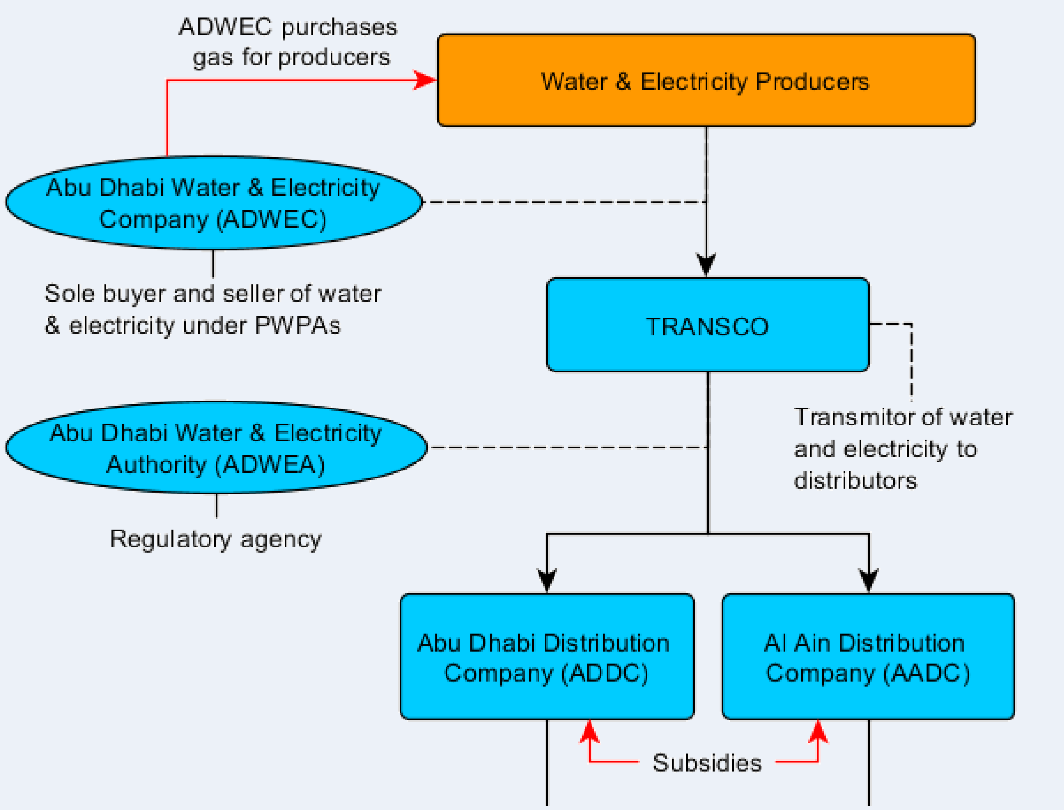


Table 4: Production cost of water and electricity in the Abu Dhabi Emirate

Product	Cost AED (before subsidies)	Cost (USD, before subsidies)
Electricity	0.25 - 0.32 /KWh (commercial, residential)	0.07 - 0.09/KWh
Water	9.11/m^3	2.48/m^3

Data from Zawya, 2012

Table 5: Water and electricity tariffs for various customer categories in the Abu Dhabi Emirate

Product	Customer Category	Tariffs (AED)	Tariffs (USD)	% subsidized
Electricity	UAE Nationals- Domestic	0.03-0.05/KWh	0.01/KWh	84.4%
	Non-UAE Nationals – Domestic	0.15/KWh	0.04/KWh	53.1%
	Industrial/Commercial	0.15/KWh	0.04/KWh	40.0%
	Government & Schools	0.15/KWh	0.04KWh	40.0%
	Farms	0.03/KWh	0.01/KWh	88.0%
Water	UAE Nationals- Domestic	0.00/m^3	0.00/m^3	100%

	Non-UAE Nationals – Domestic	0.022/m^3	0.60/m^3	75.9%
	Industrial/Commercial	0.022/m^3	0.60/m^3	75.9%
	Government & Schools	0.022/m^3	0.60/m^3	75.9%
	Farms	0.022/m^3	0.60/m^3	75.9%

Data from RSB, 2012

4.3. Private sector involvement in Qatar & UAE:

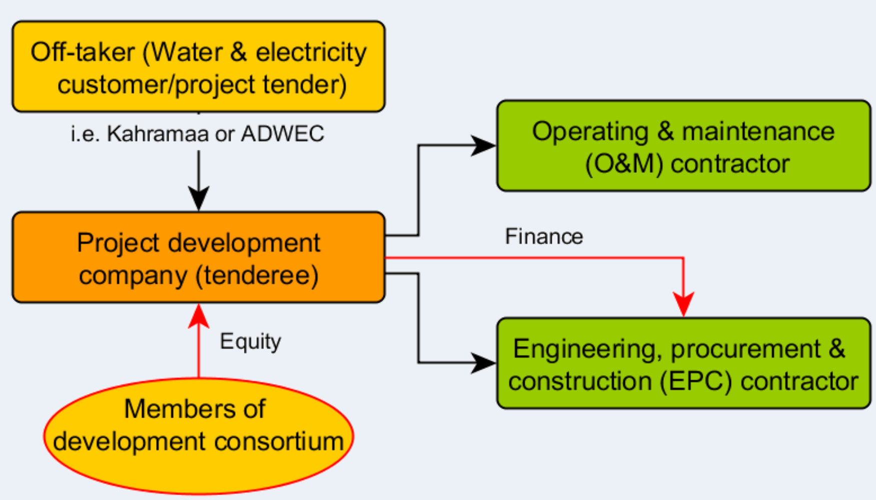
There is a growing push within Qatar and the UAE (particularly Abu Dhabi) to privatize the water and energy sector (DesalData, 2012; RSB, 2012; Halabi, 2012). In Qatar and some of the Emirates (primarily, Abu Dhabi and Dubai) privatization is mostly seen at the water and electricity production level, while transmission and distribution agencies remain largely public sector as outlined earlier. Privatization at the production level is evident in Qatar through QEWC's acquisition over Kahramaa's water and electricity producing assets in 2003 (GWI, 2011). In Abu Dhabi, ADWEA has a privatization directorate which conducts studies and manages privatization projects (ADWEA, 2010). For both the UAE and Qatar, the unique nature of privatization is best exemplified by the adoption and use of the Independent Water & Electricity Projects (IWPP) approach for power and desalination plant projects.

4.3.1. Independent water & power projects (IWPP):

Independent Water & Power Project (IWPP) is a financing and project approach, which generally uses Build-Operate-Transfer (BOT) or Build-Operate-Own (BOO) model but is applied specifically to joint water and power projects (DesalData, 2012). Abu Dhabi was among the first adopters of IWPP, now with 8 such projects operational (RSB, 2012). The rising demand for both water and energy in Qatar and UAE along with the continued dominance of cogeneration plants has made joint projects a logical solution (DesalData, 2012). The IWPP model is now used in Bahrain, Oman, Qatar, Saudi Arabia, and most recently Kuwait and Dubai (DesalData, 2012). The spread of the IWPP model reflects the increasing financial burden felt by governments in the region from supplying water and energy along with their desires to increase the efficiency of the sectors (DesalData, 2012). The general structure of IWPP projects is best represented in Figure 9.

The off-taker, who buys the water and electricity, tenders the IWPP project to a project development company through a bidding process (DesalData, 2012). To avoid risk and ensure that the off-taker will in fact pay for the water and electricity produced, they are required to be a creditworthy counterpart (DesalData, 2012). Consequently, most off-takers in the Gulf are government operated companies, such as ADWEC for Abu Dhabi or

Figure 9: Independent Water & Power Projects



Adapted from DesalData & RSB

Kahramaa for Qatar. The project development company then contracts out the engineering, procurement and construction (EPC) to one company and the operating and maintenance (O&M) to another (RSB, 2012). In order to finance the project, members of the development consortium provide equity to the project development company (DesalData, 2012). The project development company then finances the EPC process which requires the capital investment (RSB, 2012). The private consortium itself often consists of a mix between government and private investors (DesalData, 2012). In Abu Dhabi, ADWEA holds 60% of the shares for IWP projects while the remaining 40% is through private investors (RSB, 2012). Sharjah along with the other northern Emirates in the UAE have not gone down the IWPP path due to the high capital investment needed from SEWA and FEWA (DesalData, 2012). DEWA, which was planning to develop Dubai's first IWPP project, the Hassyan, cancelled the project in 2012, citing a previous overestimation in required capacity (Business Monitor International, 2012). Like Abu Dhabi, financing in Qatar is also split between government entities and private investors. Tables 6 and Table 7 below provide examples of IWPP projects in Qatar and the UAE along with the shareholders of each respective project.

Table 6: IWPP projects in Qatar

IWPP Name	Shareholders
Ras Laffan A	QEWC (80%), Qatar Petroleum (10%), Gulf Investment Corporation (10%)
Ras Laffan B	QEWC (55%), International Power (40%), Chubu Electric (5%)
Ras Girtas	QEWC (45%), Mitsui-Suez (40%), Qatar Petroleum (15%)

Source: (desadata)

Table 7: IWPP Projects in the UAE

IWPP Name	Shareholders
Shuweihat 2	ADWEA (60%), GDF Suez Energy Europe International (20%), Marubeni Corporation (20%)
Umm Al Nar	ADWEA (60%) International Power Plc (20%), Mitsui & Co. (6%), Tokyo Electric Power Company (14%)
Al-Taweelah A2	ADWEA (60%), Marubeni Corporation (34%), JGC Corporation (6%)

Source: (desadata)

5. Analysis of water and energy subsidization policies in Qatar and the UAE:

As shown in Figures 6 and Box 8, water and electricity subsidies occur both in Qatar and the UAE, a practice commonplace among other GCC countries as well (Fattouh & Katiri, 2012). The common rationale behind energy subsidization include: expanding access to energy and water, protecting the poor, consumption smoothing, fostering industrial development, avoiding inflationary pressures, and political considerations (Fattouh & Katiri, 2012). This report will not dive into the legitimacy of Qatar's and the UAE's rationale behind subsidy policies regarding water and energy but will rather highlight some of the implications associated with subsidization.

5.1. The effect of subsidies on water and electricity demand:

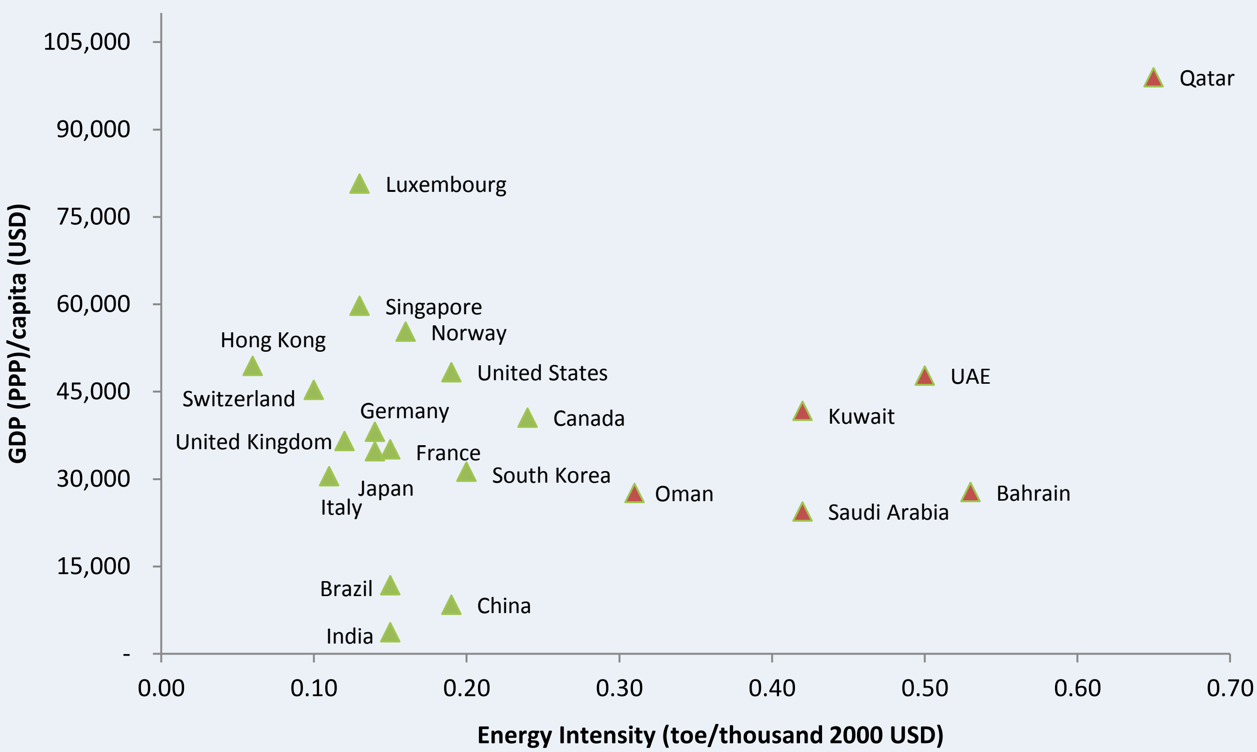
The relationship between price and resource consumption of elastic goods has been well established by numerous studies including Reiss et Al. 2008; Uri, 1982 and Yuan et Al. 2010, amongst many others. The more energy and water are subsidized, the greater the demand is for those goods as their true cost of production becomes externalized (EIU, 2011). In GCC states, this phenomenon is demonstrated by the exceptionally high energy and water uses per capita (IEA, 2010). In Qatar and the UAE the annual electricity consumption stands at 16,353 KWh/capita, and 17,296 KWh/capita respectively (IEA, 2009). Both countries consume 25% more electricity per capita than the US (IEA, 2009). In terms of water use, the water footprints of Qatar and UAE stand well over 3000m^3/yr, more than double the world average (Water Footprint Network, 2012). Although, the high electricity consumption in the region is largely the result of air conditioning and cooling, necessary for the hot desert climate, overconsumption remains largely linked to cheap energy prices, a fact acknowledged by water and electricity authorities and industries in both Qatar and the UAE (Sunna, 2012; Halabi, 2012; ADWEA, 2012; EAD, 2009).

