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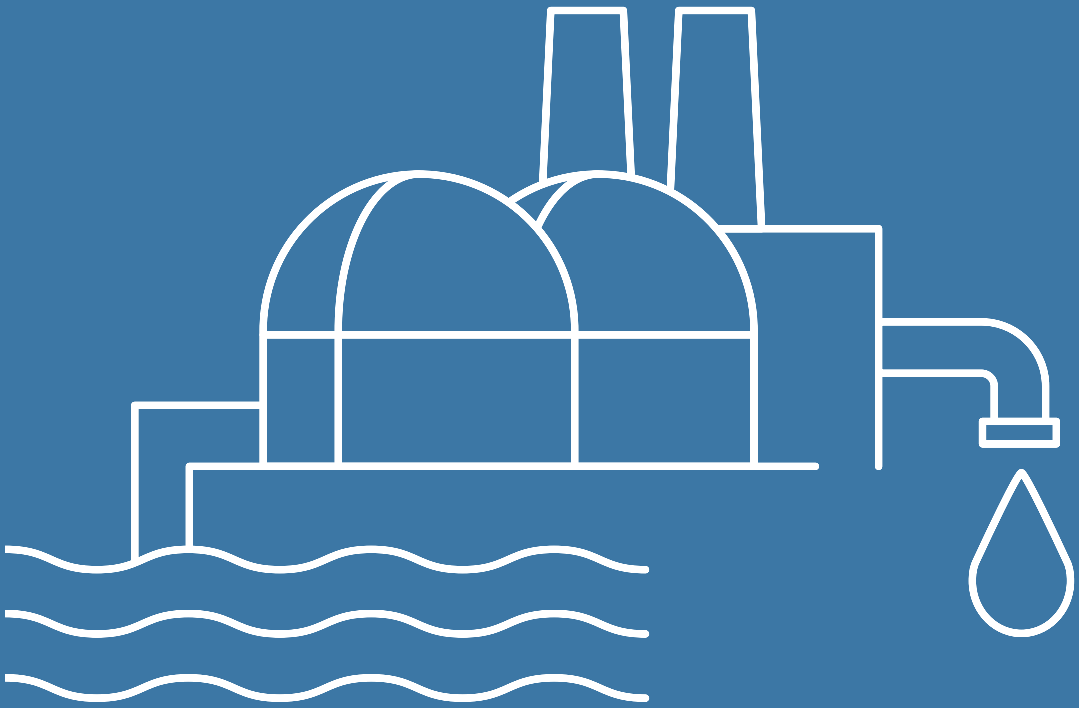
Regional Study:
„Desalination as an alternative to alleviate water scarcity and a climate change adaptation option in the MENA region“



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For ease of reading, this report does not exclusively use gender-neutral terminology. However, the report's text should always be considered to apply equally to all genders.

Content

Foreword

Water - a vital and at the same time limited resource, its availability worldwide continuously decreasing. The ongoing climate change is aggravating this situation even further. In the MENA region, the decline in the availability of drinking water is already having a noticeable impact on the security of supply for the region's population. This shortage of water resources can become an additional driver of friction, especially in an already conflict-prone region like the Middle East.

At present, the COVID-19 pandemic situation in particular impressively demonstrates how crucial unrestricted access to water is not only for the supply of drinking water but also for the implementation of hygiene measures to combat the risk of infection.

A strong demographic growth is expected for the entire MENA region in the coming decades. As a result, the demand for water will also increase in the countries of the region. In order to meet the needs of the populations despite the decline in natural resources, their states are intensively working on alternative ways of reliably meeting water needs in the future. One of the most prominent ones being seawater desalination.

While the desalination and treatment of seawater to produce drinking water has not been the focus of discussion for many years, due to the high energy input required, the increasing development of renewable energy sources in the region has lead to seawater desalination currently becoming a real and bankable alternative. Most MENA countries have wide access to seawater, as well as to sun and wind as energy sources for a more CO_2-neutral drinking water production.

Besides the need to provide sufficient potable water for a growing population, there is also an increased demand on fresh water in agricultural and industrial processes in the region. As the world is turning towards Green Hydrogen and Power-to-X, the MENA countries with their almost unlimited access to solar and wind energy are the ideal producers of these energy carriers to store renewable energies which are volatile in their creation. Therefore, they need access to sufficient fresh water, without causing a competition between the population's and the industry's needs, by raising the available amounts of drinking water through seawater desalination.

As a political foundation, the Konrad-Adenauer-Stiftung (KAS) has a great interest in supporting research in this field. Through its Regional Program Energy Security and Climate Change Middle East and North Africa (REMENA), based in Rabat, Morocco, KAS focuses, among others, on the promotion of regional cooperation through concepts and measures for resource security, especially water and energy, and in this way aims to contribute to conflict prevention in the region.