Numerous reports including Qatar's Second Human Development Report, launched in 2009 also concluded that heavy subsidies have led to a state in which water and electricity are over consumed by the Qatari population at a rate exceeding sustainable development (UNDP, 2009). Consequently, there is widespread recognition of the harmful effects caused by the current water and electricity tariff rates.

5.1.1. Subsidies and energy intensity

Domestic water and energy subsidization by Qatar, the UAE and other GCC states has been a contributive factor towards their fairly energy intensive economies (Enerdata, 2011). High energy intensity is a trend witnessed amongst all GCC states (AFED, 2010). As illustrated in Figure 10, most GCC states though sharing comparable GDP/capita's with other industrialized economies, are far more energy intensive. Though energy intensity in GCC states is also linked to energy intensive petro-chemical industries and the high cooling needs for the hot desert climate, energy inefficiency resultant of subsidies remains a prime factor (Enerdata, 2011). GCC states including Qatar and the UAE possess a tremendous opportunity for improvement in their economic efficiencies.

Figure 10: GD per Capita vs. Energy Intensity of Various Nations

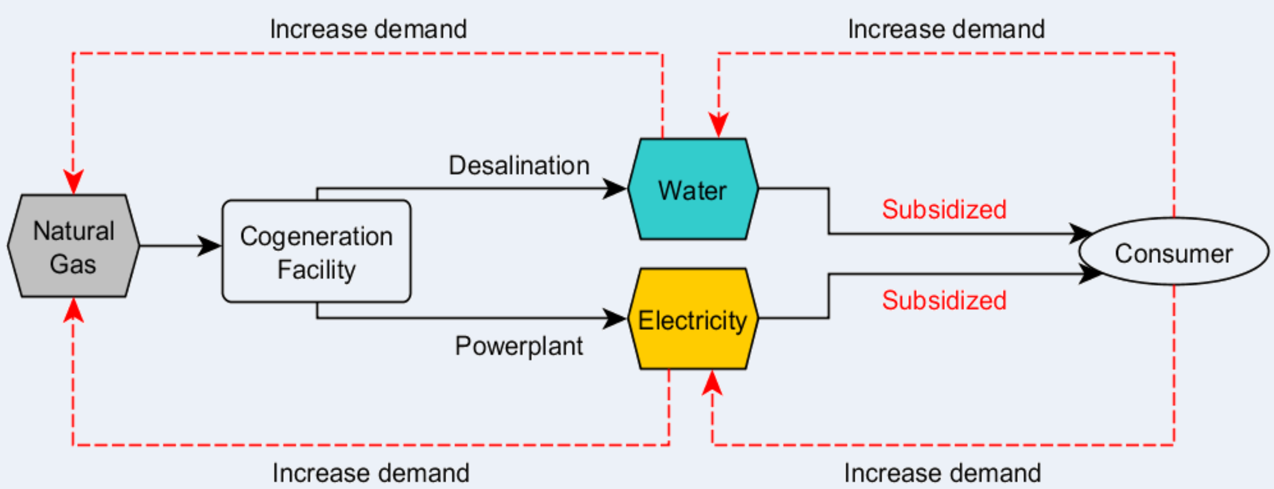


The Kingdom of Norway provides an excellent case study of how energy subsidy policy affects energy intensity and economic efficiency. Like GCC states, Norway is a major fossil fuel exporter, with around 22% of GDP coming from the petroleum industry (Norwegian Petroleum Directorate, 2010). Unlike GCC states, Norway does not subsidize its energy from the revenue brought in through fossil fuel exports, but rather invests it into its public services and infrastructure (Norwegian Petroleum Directorate, 2010). The result of which, is Norwegians paying among the highest oil prices in the world, but absorbing it relatively well given the subsidization of other key public services such as education, healthcare etc. (Randall, 2012). This subsidy shift explains Norway's relatively low energy intensity when compared with GCC states, despite sharing similarities such as being a major fossil fuel exporter and also suffering from an extreme climate which requires significant energy inputs for temperature regulation (Norwegian Petroleum Directorate, 2010).

5.1.2. Subsidies and the water-energy nexus

In addition to energy subsidies, water is also highly subsidized, often free for Gulf nationals (World Bank, 2005). Subsidized energy and subsidized water go hand in hand and are synergistically damaging due to the heavy reliance on desalination in the region. As Figure 11 illustrates, subsidized water and electricity incentivize greater use by citizens and places greater demand on water and electricity despite living in a severely water scarce region (Darwish et al, 2013). Despite the added efficiency of cogeneration plants compared with stand alone systems, the efficiency is only capitalized on when water and electricity demand are on par with one another (EAD, 2009). Even though greater capacity is available for desalination during winter months due to reduced power demand, the marginal cost of producing that water can easily double as energy for desalination has to be provided independent of power generation (EAD, 2009). Hence during winter months, desalination incurs the added cost of electricity production. Hence, a policy of water subsidization results in unnecessary power production that results in greater inefficiency, economic burden and negative environmental effects.

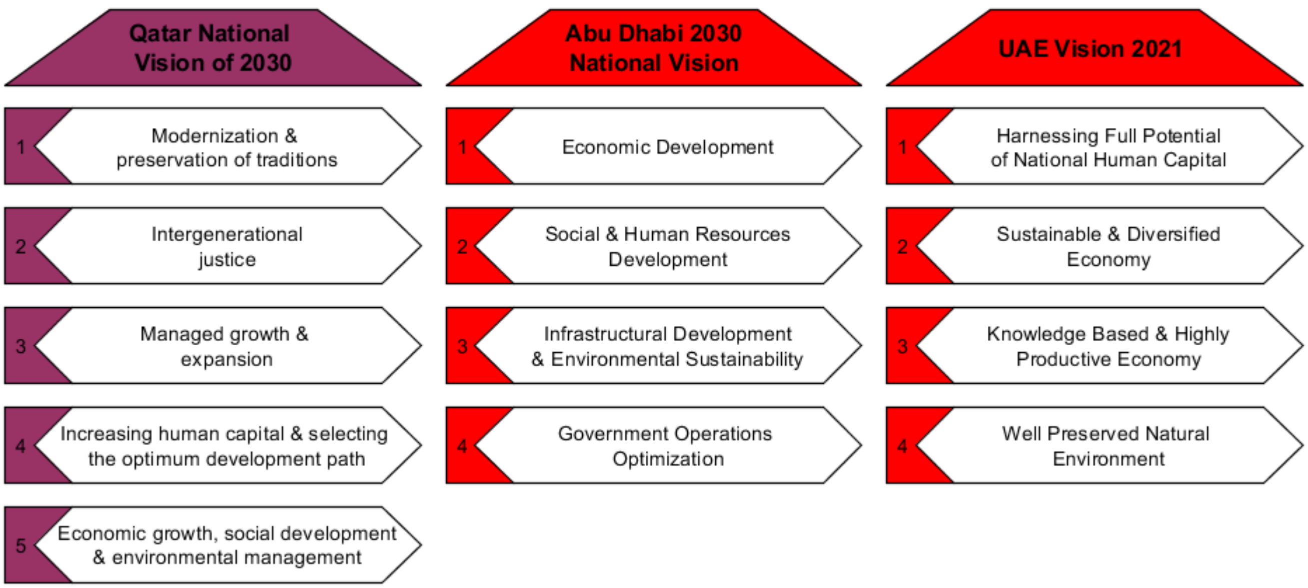
Figure 11: Water & Electricity Demand-Subsidy Relationship



6. Future outlook of water and energy sectors in Qatar and the UAE

This section will look at current and planned initiatives in Qatar and the UAE that are currently affecting or likely to affect the future of desalination and the energy/water sectors. There has been a considerate effort in the past few years by Gulf countries under the patronage of their national rulers, to outline national visions or strategies to where they would like their respective country's to head. The national visions of Qatar and the UAE are summarized below in Figure 11. It is worth noting that sustainability and/or environmental management is mentioned as a vital pillar for all of the national visions shown.

Figure 11: Distilled National Visions of Qatar, Abu Dhabi & Dubai



Adapted from national vision reports

6.1. Water & electricity supply-demand gap forecast

Figure 12 illustrates the cumulative installed desalination capacity for Qatar and the UAE based on currently online plants as well as those planned (DesalData, 2012). For both Qatar and UAE, stagnation in installation capacity following 2014 coupled with continued demand growth for water and electricity (shown in Figures 13 and 14) demonstrates the potential future gap between supply and demand. Between 2009 to 2017 water demand is expected to rise by 82% while supply will increase by 60% according to government estimates (Al Malki, 2008). Perhaps more sever, the UAE, more specifically the Abu Dhabi Emirate is expecting a supply demand gap by as early as 2014 if sufficient demand management isn't taken (EAD, 2009).

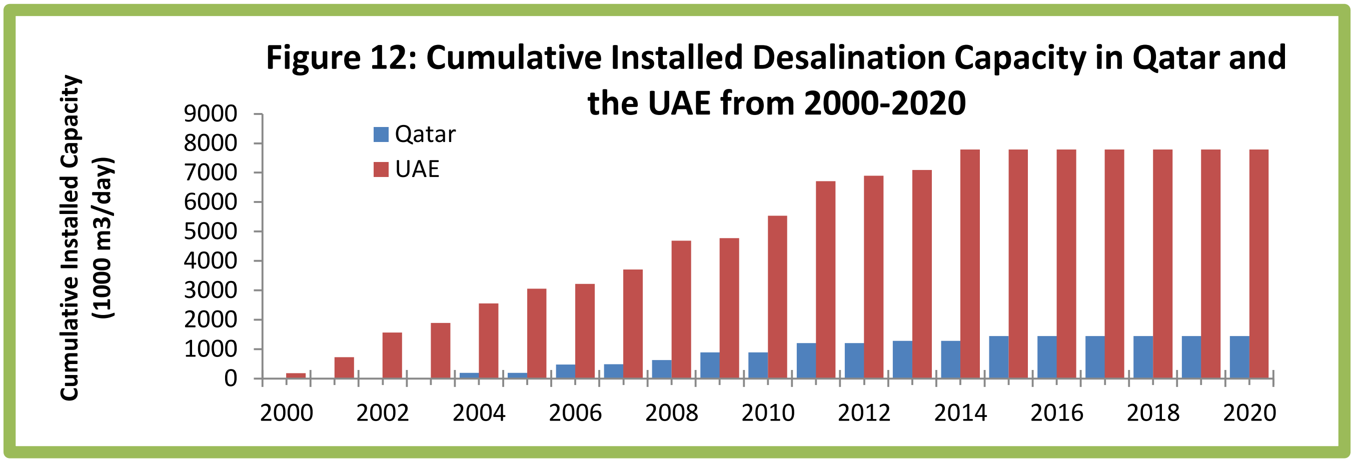


Figure 12: Cumulative Installed Desalination Capacity in Qatar and the UAE from 2000-2020

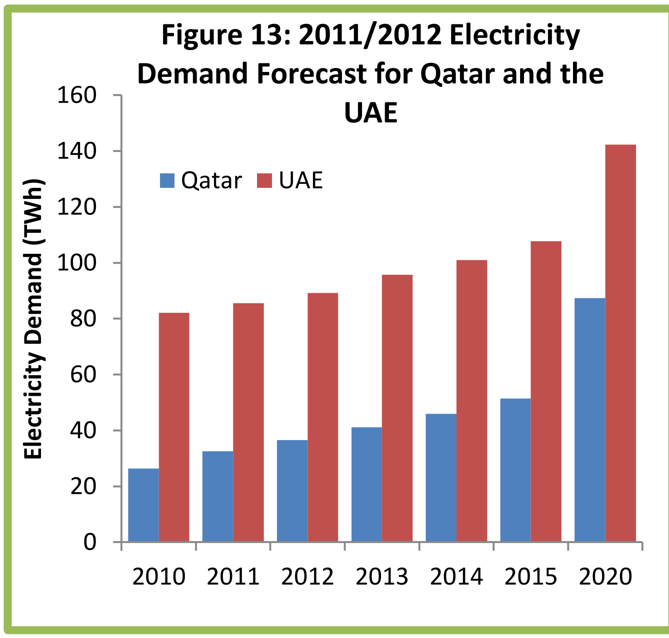


Figure 13: 2011/2012 Electricity Demand Forecast for Qatar and the UAE

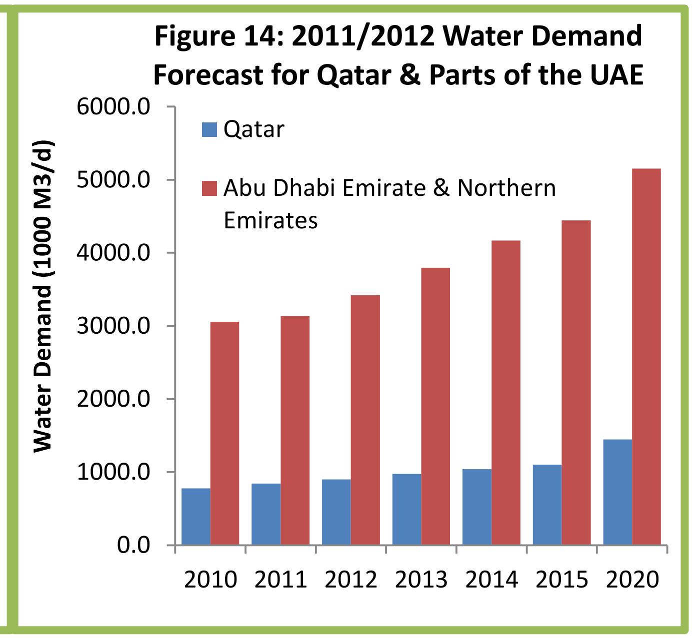


Figure 14: 2011/2012 Water Demand Forecast for Qatar & Parts of the UAE

Source: Rasmala & EIU forecasts

Source: ADWEC 2011/2012 forecast and Rasmala forecast

6.2. Sustainability Considerations:

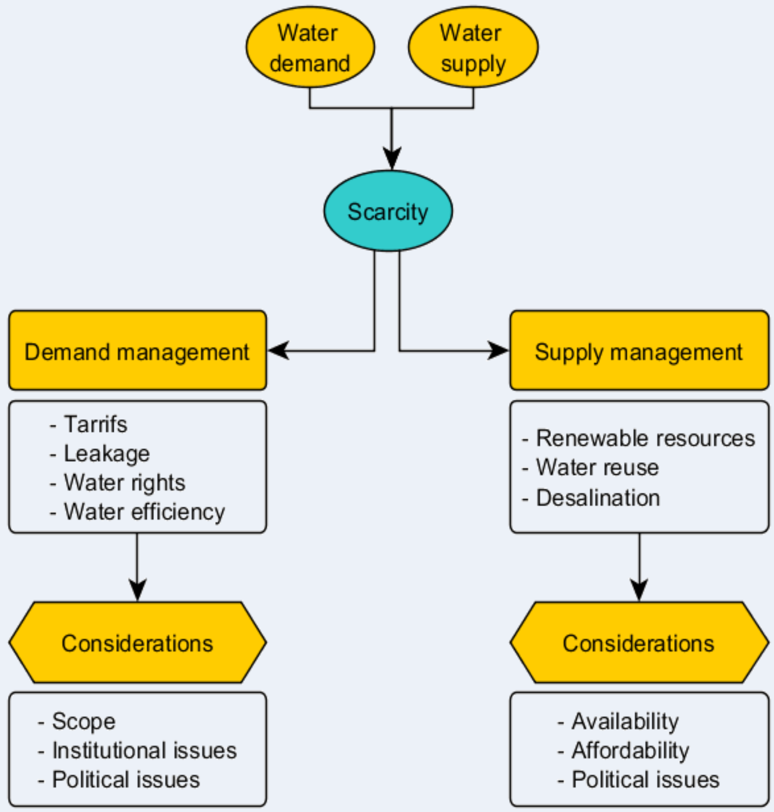
As previously mentioned the nexus that exists between energy and water in the Gulf due to desalination is unprecedented. In terms of water, roughly 99% of all municipal and industrial water use in Qatar is from desalinated water (Al Malki, 2008), while that value is lower in the UAE due to the greater presence of groundwater, particularly in the desert oasis city of Al Ain (EAD, 2009). Nevertheless, given the high cost of desalination both financially and environmentally, it becomes crucial to analyze the dynamics of water scarcity in the region and how it can be dealt both cost-effectively and sustainably.

As illustrated in Figure 15, water scarcity is a function of both water supply and water demand. So long as the supply rate is higher than the demand rate with no externalized costs, then there is water security (World Bank,

2005). Hence, water scarcity can be addressed in two ways, through demand management and through supply management.

Demand management employs strategies to decrease the demand on the water resource, while supply management looks towards strategies that can increase the supply of the water resource (Kell Nielsen, 2004). Figure 15 illustrates some supply and demand management strategies. Both approaches are important to meet any country's water needs, however, demand management should be prioritized over supply management when possible as it is both more cost effective and environmentally friendly as it avoids unnecessary investment in new water and energy infrastructure (World Bank, 2005; EAD, 2009).

Figure 15: Water Scarcity Dynamics



Adapted from GWI

6.3. Water Supply management in Qatar and UAE:

6.3.1. Continued government investment in water supply management

Despite the increasing push for privatization and private sector involvement, it is clear that both the governments of Qatar and the UAE are continuing to invest heavily in their water and energy sectors as evident by their large shares in many IWPP projects (DesalData, 2012). Between 2000 and 2008, Kahramaa invested approximately 660 million USD in its water sector, excluding investments made in IWPP projects (Al Malki, 2008). In 2009, Qatar initiated a 30 year water and electricity master plan that will see major investments in desalination, water infrastructure and wastewater treatment (DesalData, 2012). Between 2010 and 2015, the value is projects at reaching 5.47 billion USD with an additional 1.1 billion USD investment in IWPP production facilities between 2013 and 2017 (Al Malki, 2008).

Likewise, in May of 2012 at the global summit for water in the oil and gas sector, Dr Mariam Al-Shenasi, the undersecretary of the Ministry of Environment and Water announced that the UAE will be investing 13.89 billion USD in new desalination plants and distribution networks from 2012 to 2016 (The National, 2012).

Strong government investments in the water and energy sector are largely the result of rapidly rising demand coupled with higher global oil and gas prices which have provided greater revenue from exports for Qatar and the UAE (DesalData, 2012), similar to the massive investments made following the oil crisis in 1973 (Al-Faris, 2002).

6.3.2. Increasing desalination capacity:

Currently, many GCC countries are placing heavy emphasis and resources on ensuring that they are water secure for the future (Linke, 2012). Amongst other actions, this policy is translated into increasing the desalination capacity of the respective country. In Qatar, Kahramaa, the government owned water & electricity Company is planning to add an additional 1.72 million m^3/day to its existing desalination capacity between the years of 2016 and 2032 as a part of its 30-year power and water master plan (Al Malki, 2008; DesalData, 2012). This would represent an increase of roughly 140% compared to the current installed capacity of 1.2 million m^3/day (Al Malki, 2008). Table 8 below highlights the combined capacity of contracted and planned plants for both Qatar and UAE.

Table 8 Contracted and planned desalination plants in Qatar and the UAE by capacity

Plant Status	Qatar (m^3/day)	UAE (m^3/day)
Contracted	537,135	353,410
Planned	337,060	2,242,573
Total	**874,195**	**2,595,983**

Data from DesalData

6.3.3. Diversification of energy sources for desalination:

Despite the vast fossil fuel wealth that both Qatar the UAE, and other GCC states enjoy, significant investments are being made to diversify the energy mix of the region and shift away from dependence on fossil fuels (Bachellerie, 2012). Investments in energy diversification would allow the region to export greater amounts of fossil fuel – earning greater revenue and also prepare them for a post-fossil fuel world (Reiche, 2010). Most investments are currently being made by public sector entities opposed to the private sector (Baldwin, 2012; Bachellerie, 2012), though public-private- partnerships particularly in research is growing (Reiche, 2010).

Both Qatar’s and the UAE’s desire to diversify their energy mix is best represented by some of the initiated programs and projects. In 2008 the UAE published a report on nuclear energy for the country citing that by 2020, natural gas will only be sufficient to meet 50% of electricity needs, the remaining will have to come from other sources such as nuclear and renewables (ENEC, 2008). The report estimated that renewables will supply around 6-7% by 2020, with the remaining 43-44% coming from nuclear through an estimated 14 plants, 4 of which will be operational by 2020 (ENEC, 2008). In terms of renewables, UAE’s Shams 1 is a concentrated solar power plant project constructed near Madinat Zayed in Abu Dhabi (Abengoa Solar, 2011). The project, the largest parabolic trough power plant in the world and the largest solar power plant in the Middle East is being led primarily by Masdar (Abengoa Solar, 2011). Details on Shams-1 and the Barakah nuclear power plants are summarized below in Tables 9 and 10.

Table 9: Shams 1 CSP Project

Project Owners	Project Cost	Energy capacity	Tonnes of CO_2 displaced	Status
Masdar (60%), Abengoa SA (20%), Total SA (20%)	600 million USD	100 megawatts	175,000/year	Operational as of end of 2012

Data from Abengoa Solar

Table 10: Barakah Nuclear Power Plant (4 plants)

Project Owner	Project Cost	Energy capacity	Tonnes of CO_2 displaced	Status
Emirates Nuclear Energy Corporation (ENEC)	20 billion USD	5600 megawatts (1400MW/plant)	12,000,000/year	Under construction

Data from World Nuclear Association & Arabian Business.com

Similar to the UAE, Qatar is also looking to diversify its energy mix. Qatar is currently looking for tenders for an 1800MW solar power plant which is expected to be operational by 2018 and cost anywhere between 10 to 20 billion USD (Laylin, 2012). According to Fahad Al Attiya, chairman of the Organising Sub-Committee for COP18/CMP8 in Doha, the solar power plant will be used power 80% of the country's desalination plants (The Peninsula, 2012) and will raise Qatar's renewable energy mix up to 16% (Laylin, 2012).

6.3.4. Increasing storage capacity

Both Qatar the UAE and other GCC states suffer from severe water storage capacity issues (Al Attiya, 2012). It is estimated that Qatar's water storage capacity is only 1.23 days if desalination plants were to stop operating (Sunna, 2012; Al Malki, 2008). That number standing at 2 days in the UAE (AED, 2009). As such, both countries along with other GCC states are researching and investing in water storage technologies, be they manmade reservoirs or aquifer storage and recovery (ASR) (World Bank, 2005).

Under Qatar's National Food Security Programme (QNFSP), a ban on groundwater use for agricultural purposes which represents 93% of groundwater usage is being proposed (Linke, 2012). Aside from supplying the agricultural sector with freshwater, a core objective of QNFSP is to use solar desalinated water to replenish the country's aquifers, increasing the country's water storage capacity and decreasing the need for large water storage containers (QNFSP, 2012). Similar to Qatar's QNFS program, Abu Dhabi has already invested in ASR as a means of increasing the country's water storage capacity (EAD, 2009). The 5 billion dollar project in Liwa is being implemented by the Environment Agency of Abu Dhabi (EAD, 2009). The water reservoir can be tapped into whenever needed, particularly in times of emergency or a natural crisis (EAD, 2009).

Manmade reservoirs are also being built by both countries. In Qatar, Kahramaa is planning to add 442 MIG in secondary reservoirs and 1,902 MIG mega reservoirs by the end of 2015 (Al Malki, 2008). The secondary reservoirs will provide an additional 2 day reserve capacity while the mega reservoirs will add 5, for a planned total of 7 day of 24 hour supply (Al Malki, 2008).

In the UAE, where most water networks are Emirate specific, linking water-grid networks between various Emirates (particularly Abu Dhabi and Dubai) to provide system redundancy is being considered (World Bank, 2005). Such a network would decrease the country's water vulnerability in case of emergencies or disasters such as major oil spills or desalination plant failures as water can be allocated from different population centers to

areas of need (World Bank, 2005). Though not on a national scale, Abu Dhabi and Fujairah are connected to the Al Ain region through TRANSCO's water transmission system (Transco, 2012; EAD, 2009).

6.4. Water demand management in Qatar and UAE:

A general dichotomy exists within demand management; technical and behavioural (Kell Nielsen, 2004). Technical efficiency is generally the ratio of water inputs and outputs, encompassing: storage, distribution and consumption (Kell Nielsen, 2004). Behavioural includes actual consumptive patterns of water by all sectors (Kell Nielsen, 2004). It is worth noting that traditionally, most GCC states including Qatar and the UAE prioritize infrastructural projects and enhancements over behavioural change of consumption (Halabi, 2012).

6.4.1. Technical efficiency

One of the major technical efficiencies being worked on in both countries is related to the construction sector (Bachellerie, 2012). In 2009 Dubai launched its green building code which aims to harmonize various building and planning policies within the emirate (Reiche, 2010). The building code is based largely on the United State's LEED rating system, however modified to suit Dubai's environmental conditions (Reiche, 2010). Dubai's building codes will be mandatory for both the public and private sector as of 2014 (Construction Week Online, 2012). In Abu Dhabi, under "Plan Abu Dhabi 2030", a key program emerged named Estidama, which operates as a "building design methodology for constructing and operating buildings and communities more sustainably" (Abu Dhabi UPC, 2012). One of the outputs of Estidama is the Pearl Rating System, which harmonizes existing codes such as BREEAM, LEED and Green Star, to evaluate the sustainability of building development practices in Abu Dhabi (Abu Dhabi UPC, 2012). As of 2010, all new community, building and villa developments within Abu Dhabi are mandated to achieve a minimum of one pearl (out of five), while government buildings must achieve a minimum of two (Abu Dhabi UPC, 2012).

Similarly, Qatar has recently developed its own system called the Global Sustainability Assessment System (GSAS) (GORD, 2012). GSAS was developed after studying 40 different green building codes from around the world, with the objective of creating a system that can assess all types of developments, at both the macro and micro level (GORD, 2012). GSAS is mandatory for all government buildings, while private sector developments are to adhere to unspecified water and energy saving measures (GORD, 2012).

Another key area of water efficiency is through transmission networks. Current transmission water loss stands at 17% in Abu Dhabi, with effort by ADWEA along with its subsidiary distributors to reduce that value to 10% through more sophisticated management (EAD, 2009). Distribution companies in the country are currently installing automatic smart meters to all outlets in the network, to better account for water loss in the system (EAD, 2009).

In Qatar, the opportunity for water savings are greater as current water transmission losses are high, estimated at 30-35% (GWI, 2012; Rasmala, 2011). Consequently, Kahramaa has made water transmission efficiency a priority with plans to cut leaks to 10% by 2013 (Ramsala, 2011). In 2009, Kahramaa invested 58 million USD into a Supervisory Control and Data Acquisition (SCADA) system for the control and monitoring of the country's water system (Al Malki, 2008). This system is to be coupled with greater control management which includes new district flow meters and advance meter information (Al Malki, 2008).

6.4.2. Behavioural change

Behavioural changes within the water sector are related largely to consumptive patterns (Kell Nielsen, 2004). Water consumption amongst any sector or user is determined primarily by the cost of the utility and the general level of awareness surrounding water conservation (Kell Nielsen, 2004). In section 4, the subsidized tariffs of electricity and water were outlined for both countries according to the various customer categories. The large subsidies in place have a significant impact on consumption patterns as they encourage over-consumption of both water and electricity. An increase in water and electricity tariffs through subsidy removal would likely decrease consumption by a great deal (Sunna, 2012; Mezher, 2012). However, within GCC states there are considerable social and political considerations when it comes to subsidies (IEA, 2010; Fattouh & Katiri, 2012). Given the high fossil fuel in the GCC, a culture has emerged in which citizens feel they have a birth right to those resources and that such utilities should be made free for them (Mitchell, 2012; Kamarck, 2012). Consequently, increasing water and electricity tariffs for citizens would be extremely unpopular (Kamarck, 2012).

There is broad consensus from utility companies, academics, researchers and those in the desalination industry that subsidies for water and electricity need to go down across all GCC states and that such an outcome is inevitable (Halabi, 2012; Sunna, 2012; Linke, 2012; Fath, 2012). The Dubai Electricity & Water Authority (DEWA) did just that in 2011 as it introduced a fuel surcharge for electricity production which was passed on to consumers (Collins, 2012). The result was a 2.2% drop in per capita electricity consumption the following year (Collins, 2012).

However, given the political and social sensitivity of tariff increases an emphasis on awareness building is being placed instead (Collins, 2012). Consequently, conservation campaigns are starting to flourish to educate the public in both countries. In the UAE and Qatar key government institutions including environmental ministries, water and electricity authorities, along with the utility/distribution companies have begun to seriously promote greater conservation through various avenues. Significant work has been carried out on government websites (particularly utility websites) to promote conservation and sustainability, through open access to statistical information, online consumption calculators, water and electricity saving tips amongst others (Kahramaa, 2012; ADWEC, 2012; DEWA, 2012).