This publication was produced in cooperation with MEDRC Water Research. KAS - REMENA would especially like to thank Dr. Jauad El Kharraz (Head of Research, MEDRC Water Research) and his team for their intensive work on this joint project.

The study provides an overview of the current state of research and the establishment and use of seawater desalination technologies in the MENA region. Selected country examples from the region are examined in more detail. Based on this review, the study addresses the ecological and socio-economic consequences of this new technology and delivers recommendations for political decision-makers.

We hope you will find the report an inspiring read.

Yours,

Daniela Diegelmann

Head of Regional Program Energy Security and
Climate Change Middle East and North Africa
(KAS - REMENA)

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Abbreviations

5+5	Western Mediterranean Countries
AAR	Artificial aquifer recharge
AD	Absorption desalination
AD	Anno domini (B.C.: before the birth of Jesus Christ)
ADE	Algerian Waters (National water and Sanitation Company)
ADIRA	Autonomous Desalination System Concepts for Sea Water and Brackish Water in Rural Areas with renewable energies (project)
AFED	Arab Forum for Environment and Development
ASEZA	Aqaba Special Economic Zone Authority
AWC	Arab Water Council
bn	Billion
BMCE	Banque Marocaine du Commerce Extérieur (Moroccan Bank for Foreign Commerce)
BOO	Build-own-operate
BOT	Build-operate-transfer
BOOT	Build-own-operate-transfer
BST	Bulk supply tariff
BW	Brackish water
BWRO	Brackish water reverse osmosis
CAPEX	Capital expenditures (cost)
CDI	Capacitive deionization
CIEMAT	Research Centre for Energy, Environment and Technology (Spain)
CO_2	Carbon dioxide
CSP	Concentrated solar power
CTA	Cellulose tri-acetate
DAF	Dissolved air floatation
DB	Design-build
DC	Direct current
DBB	Design-bid-build
DBO	Design-build-operate

DBOOT	Design-build-own-operate-transfer
DEWA	Dubai Electricity and Water Authority
DMF	Dual media filtration
DMGF	Dual media gravity filtration
DS	Draw solution
EAD	Environment Agency – Abu Dhabi
ED	Electrodialysis
EDI	Electro deionization
EDR	Electrodialysis reversal
EMWIS	Euro-Mediterranean Water Information System
EPC	Engineering, Procurement and Construction
ERI	Energy Recovery Inc.
EU	European Union
FAO	Food and Agriculture Organization (United Nations)
FO	Forward Osmosis
GCC	Gulf Cooperation Council
GDP	Gross domestic product
GHG	Greenhouse gas
GTZ	German Technical Cooperation Agency (GIZ currently)
GWP	Global Water Partnership
ha	Hectare
HABs	harmful algal blooms
HFF	Hollow Fine Fiber
IBM	International Business Machines Corporation (Company)
ICBA	International Center for Biosaline Agriculture
IDA	International Desalination Association
IEA	International Energy Agency
INWEH	International Network on Water, Environment and Health
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IsDB	Islamic Development Bank
JSTOR	Journal Storage
IWP	Independent water projects
IWPP	Independent water and power projects
JVA	Jordan Valley Authority
KAC	King Abdullah Canal
KACST	King Abdulaziz City for Science and Technology
KAS	Konrad-Adenauer-Stiftung
KAUST	King Abdullah University of Science and Technology
KSA	Kingdom of Saudi Arabia
kW	Kilowatt
kWh	Kilowatt hour
kWh/m^3	Kilowatt hour per cubic meter
kWp	Kilowatt peak
L	Litter
L/day	Litres per day
M	Million
MCM	Million Cubic Meter