In the UAE, some utility companies including ADDC, AADC and SEWA have begun to print the true cost of water and electricity production on the water and electricity bill of customers and how much they are saving via government subsidies in an effort to raise awareness amongst the public about the true value of these utilities (H2O Middle East, 2010; Collins, 2012; Halabi, 2012). Such an initiative may prove useful in the future if water and electricity subsidies are to be reduced or eliminated.

6.5. Environment

Many of the environmental impacts associated with desalination were explored earlier in section 3 and summarized in Figure 5. It is worth mentioning that although desalination may never become a 100% environmentally friendly method of freshwater production in the Gulf, its environmental impacts can be greatly reduced through a dual approach of technology application and regulation. Renewable energy installations by Qatar and the UAE which were discussed in section 6.3.3 are examples of such. Hence, the bulk of environmental concern surrounding desalination is now focused in water intake and brine discharge.

6.5.1. Desalination regulation in Qatar & UAE

Table 11 below outlines the regulatory guidelines in Qatar and UAE on seawater quality for brine discharge. Regional experts interviewed from industry, public sector utility companies and academia have indicated that Qatar's environment ministry has fairly strict environmental regulations regarding desalination and water quality (Boer, 2012; Halabi, 2012; Sunna, 2012). The ministry provides permits for all major projects based on environmental impact assessments (Sunna, 2012). EIA's are conducted for each desalination plant site with post construction monitoring of environmental quality (Sunna, 2012). The ministry sets standards on water intake, brine discharge amount and water quality of brine discharge (Sunna, 2012).

Table 11: Seawater water quality regulation in Qatar and Abu Dhabi

Country/Jurisdiction	Max discharge temp (˚C)	Max. Discharge TDS
Qatar	3˚C higher than ambient	20,000mg/L above ambient or 33 - 45 ppt
Abu Dhabi	8˚C higher than ambient	No data (1500mg/L for wastewater)
		Qatar data from Darwish et al; UAE data from Al-Omar, 2012

In the UAE, environmental standards are less strict than those of Qatar's, as illustrated in table 11. This was confirmed by Bassem Halabi, a representative of Metito, an international desalination company operating in both Qatar and the UAE (Halabi, 2012). Halabi outlined how the EIA process for Qatar was more rigorous given the stricter standards, citing that within the UAE variation also exists, Abu Dhabi being generally stricter than Dubai when it comes to brine discharge quality (Halabi, 2012).

6.5.2. Advances in environmental impact mitigation technology

It is worth noting that the type of desalination technology employed along with the plant site plays a significant role in how the marine ecosystem is affected and to what degree. For example, RO uses fewer chemicals in the treatment process with little to no temperature variance from intake when compared to MSF or MED (Halabi, 2012; Fath, 2012). However, in terms of salinity RO will usually produce more concentrated brine (Shannon et al, 2008; Halabi, 2012). The site of brine discharge and the way it is discharged is also crucial. Historically, many plants in the Gulf released brine right at the shore with little dispersion methods. However, newer plants following stricter guidelines such as Metito's RO plant at the Pearl in Qatar use alternative methods to mitigate the negative impacts of brine discharge (URS Qatar LLC, 2009). The Pearl plant uses a subsurface seawater intake pipe, which eliminates a lot of potential impingement and entrainment along with reducing the need for chemical pre-treatment of the water (URS Qatar LLC, 2009. Furthermore, it uses diffusers to disperse the hypersaline discharge and avoid localization (URS Qatar LLC, 2009).

Other environmental mitigation measures may include diluting the brine prior to its release into the sea by combining it with the outfall of wastewater treatment facilities or power plants (Pankratz, 2004). Other areas of innovation include zero-liquid-discharge technology which completely separates freshwater, resulting in zero brine discharge (El Said, 2012; Halabi, 2012). However, in order to effectively steward the marine environment technological innovations in brine management must be coupled with adequate government regulations that either stipulate their use or encourage it through tougher environmental standards.

6.6. Human Capital

A recurring issue that was raised by numerous regional experts throughout interviews was the strong need for greater human capital investment in Qatar, UAE and GCC countries as a whole (Orfali, 2012; Mezher, 2012; Fath, 2012; Al-Attiya, 2012; Kamarck, 212; Boer, 2012). This need has been has also been identified by the governments of Qatar and the UAE and emphasized in their respective national visions in Figure 11.

In both Qatar and the UAE, there have been great investments made in creating regional centers for cutting edge research and the development of human capital for nationals. Education City, located on the outskirts of Doha, Qatar, hosts numerous prestigious international universities including Carnegie Mellon, Texas A&M, Georgetown, Northwestern, amongst others (Qatar Foundation, 2012). Qatar University, the country's only public university, is also a significant research player in the country with strong links to business and industry (Qatar University, 2012).

Similarly, the UAE has sought to attract numerous international universities over the years such as New York University, Tufts, George Mason, Michigan State, amongst others (Arabian Campus, 2012). It is worth noting that both Qatar and the UAE along with other GCC countries have begun to acknowledge the need to develop their own academic institutions opposed to simply importing them from outside (Karoly, 2010). Investments in locally developed universities such as Qatar University and Masdar Institute for Science & Technology in Abu Dhabi or the King Abdullah University for Science & Technology (KAUST) in Saudi Arabia are a few examples. These institutes are fervently trying to attract the best minds in the world to teach and research at these facilities (Orfali, 2012). There is very little research output from this region of the world compared to other countries and regions (Orfali, 2012; Mezher, 2012; Jocelyn, 2012).

A certain cultural stigma has been traditionally attached to research, as many nationals prefer desk jobs over research related jobs (Orfali, 2012; Jocelyn, 2012). Consequently, a push for Qatari and Emirati nationals to continue on to higher education and enter research positions is being encouraged by both respective governments (Karoly, 2010). At the request of Qatar's Supreme Education Council the Rand-Qatar Policy Institute released a report in 2007 titled "Post-Secondary Education in Qatar: Employer Demand, Student Choice, and Options for Policy" which assessed current educational opportunities in Qatar and how well they align with the country's socio-economic goals (Stasz et al, 2007). The report emphasized the need to make education more accessible, diverse, and specialized to better meet the country's socio-economic goals.

The study undertaken is reflective of a policy currently being carried out by both Qatar and the UAE known as "Qatarization" and "Emiritization" respectively, other GCC countries such as Saudi Arabia and Oman having similar programs (Mashood et al, 2009). The terms refer to both governments' desire to increase the percentage of nationals in the professional workforce, particularly in the private sector (Mashood et al, 2009). Currently, much of the professional workforce in the private sector is composed of expats, which makes retaining human capital difficult (Mezher, 2012; Orfali, 2012). Consequently, these programs have been created to develop human capacity in the respective country and ensure its long term sustainability (Orfali, 2012; Ministry of Energy & Industry, 2012; ManpowerGroup, 2012).

Qatar has set a 50% Qatarization target for its industries and energy sectors, with other private sector industries and companies also being challenged to adopt the Qatarization program through quotas (Ministry of Energy &

Industry, 2012). Similarly, the UAE has set in place similar quotas for its private sector and even educational institutions such as Masdar as a part of its Emiritization program (ManpowerGroup, 2012; Fath, 2012). However, the private sector is finding it quite difficult to achieve the required quotas given the more secure and higher paying public sector jobs which often do not require post-secondary education (karoly, 2010; Williams, 2011). Table 12 below illustrates the challenge of Qatarization and Emiritization of getting nationals into the private sector, which is currently dominated by expatriates.

Table 12: Percent of Qatari and Emirati workforce by sector

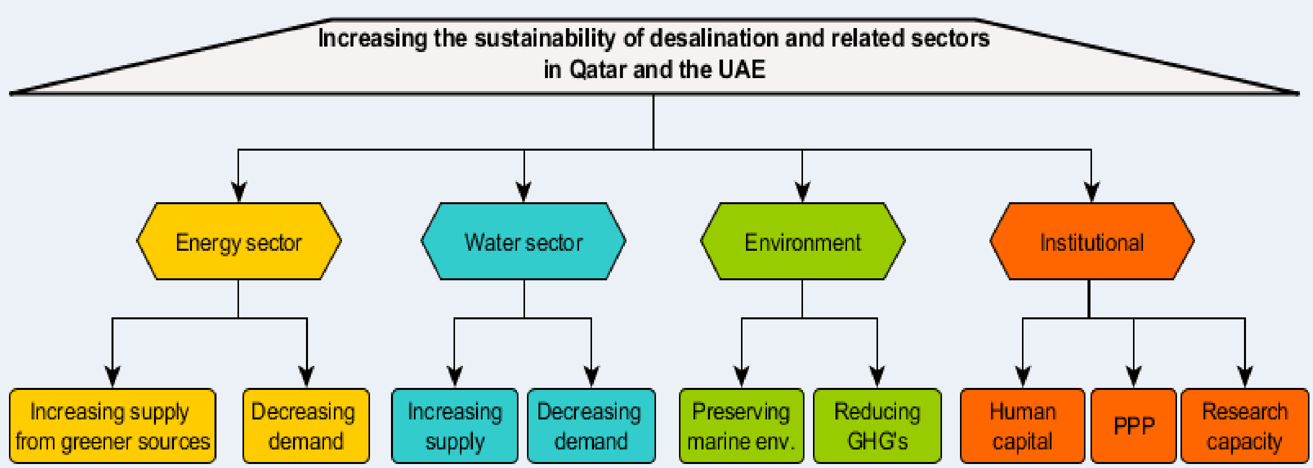
Country	% of Nationals in Public Sector	% of Nationals in Private Sector
Qatar	71%	0.5-5%
UAE	60-70%	4-5%,

Qatar data from Karoly, 2010; UAE data from Williams, 2011

7. Policy Recommendations:

Based on all of the findings presented in previous chapters, this section will summarize many of the key learnings and summarize them through key policy recommendations. These policies, if implemented will vastly increase the sustainability of desalination in Qatar and the UAE along with the energy and water sectors in both countries. Though these policy recommendations have been formulated specifically for Qatar and the UAE, the numerous commonalities shared by GCC states suggests that many of the recommendations can be equally relevant to other GCC members. The process undertaken for policy identification and prioritization uses the Analytical Hierarchical Process methodology. Figure 16 shown below summarizes the main areas requiring policy focus. It is worth mentioning that many of the policies mentioned below enable one another, particularly those at the institutional level.

Figure 16: Policy prioritization using AHP Methodology



7.1. Decrease water & energy demand

As outlined in the section 6.4, demand management is a function of both decreasing the input/output ratio through technical efficiency as well as by managing behaviour through consumptive patterns. Consequently, the following are the recommended policies:

1) Adopt an Integrated Water Resource Management (IWRM) approach.

a. Both Qatar and the UAE, by the leadership of their respective environmental and water ministries, need to take a more holistic approach to water management through IWRM that would:

I. Develop national master water plans (similar to Abu Dhabi's 2009 Master Water Plan) that identify major areas of water inefficiency, counterproductive policies and opportunities for new policies and initiatives.

i. Disseminate across the various government ministries for implementation and uptake.

II. Similar to the strategic investments being made in water supply enhancement, demand management investment strategies need to be well developed.

III. Research and adopt relevant best practices from other national water management programs, such as Singapore's successful and exemplary system (Poh Onn, 2005).

2) Increase public awareness about water and energy consumption.

a. Relevant government ministries, water & electricity authorities and utility companies in both Qatar and the UAE should continue and expand their positive online awareness building.

b. Relevant government ministries, water & electricity authorities and utility companies should expand their partnerships with advocacy groups and environmental groups (permitting them if they are currently banned).

3) Increase water and electricity tariffs for all sectors.

a. Water & electricity authorities such as Kahramaa, ADWEA, SEWA, DEWA, and FEWA (along with regulatory bodies such as the RSB) need to introduce a progressive tariff structure for both water and electricity based on level of consumption.

I. Industry and agriculture are good starting points as they have higher price elasticity and respond immediately to small changes in tariff price (Kell Nielsen, 2004).

II. As EAD mentioned in their 2009 Master Water Plan, significant household research and surveys is required to create a comprehensive and working tariff policy for both Qatar and the UAE.

4) Increase the technical efficiency of water and electricity systems.

a. Transmission and distribution companies including Kahramaa, Transco, ADDC, AADC, SEWA, DEWA and FEWA, should continue on with efforts to decrease network losses in both their water and electrical grids. This includes:

I. Installation of smart meters for water and electricity at the district and household level.

II. Replacement of old piping and/or wiring.

III. Promotion of new water and energy efficient technologies through regulation and/or incentives.

b. The urban planning councils of Qatar and the various Emirates should expand building/planning code regulations to all new developments including private sector projects.

5) Increase the water use efficiency in the agricultural sector.

a. In conjunction with tariff increases, Qatar and UAE's ministries of energy & industry, Water/environment along with specialized programs such as QNFSP, need to revise their agricultural sectors to make it more reflective of the region's water scarcity and desert climate. This is to be done through:

I. Incentivize the planting of drought resistant crops and/or ban plantation of water intensive crops.

II. Expand the adoption of more water efficient irrigation methods through incentives and/or regulations.

III. Continue and expand current research on hydroponics, micro-irrigation, real-time irrigation scheduling and other emerging fields of desert farming.

7.2. Increase energy supply from greener sources

As outlined in section 5.1.2.3 both the governments of Qatar and the UAE are beginning to invest in alternative and renewable energy for both desalination and to increase the national energy mix. However, such a transition requires enabling policies such as:

1. Creation of a renewable energy roadmap at the national and emirate based level.

a. Utilize renewable energy mapping (ex. Solar and wind atlases) to identify investment opportunities.

I. Both Qatar and the UAE have recently mapped their countries renewable resources and shared their findings with IRENA (IRENA, 2012a).

b. Harmonize national visions, ministry visions and programs towards a common renewable energy roadmap.

2. Decouple water and energy production.

a. An important enabling policy particularly for energy diversification and use of renewables in desalination is the decoupling of water and energy production. As outlined in section 4, the traditional use of cogeneration plants in the Gulf region presents an obstacle to the employment of new desalination technologies or alternative sources of energy to power the process. As outlined in Appendix 3, the Gulf's trend toward RO technology is causing a separation in power and water production, a breakthrough for renewables such as solar and wind which are significantly more site specific

.

3. Continue and expand alternative/renewable energy projects through greater public-private-partnerships.

a. Ensure a sustainable transfer of investments from the public to the private sector for alternative energy projects. A transition to the private sector will require many policy changes including:

I. Phasing out of fossil fuel subsidies, particularly within commercial/industrial sector

II. Promotion of small and medium scale developments, which are more affordable to the private sector, such as rooftop PV panels and solar-water heaters (IRENA, 2012b).

i. This can be applied through tax incentives to businesses, rebate programs for end users/customers amongst other policy mechanisms.

4. Continue and expand research on alternative and renewable energy.

a. Under the direction of the environment, education, energy and industry ministries along with specialized programs such as QNFSP, Qatar Foundation, Masdar and so forth; region specific application of the following areas should be further researched:
   - I. Alternative energy production, particularly solar (PV & CSP), wind and nuclear.
     - i. Hybrid systems
   - II. Energy storage systems
   - III. Smart grids

7.3. Increase water supply and system capacity

As discussed in section 5.1.1, when dealing with water scarcity, demand management should almost always be prioritized over increasing supply as it is often much more cost effective and environmentally friendly. However, given the large population and demand growth in Qatar and the UAE along with the currently vulnerability of the water system, enhancing the water supply sustainably is essential for the future.

1. Increase rates of reclaimed water utilization.

a. Under the direction of the water/environment ministries and the water and electricity authorities, private sector industries and municipal waste water treatment plants within Qatar and the UAE should be mandated to treat their wastewater to secondary or tertiary levels, dependant on the intended use of the treated water.
   - I. Distribution/utility companies within Qatar and the UAE should be mandated to purchase the treated water from the private sector industries and municipal waste water treatment plants and then re-distribute and sell it as either irrigation or potable water depending on level of treatment.

2. Increase desalination capacity.

a. Under the authority of the water/environment ministries, Water & electricity authorities should be mandated to regularly refer to their country’s IWRM strategy before asking for tenders on any new desalination project. Increasing desalination capacity should take place only after demand management and reclaimed water measures have been exhausted.

b. The ministries of water/environment, energy/industry, education and specialized programs such as QNFSP should continue to encourage and incentivize research and academic institutes to research new desalination technologies and applications that maximize recovery, while minimizing energy use, cost and environmental impacts. recommended research areas include:
   - I. New membrane technologies
   - II. New pre-treatment methodologies
   - III. Hybrid desalination systems
   - IV. Application of alternative energy supplies with various desalination systems

3. Increase system capacity.

a. Water and electricity authorities along with utility companies in both Qatar and the UAE need to increase their water system storage capacity through:
   I. Investments in water reservoirs
   II. Greater conservation of the country's existing groundwater
      i. To be done in line with other relevant ministries and stakeholders
   III. Conduct more research and pilot projects on aquifer storage and recharge (ASR) technology

7.4. Increase environmental management

Many of the aforementioned policies indirectly reduce the environmental impacts of desalination and the water & energy sectors. However, it still remains important to introduce mechanisms that deal directly with some of the environmental issues, particularly relating to the desalination process outlined in section 3.

1. Adopt an Integrated Coastal Zone Management (ICZM) approach.

a. Given the semi-enclosed nature of the Gulf and its ecological sensitivity outlined in section 3, it is vital that the environment, water, tourism and fisheries ministries of Qatar and the UAE not only adopt ICZM, but also develop it jointly alongside other Gulf states including Iraq, Kuwait, Saudi Arabia, Iran and Oman.
   I. The aforementioned ministries of Qatar and the UAE along with other Gulf countries need to enhance their capacities in monitoring, modelling, conducting vulnerability assessments, environmental impact assessments and regulation enforcement. UNU-INWEH's 2011 policy report "Managing the growing impacts of development on fragile coastal and marine ecosystems: lessons from the Gulf" provides an excellent roadmap for some of the challenges and steps needed to realizing ICZM in the region.

b. The environment ministries of both Qatar and the UAE should welcome and invite independent environmental agencies into the country, to regularly monitor environmental and marine issues.

2. Reduce environmental impacts of seawater intake by desalination plants on the marine environment.

a. Under the authority of the ministries of the environment, water, fisheries and industry in both Qatar and the UAE, desalination plants should be mandated to reduce levels of impingement and entrainment of marine organisms at feedwater intake pipes. This is to be achieved by mandating the use of appropriate technology and placement of intake pipes according to site suitability. Such measures may include:
   I. Installation of subsurface seawater intake pipes, which eliminate impingement and entrainment. Some of the available technologies include (Reynolds & Maley, 2008):
      i. Vertical wells, Horizontal collector wells, Slant wells and engineered infiltration gallery
   II. Open water intakes may utilize:
      i. Velocity caps, which reduce impingement (Reynolds & Maley, 2008).
      ii. Travelling water screens, which reduce entrainment when coupled with velocity caps (Reynolds & Maley, 2008).
      iii. Vertical and cylindrical wedgewire screens, which also reduce entrainment (Reynolds & Maley, 2008).

b. Site specific research on the aforementioned technologies by water/environment ministries in partnership with industry and academia is needed to determine the most cost effective technology for marine protection.

3. Reduce environmental impacts of brine discharge by desalination plants on the marine environment.

a. Under the authority of the ministries of the environment, water, fisheries and industry in both Qatar and the UAE, desalination plants should be mandated to manage their brine discharge and reduce its negative impacts on marine organisms.

I. Reduce thermal pollution by setting and enforcing stricter regulations on the allowed temperature difference between discharge and intake water (Qatar's current maximum allowed difference of 3 degrees is a good standard for industries).

i. This is may be achieved through various established methods such as brine dilution or combining discharge from thermal plants with RO plants.

II. Reduce saline pollution by setting and enforcing stricter regulations on the allowed salinity difference between discharge and intake water

i. This may be achieved through various established methods such as brine dilution or dispersion through discharge diffusers.

III. Reduce chemical pollution by setting and enforcing stricter regulations on allowed chemicals as well as mandating the use of appropriate technology and placement of discharge pipes according to site suitability.

i. This may be achieved through measures including:

a. The installation of subsurface seawater intake pipes, which eliminates the need for chemical pre-treatment (Reynolds & Maley, 2008).

b. Using advanced membrane technology that reduce pre-treatment needs

c. Use of eco-friendly chemicals as replacements where applicable

b. Research on the mitigation of thermal, saline and chemical pollution by water/environment ministries in partnership with industry and academia is needed to determine the most cost effective technology for brine management and marine protection.

4. Reduce green house gas emissions resultant of water production from desalination.

a. Reducing GHG's resultant of water production from desalination is largely dependent on energy diversification covered in policy 6.2.

7.5. Institutional:

1. Enhance human capital, research capacity and public-private-partnerships.

a. This policy is both cross-sectoral and inter-agency, providing support for all the aforementioned ones. More specific institutional policy recommendations include:

I. Continue and expand post-secondary education enrollment by Qatari and Emirati nationals.

II. Continue and expand the uptake of research positions by Qatari and Emirati nationals.

i. Integrate research into more public sector jobs where majority of nationals work.

8. Conclusion:

In conclusion, Qatar, the UAE and other GCC states will continue to exhibit significant economic and population growth over the coming years. The result of which will be a continued rise in water and electricity production to meet the rising demand. Such growth is not without its environmental impacts, particularly on the marine environment and the climate. The challenges faced by GCC countries will be to imbedding the tenants of sustainability into their development practices to ensure intergenerational justice, and environmental stability. Though traditionally GCC countries have shown little attention to issues surrounding resource consumption, the environment and sustainability, recent developments suggest that the region is evolving. Primary and secondary research conducted suggests that governments within the region are becoming increasingly aware about water, energy, and environmental issues. The massive investments being made in renewable energy by governments in the region is reflective of the new attitude. However, in the context of water/energy security and sustainability it is pivotal that governments in the region place greater emphasis on demand management strategies opposed to the usual supply management response.

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Appendix 1

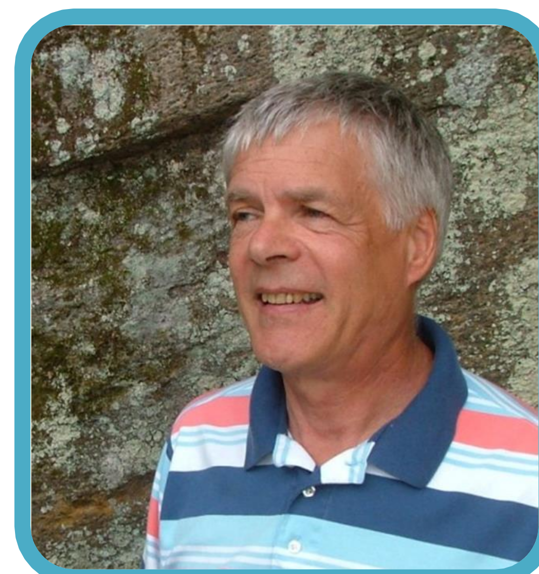
Supervisor committee & research methodology

Supervisor Committee

Dr. Krantzberg is actively engaged in research at the interface between science and public policy with extensive expertise on disciplines that could advance Great Lakes sustainability. She worked for the Ontario Ministry of Environment from 1988 to 2001, as the Coordinator and Senior Policy Advisor for the Great Lakes Program. She is a past president of the International Association of Great Lakes Research and sits on the Board of Directors for several Great Lakes and Policy related non-profit organizations. Dr. Krantzberg was the Director of the Great Lakes Regional Office of the International Joint Commission from 2001 to 2005. She is currently Professor and founding Director of the Dofasco Centre for Engineering and Public Policy in the School of Engineering at McMaster University offering Canada's first Master's Degree in Engineering and Public Policy. She also serves as Adjunct Professor at UNU-INWEH, working on lake management research. She has authored more than 100 scientific and policy articles on issues pertaining to ecosystem quality and sustainability and is a frequent speaker to media and the public. Gail completed her Ph.D. at the University of Toronto in environmental science and ecosystem health

Dr. Gail Krantzberg Director of Engineering & Public Policy, McMaster University

Prof. Peter Sale is a marine ecologist with over 40 years experience in tropical coastal ecosystems, particularly coral reefs. Prior to joining UNU-INWEH, he was a faculty member at the University of Sydney, Australia (1968-1987), University of New Hampshire, USA (1988-1993) and University of Windsor, Canada (1994-2006) where he remains Professor Emeritus. His work has focused primarily on reef fish ecology, most recently on aspects of juvenile ecology, recruitment and connectivity. He has done research in Hawaii, Australia, the Caribbean and the Middle East, and visited reefs in many places in between. He has successfully used his fundamental science research to develop and guide projects in international development and sustainable coastal marine management in the Caribbean and the Indo-Pacific. His laboratory has produced over 200 technical publications and he has edited three books dealing with marine ecology. Dr. Sale currently leads the Connectivity program within the Coral Reef Targeted Research Project as well as Coastal Zone Management in the Arabian Gulf.



Dr. Peter Sale, Assistant Director, Coastal Programme, UNU-INWEH

Supervisor Committee

Dr. Hassan Fath, Professor, Masdar Institute

Prof. Dr. Hassan Fath has wide academic and industrial experience in desalination & energy technologies. Currently he is the Professor of Practice at Masdar Institute of Science and Technology. Prior to that Dr. Fath was a Professor in Alexandria University (Egypt) and Visiting Professor at the following institutes: King Abdul Aziz University, (KSA), Qatar University, University of Beirut and University of Technology (Iraq).

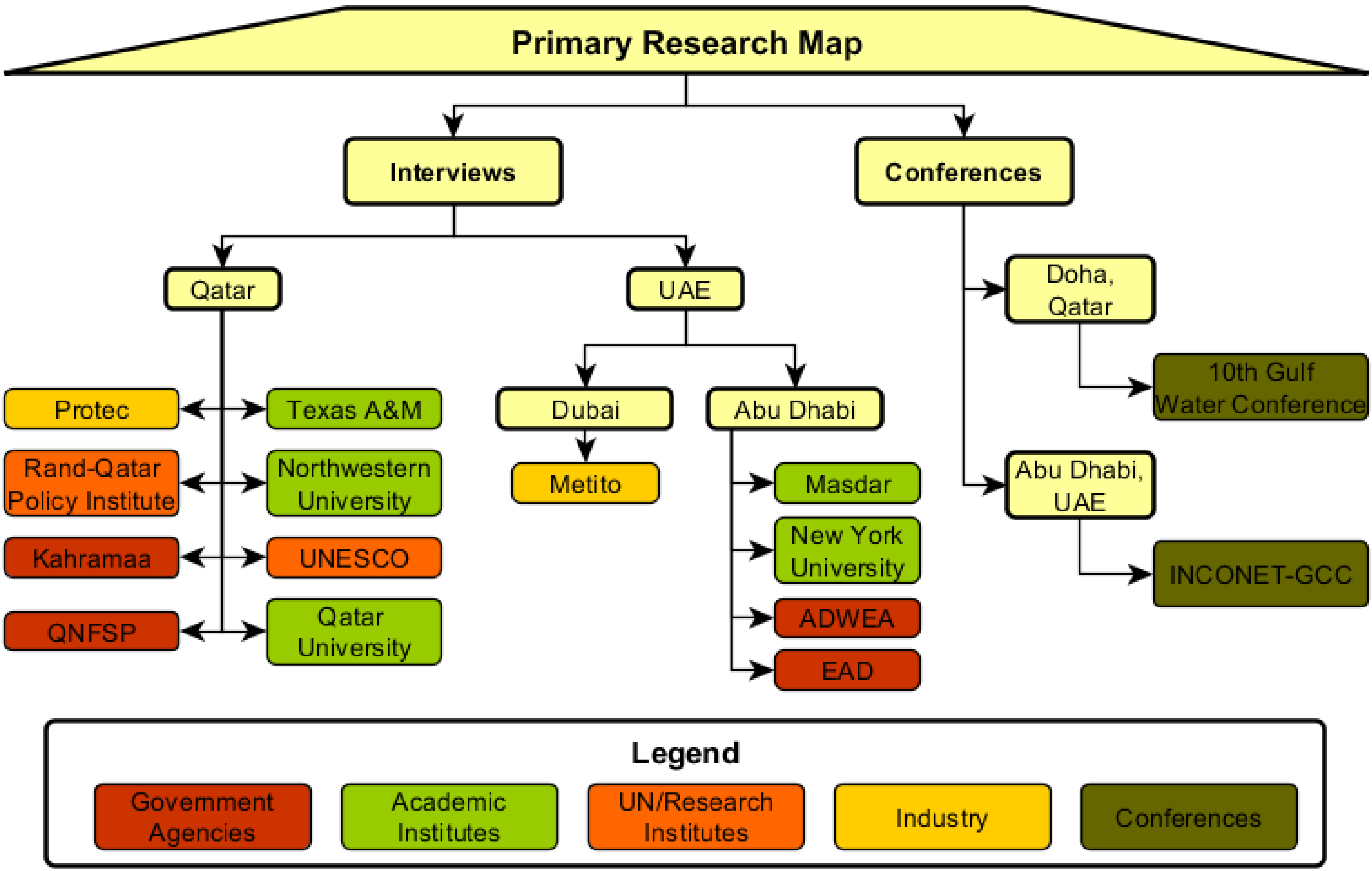
Dr. Fath is the author of two filed patents in MSF- MED desalination technologies. He has published a book entitled "Desalination Technology", and is the co-author of the Encyclopedia of Desalination & Water Reuse (DESWARE) and author of "Selections of Desalination Scientific Encyclopedia" (in press). In addition he has published over 100 papers in desalination and energy technologies.

Dr. Fath also has a significant industrial and engineering experience, having worked for Atomic Energy of Canada Limited (AECL) and Ontario Hydro (Canada); Saudi Arabian Marketing and Refining Co. (SAMAREC/ARAMCO), Consolidated Electricity Company (SCECO-W), and Saline Water Conversion Corporation (SWCC), Saudi Arabia; and the leader of new thermal desalination processes, Doosan's Water Research and Development Center, UAE.

Ms. Hanneke Van Lavieren completed her masters degree inMarine Biology and Ecology in 1997 at the University of Groningen, the Netherlands. Her research focused on the relationship between the structural complexity of corals and associated reef fish communities and the impact of small-scale fisheries in the Spermonde Archipelago, Sulawesi, Indonesia. She began her career as a Fisheries Biologist for the Netherlands Institute for Fisheries Research where she studied catch composition and population dynamics of target and non-target fish species in the Dutch beam trawl fishery and alternative fishing methods to reduce by-catch. Longing to return to the tropics, she took up a position as (coastal/marine) Technical Advisor for a conservation project in the Philippines for the Netherlands Development Agency in 1999. Here she worked closely with local communities, conducted extensive coastal monitoring and training activities, and developed an integrated coastal management plan. In 2001, she moved to Kenya to join the United Nations Environment Programme, Regional Seas Programme, where she dealt with issues such as small islands, MPAs, coastal biodiversity, cetacean management, mangroves, climate change and marine invasive species within 18 regional programmes. Since September 2006, she has been working for UNU-INWEH as the Coastal Ecosystems Programme Officer, and together with Dr. Peter Sale manages and coordinates coastal projects.

Ms. Hanneke Van Lavieren, Programme Officer, Coastal Programme, UNU-INWEH

Interview Map



Appendix 2

Qatar & UAE country profiles

Qatar Country Profile

Geography:

Located within the Arabian Peninsula Qatar is surrounded by Persian/Arabian Gulf, sharing borders with Saudi Arabia.

Total area of 11,437 km^2 *

Capital city: Doha

Maps from CIA World Factbook

Climate:

Under the Koppen Climate Classification Qatar is considered a hot desert climate (BWh)

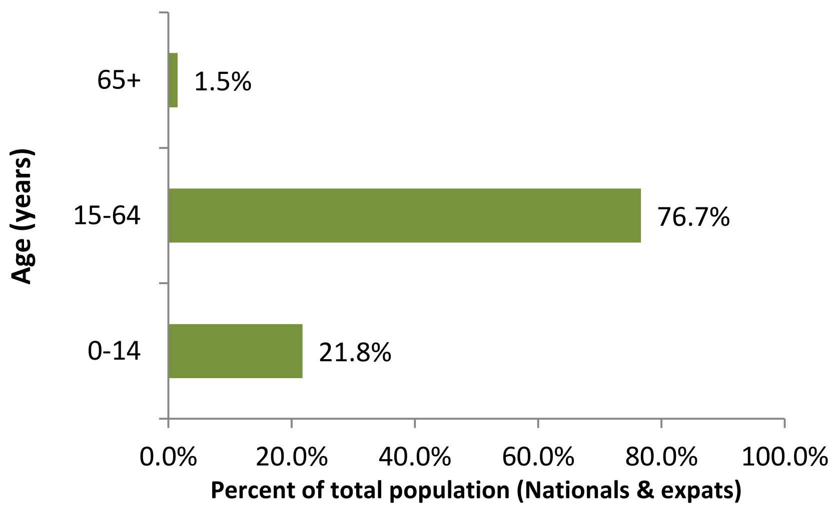
Demographic:

Total Population: 1,951,591 (2011 est.)*

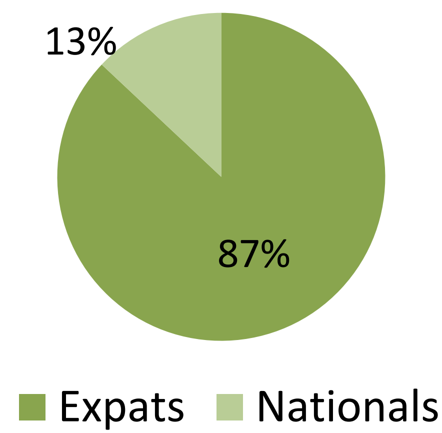
Population Growth Rate: 4.93% (2011 est.)*

Labour Force:
1.241 million (2011 est.)*

Age Structure in Qatar**



Qatar Population Breakdown*



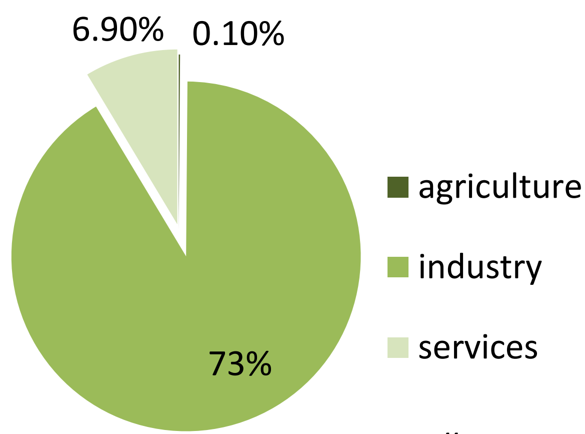
Qatar Country Profile

Economy:

Table:

Economic Indicators (2011 est.)	
Total GDP (at PPP)	$181.7 Billion
GDP per capita (at PPP)	$102,700
GDP real growth rate	18.7%
Currency in USD	

GDP Composition by Sector



Main Industries:

liquefied natural gas, crude oil production and refining, ammonia, fertilizers, petrochemicals, steel reinforcing bars, cement, commercial ship repair

All economic data is based on 2011 estimates

Energy:

Share of Total Primary Energy Supply in Qatar 2009**

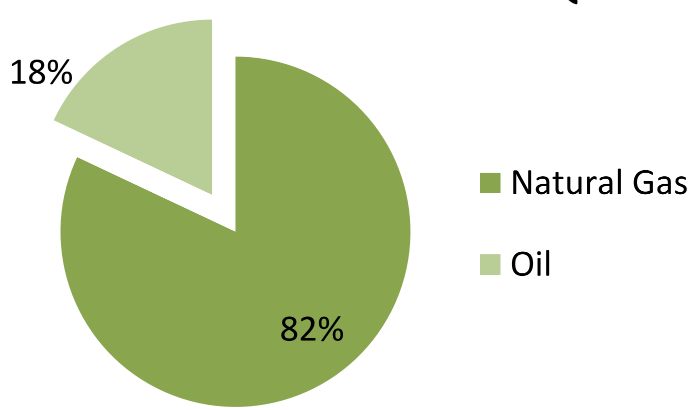


Table:

Key Indicators		Compound Indicators	
Energy Production (Mtoe)	139.95	TPES/Population (toe/capita)	16.91
Total Primary Energy Supply (Mtoe)	23.82	TPES/GDP (PPP) (toe/thousand 2000 USD)	0.65
Electricity Consumption (TWh)	23.04	Electricity Consumption/ Population (KWh/capita)	16,353
CO_2 Emissions (Mt of CO_2)	56.53	CO_2/Population (t CO_2/capita)	40.12
		CO2/GDP (PPP) (kg CO2/2000 USD)	1.55

Qatar Country Profile

Water:

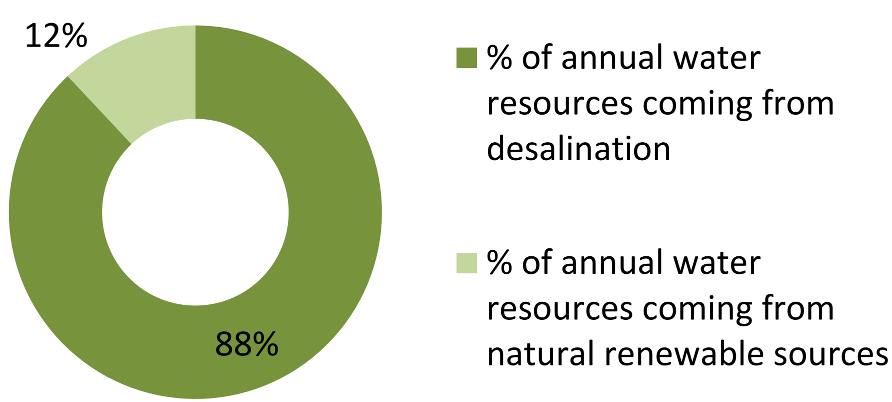
Water footprint of Qatar resident : **>3000m^3 /yr**

>2 ✖ the global average

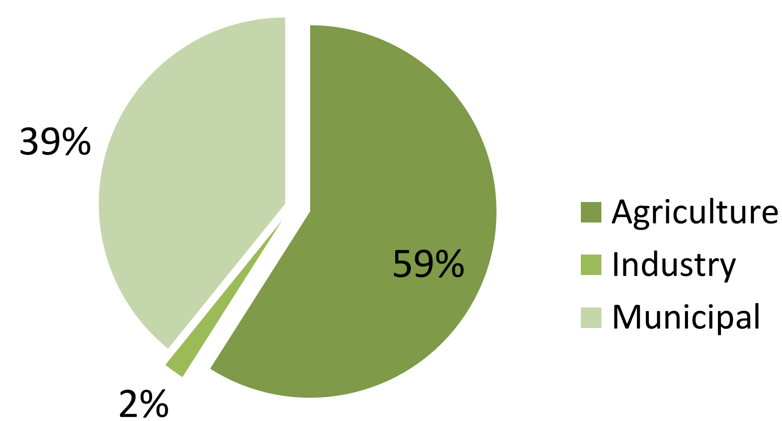
Table:

Water Resources	Volume (km^3/yr)	Source
Renewable Natural Resources:		
Groundwater	0.06	FAO AQUASTAT, 2010
Surface water	0.00	FAO AQUASTAT, 2010
Total water resources	**0.06**	FAO AQUASTAT, 2010
Total renewable per capita	**32.97m^3/yr**	FAO AQUASTAT, 2010
Higher quality nonconventional resources:		
Desalination	0.40	DesalData
Reuse – tertiary or better	0.07	Global Water Market 2011, GWI
Total nonconventional resources	**0.47**	

Annual Water Resources by Source

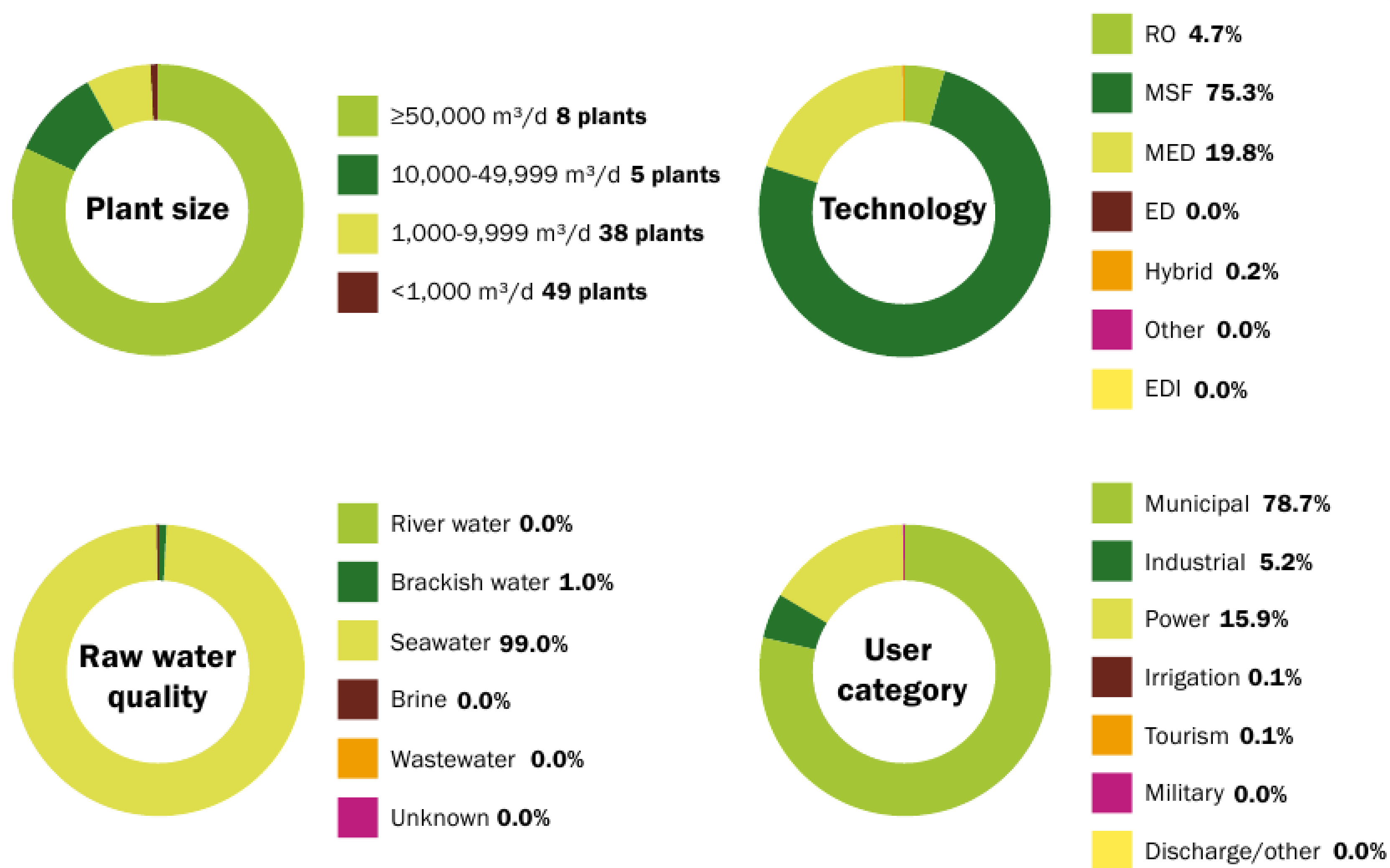


Fresh Water Withdrawal by Sector



Desalination:

Figure: Installed capacity by plant size, technology, raw water quality and user category



Qatar Country Profile

Desalination sites in UAE with a plant capacities over 50,000m³/day

Table: Desalination plants in Qatar with capacities over 50,000m³/day

Plant Name	Technology	Capacity (m^3/d)
Ras Laffan 1	MSF cogeneration	182,000
Ras Laffan 2	MSF cogeneration	272,760
Ras Abu Fontas A1	MSF	204,570
Ras Abu Fontas A3	MSF	90,920
Ras Abu Fontas B	MSF cogeneration	150,000
Ras Abu Fontas B2	MSF cogeneration	136,380

UAE Country Profile

Geography:

Located within the Arabian Peninsula UAE's coastline lies predominantly on the Persian/Arabian Gulf, with a small portion also on the Gulf of Oman. It shares borders with Saudi Arabia and Oman.

Total area of 83,600 km^2 **

Capital city: Abu Dhabi

Maps from CIA World Factbook

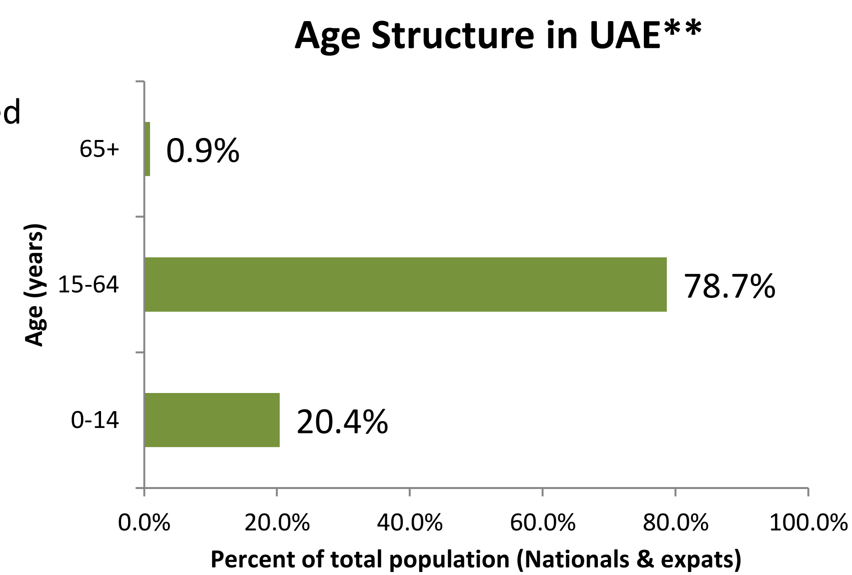
Climate:

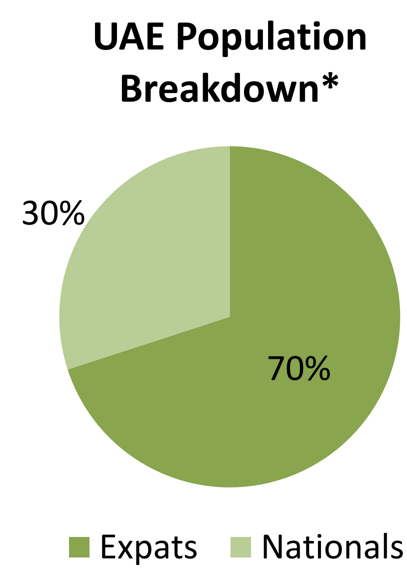
Under the Koppen Climate Classification the UAE is considered a hot desert climate (BWh)***

Demographics:

Total Population: 5,314,317 (2012 est.)**

Population Growth Rate: 3.055% (2011 est.)**





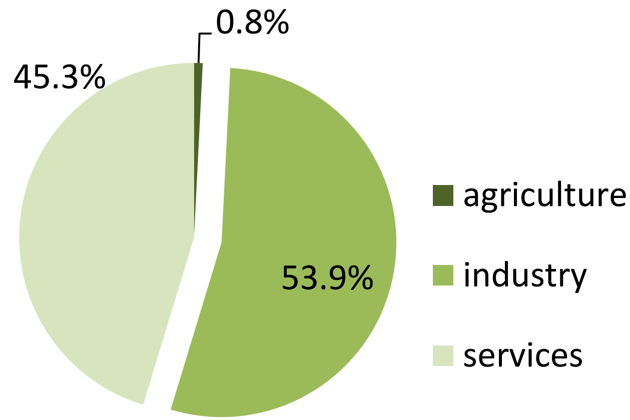
UAE Country Profile

Economy:

Table:

Economic Indicators (2011 est.)	
Total GDP (at PPP)	$260.8 Billion
GDP per capita (at PPP)	$48,500
GDP real growth rate	3.30%
Currency in USD	

GDP Composition by Sector



Main Industries:

liquefied natural gas, crude oil production and refining, ammonia, fertilizers, petrochemicals, steel reinforcing bars, cement, commercial ship repair

All economic data is based on 2011 estimates

Energy:

Share of Total Primary Energy Supply in UAE 2009

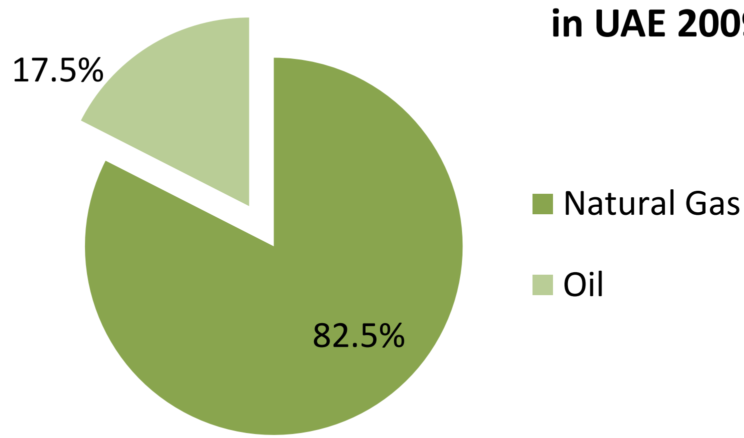


Table:

Key Indicators		Compound Indicators	
Energy Production (Mtoe)	168.8	TPES/Population (toe/capita)	12.96
Total Primary Energy Supply (Mtoe)	59.6	TPES/GDP (PPP) (toe/thousand 2000 USD)	0.50
Electricity Consumption (TWh)	79.5	Electricity Consumption/ Population (KWh/capita)	17,296
CO_2 Emissions (Mt of CO_2)	147.0	CO_2/Population (t CO_2/capita)	31.97
		CO2/GDP (PPP) (kg CO2/2000 USD)	1.26

UAE Country Profile

Water:

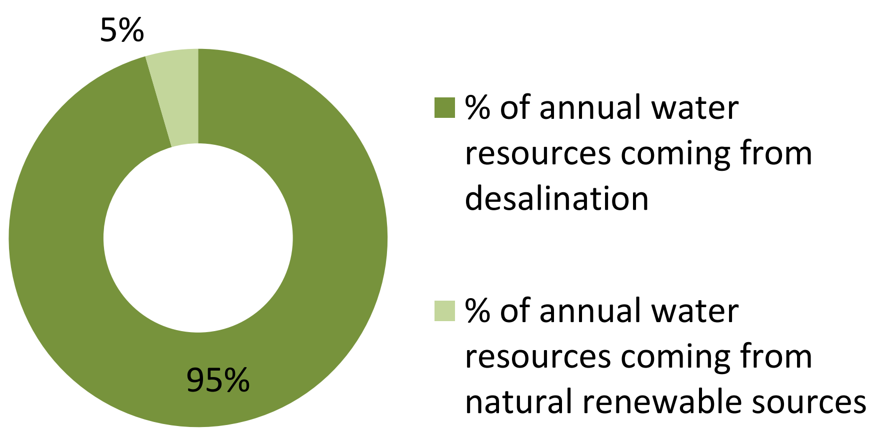
Water footprint of UAE resident : **3136m³/yr**

2.26 ✖ the global average

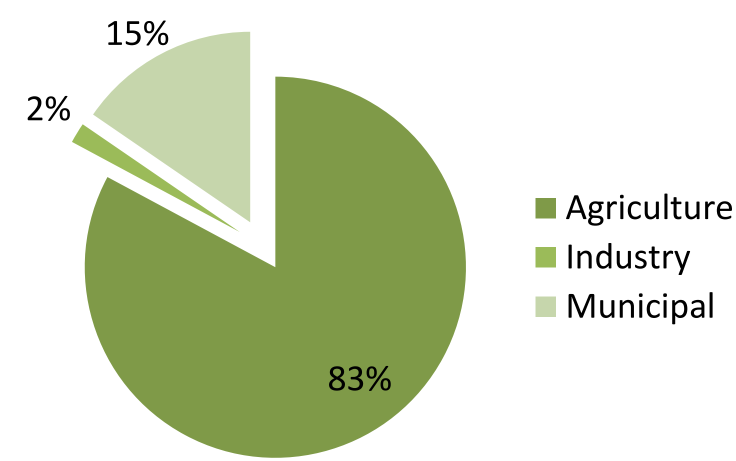
Table:

Water Resources	Volume (km³/yr)	Source
Renewable Natural Resources:		
Groundwater	0.12	FAO AQUASTAT, 2010
Surface water	0.15	FAO AQUASTAT, 2010
Total water resources	**0.15**	FAO AQUASTAT, 2010
Total renewable per capita	**19.97m³/yr**	FAO AQUASTAT, 2010
Higher quality nonconventional resources:		
Desalination	3.18	GWI DesalData
Reuse – tertiary or better	2.17	Global Water Market 2011, GWI
Total nonconventional resources	**5.35**	

Annual Water Resources by Source



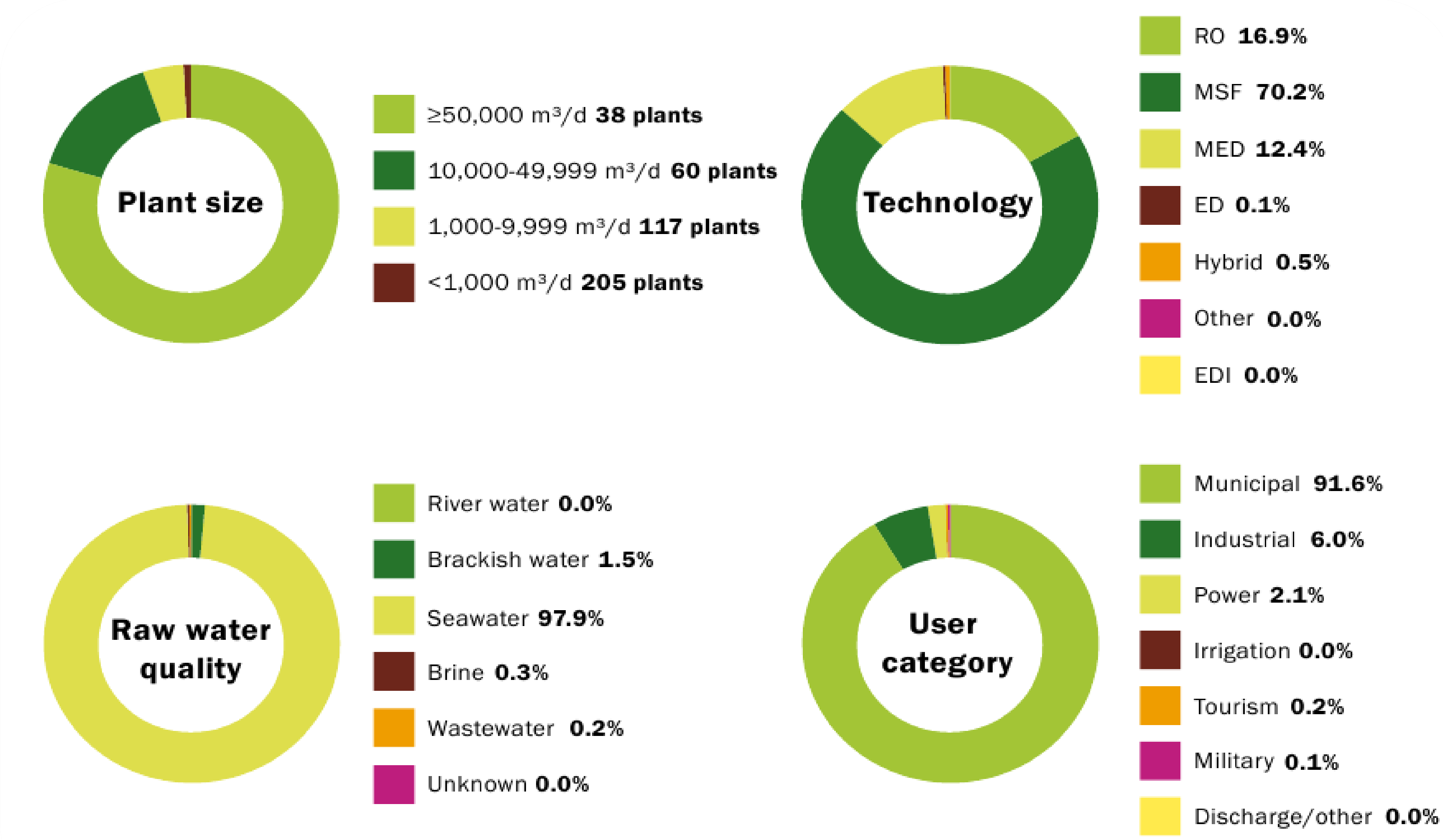
Fresh Water Withdrawal by Sector



UAE Country Profile

Desalination:

Figure: Installed capacity by plant size, technology, raw water quality and user category



Source: GWI DesalData

UAE Country Profile

Desalination sites in UAE with a plant capacities over 50,000m^3/day

UAE Country Profile

Table: Desalination plants in UAE with capacities over 50,000m³/day

Plant Name	Technology	Capacity (m^3/d)
Shuweihat 1	MSF cogeneration	454,200
Shuweihat 2	MSF cogeneration	459,146
Al Mirfa	MSF cogeneration	102,144
Al Mirfa	MSF cogeneration	73,800
Abu Dhabi	MSF	950,000
Abu Dhabi	MSF	60,000
Umm AL Nar East A	MSF	82,500
Umm AL Nar East B	MSF	98,400
Umm AL Nar West 7-8	MSF	110,000
Umm AL Nar 1-4	MSF	76,400
Umm AL Nar IWPP	MSF cogeneration	113,650
Umm AL Nar B	MSF	284,125
Al Taweelah A1	MSF cogeneration	98,000
Al Taweelah A1	MED cogeneration	240,000
Al Taweelah A2	MSF cogeneration	227,000
Al Taweelah B1	MSF cogeneration	340,950
Al Taweelah B2	MSF cogeneration	104,400
Al Taweelah B3	MSF cogeneration	314,600
Jebel Ali	MSF	127,200
Jebel Ali M Station	MSF cogeneration	636,440
Jebel Ali G	MSF cogeneration	273,000
Jebel Ali L1	MSF cogeneration	317,800
Jebel Ali L2	MSF cogeneration	250,000
Jebel Ali K2	MSF cogeneration	182,000

Plant Name	Technology	Capacity (m^3/d)
Palm Jumeriah	RO	64,000
Dubai Ext.	MSF	60,000
HAMPS Phase II	RO cogeneration	91,000
Ras Al Khaimah	MED	68,190
Al Fujairah 1	MSF	284,000
Al Fujairah 1	RO cogeneration	170,000
Al Fujairah 2	MED	454,200
Al Fujairah 2	RO cogeneration	136,260

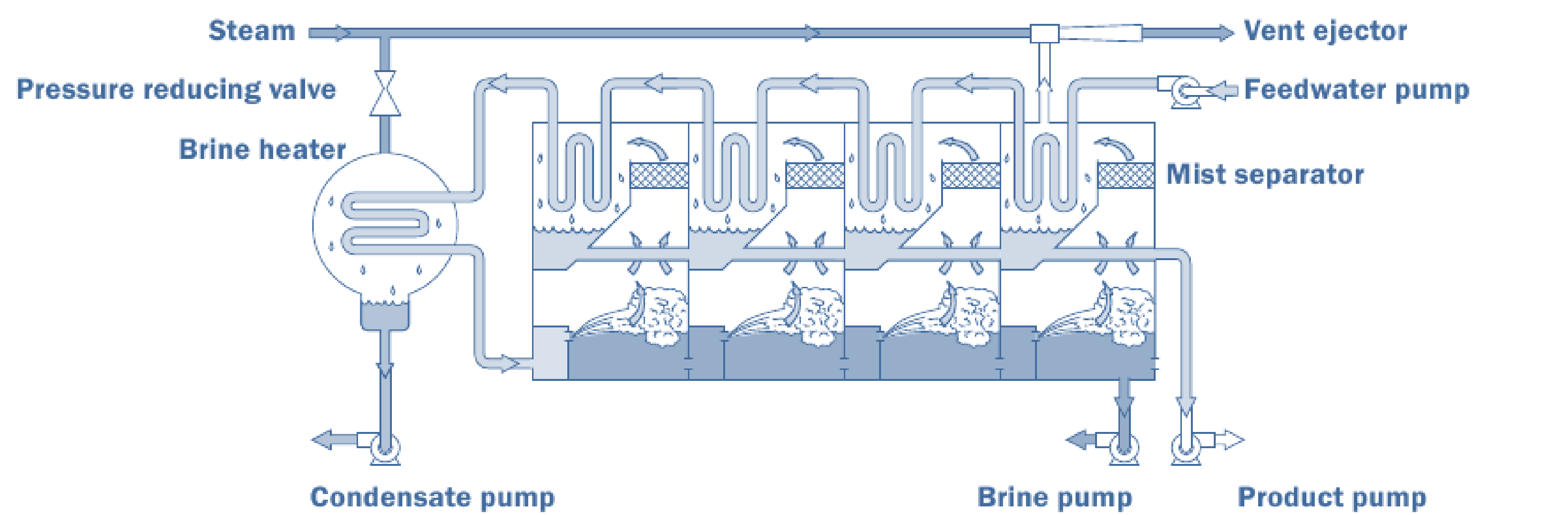
Appendix 3

Desalination technology profiles

Multi-Stage Flash (MSF) Profile

The MSF process takes advantage of the fact that water boils at successively lower temperatures if the pressure decreases accordingly. In the process, a stream of heated seawater flows though the bottom of a vessel containing up to 40 chambers, or stages, each operating at a slightly lower pressure than the previous one. The lower pressure causes the hot seawater to begin boiling immediately upon entering each new stage, causing a portion of the seawater to instantly vaporise, or flash, into steam. The flashed vapour rises rapidly, passing around the outside of a tube bundle carrying cool seawater, where it is condensed into pure, distilled water.

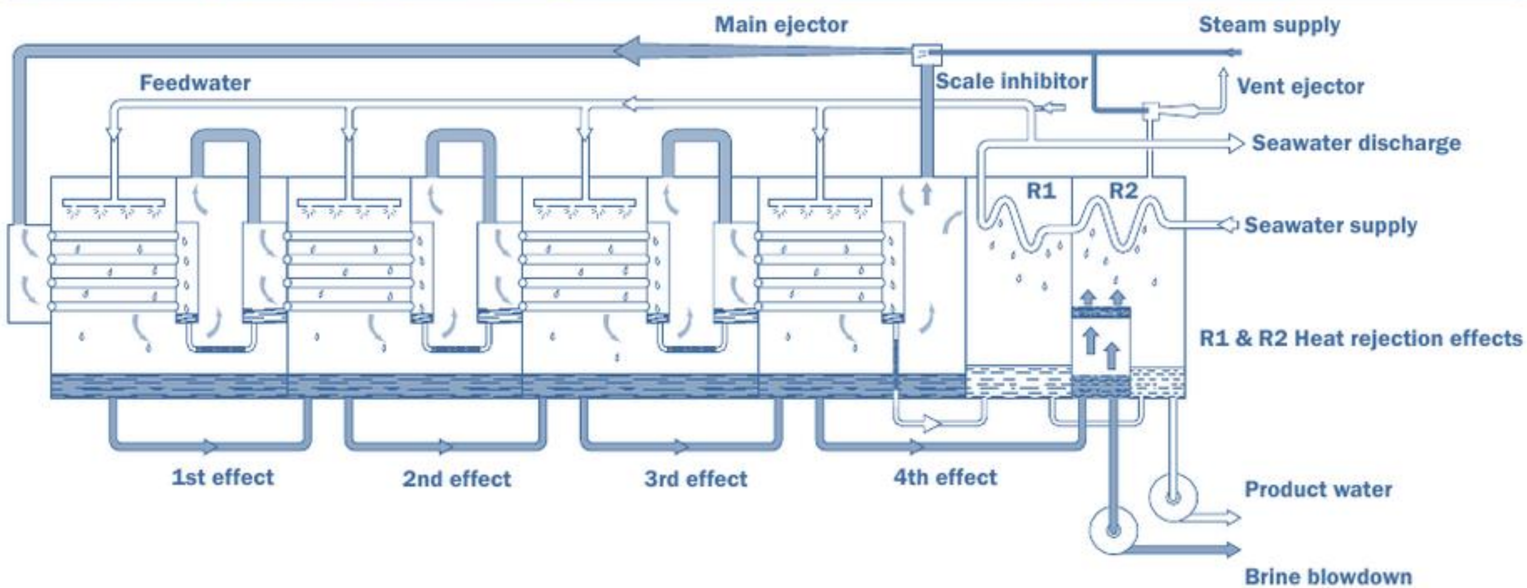
Figure 1.2 Multi-Stage Flash desalination



Multi-Effect Distillation (MED) Profile

In the MED process, distillation takes place in a series of chambers, or effects, operating at progressively lower pressures. Within each effect, cool seawater is sprayed over a heat exchanger tube bundle while steam flowing through the tubes is condensed into pure product water. Outside the tubes, the thin seawater film boils as it absorbs heat from the steam. The resulting vapour is introduced into the tubes in the next effect. The process is repeated through the length of the plant. The efficiency of the MED process can be increased with the introduction of vapour compression to energise low pressure steam going into the evaporator.

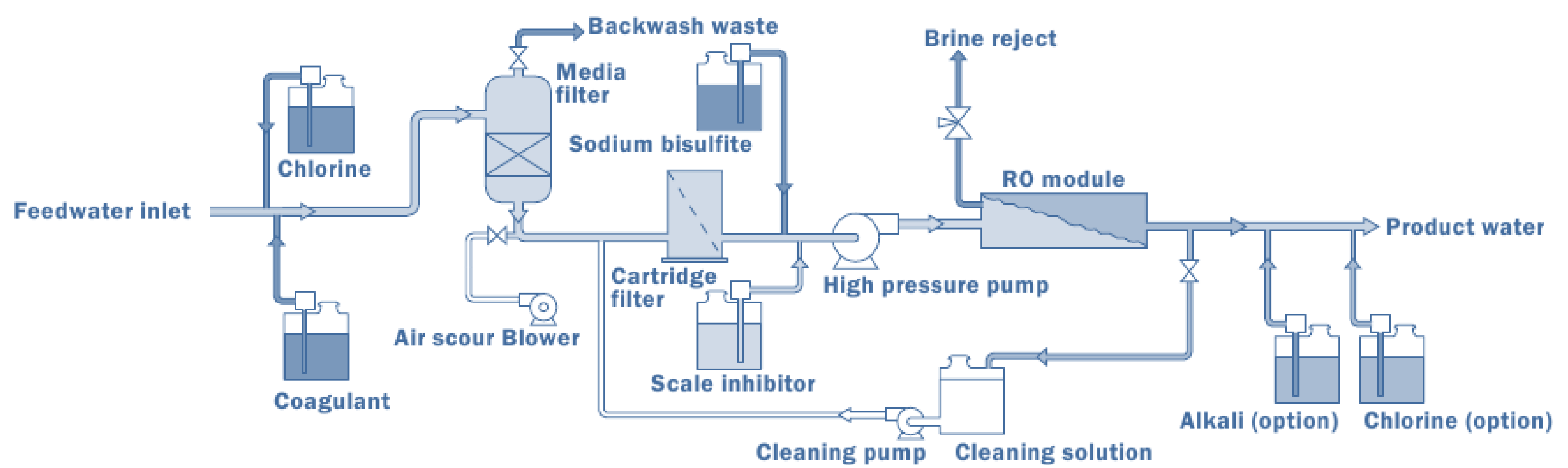
Figure 1.5 The Multi-Effect Distillation desalination process with thermal vapour compression



Reverse Osmosis (RO) Profile

The process of osmosis involves water molecules in a dilute solution diffusing through a semi-permeable membrane to a concentrated solution until equilibrium is achieved (i.e. when both solutions are equally concentrated). The reverse movement on water molecules from a concentrated solution to a dilute solution can be achieved by putting pressure on the concentrate. Pure water goes through the semi-permeable membrane, but the solute ions do not. The use of reverse osmosis in desalination was pioneered in the 1960s and commercialised in the 1970s. Since then, there has been a dramatic fall in the cost of desalination using this process. This has been driven by greater membrane efficiency and falling membrane costs.

Figure 1.7 The Reverse Osmosis desalination process



Cogeneration

Thermal/membrane hybrid plants are becoming an important area of development in desalination. There are two different kinds, although the first kind is not strictly a hybrid. It is a combination of co-located thermal and membrane desalination plants attached to a power generation facility. This enables the power plant to maintain a high baseload throughout the year, switching output to water production during off-peak periods. This is the method most often employed by desalination plants in the Gulf region, usually using an MSF system which can capitalize on waste heat from power generation plants.

MSF/MED & RO Hybrid Systems

The second kind of hybrid — the true hybrid — involves integrating a thermal and a membrane process either simultaneously or in series in a single production train. Membrane distillation is the term used for a hybrid where the two processes take place simultaneously. This approach has been proven on a small scale, but so far the response from industry has been lukewarm. The use of membranes — particularly nano-filtration (NF) membranes – used in series with thermal technology is better established. The next development in this area will be to develop an MED/RO/NF tri-hybrid, with NF operating as a pre-treatment for the MED process and the RO process (which would operate in parallel), and the RO taking feedwater which has been pretreated by the MED process. Recent research suggests that raising the feed-water temperature in the RO process reduces the feedwater pressure required.

Desalination Process Comparison

Figure 1.9 Desalination process comparison

Parameter	MSF	MED (TVC)	SWRO
Pretreament required	Minimum	Minimum	Critical
Chemical consumption	Low	Low	Higher
Sludge production	None	None	Some
Scaling	Low	Low	Lowest
Fouling	Low	Low	Higher
Operational simplicity	Lowest	Low	Higher
Reliability / Robustness	Highest	High	Pretreatment dependant
Capital cost	Highest	High	Lower
Electricity consumption (kWh/m^3)	3.5	1.2	4
Steam consumption (GOR)	10:1	7:1	n/a
Concentration factor (Brine/Feed)	1.7	1.7	1.9
Top brine temperature (°C)	110	65	n/a
Feedwater pressure (bar)	2	2	65
Feed : Product flow	8:1	8:1	2.2:1
Product TDS, mg/l	<25	<25	450
Max capacity per unit/train (m^3/d)	78,700	37,850	240,000

Source: GWI DesalData