MDC	Microbial Desalination Cells
mg/L	Milligram Per Litre
MIT	Massachusetts Institute of Technology
m^3	Cubic meter
m^3/y	Cubic meter per year
MD	Membrane distillation
MEDRC	Middle East Desalination Research Center
MED	Multi-effect distillation
MF	Microfiltration
MoU	Memorandum of understanding
MoWI	Ministry of water and irrigation
MSF	Multi-stage flash distillation
MSL	Moisture sensitivity level
MVC	Mechanical vapour compression
MW	Megawatt
N/A	Not applicable
NAMA	Omani highest governmental entity in charge of delivering water services
NF	Nanofiltration
NG	Natural gas
NRW	Non-revenue water
NTU	Nephelometric Turbidity Unit
NWSAS	North Western Sahara Aquifer System
OCP	Morocco's Office Chérifien des phosphates
ONA	Algerian National Sanitation Office
ONEE	Moroccan National Office of Electricity and Drinking Water
O&M	Operation and maintenance
OPEX	Operating expenses (cost)
OPWP	Oman Power and Water Procurement
OWD	Offshore Water Desalination
OWS	Oman Water Society
PPP	Public Private Partnership
PRIMA	Partnership for Research and Innovation in the Mediterranean Area
PRO	Pressure retarded osmosis
PV	Photovoltaic
PWA	Palestinian Water Authority
R&D	Research & Development
RED	Reverse electrodialysis
REMENA	Regional Program Energy Security and Climate Change Middle East and North Africa
RO	Reverse osmosis
MENA	Middle East and North Africa
FAO	Food and Agriculture Organization of the United Nations
GWI	Global Water Intelligence
RE	Renewable Energies
RFP	Request for Proposal
RFQ	Request for Quote
RO	Reverse osmosis
SDG	Sustainable development goals
SEAAL	Algerian Society of Water and Sanitation

SGSP	Salinity-gradient solar ponds
SONEDE	Tunisian National Water Supply Utility
SPVs	Special purpose vehicles
SW	Seawater
SWCC	Saline Water Conversion Corporation
SWRO	Seawater reverse osmosis
T&C	Terms and Conditions
TDS	Total Dissolved Solids
TRC	The Research Council in Oman
TRL	Technology Readiness Level
TVC	Thermal vapour compression
TWW	Treated waste water
UAE	United Arab Emirates
UfM	Union for the Mediterranean
UNU	United Nations University
US	United States
USAID	United States Agency for International Development
USD	United States Dollar
VC	Vapour compression
WAJ	Water Authority of Jordan
WFD	Water framework directive
WHO	World Health Organization
WWC	World Water Council

Introduction

I. Rationale

According to the World Water Council (WWC), while the world population tripled in the 20th century, the use of renewable water resources grew six-fold (WWC, 2000). Still, around one billion (bn) people do not have access to adequate water supply and that more than two billion lack access to proper sanitation facilities. Within the next fifty years, the world population will increase by 40 to 50 %. This growth - coupled with industrialisation and urbanisation as well as food production - will result in an increasing demand for freshwater and will subsequently have severe consequences for water environments. At the same time, climate change and some of its most pernicious effects such as floods and droughts will likely exert additional pressures on already stressed water resources in many areas.

Given the magnitude of challenges an increasing number of reports call for integrated approaches to water planning and management able to accommodate traditional and alternative water supply systems as well as introduce demand management measures capable of increasing efficiencies and savings. While still far from achieving significant results at the global level, integrated approaches and especially demand management have been partially successful in reducing water demand and consumption in the developed world. Concurrently, alternative resources, especially treated wastewater and desalination, are rapidly gaining ascendancy in some regions of the world for which more conventional options such as dams or water transfers face rapidly increasing economic and environmental costs and also social and political opposition.

In many respects the worsening water scarcity in the Middle East and North Africa (MENA) region has become an object-lesson in the water crisis facing the whole world as climate change becomes a reality. The increases in water requirements for the dynamic socio-economic development of the region will also be affected negatively by climate change. By 2050, water scarcity could cost the MENA region a drop of between 6 % and 14 % of GDP each year (World Bank, 2017).

With 6.3 % of the world's population having access to merely 1 % of the world's total water resources (Abou-Elnaga & Aydin, 2018 and FAO, 2016), water scarcity in the MENA Region is one of the major and most critical development challenges. This challenge is expected to grow over time due to many pressing driving forces, including population and economic growth, tourism, food & energy demand, political and social conflicts and climate change. Most of the MENA countries are already living in conditions of absolute water scarcity. The region is one of the most water-stressed areas of the world, with an average per capita of renewable water resources of 351 m^3/y in 2014, whereas water availability per person in other geographical regions is about 7,000 m^3/y. Twelve MENA countries are below the absolute water scarcity level of 500 m^3/y per capita. It is also worth noting that renewable water resources are unequally distributed across the region as evidenced by the annual share per capita that varies between 5 m^3/y in Kuwait and 2,802 m^3/y in Mauritania (AWC, 2015).

For dry regions like the MENA, desalination has long been part of national water strategies. As a whole, the region accounts for almost the half of the world's desalination capacity and is home to some of the largest desalination plants. Interest and investment in desalination are expanding beyond this part of the world, however, driven in part by water-scarcity concerns —14 % of the world population is expected to live in water-scarce areas and will be facing a major challenge of a widening gap in water supplies and demand by 2030, by which nearly half the global population could be facing water scarcity, with demand outstripping supply by 40 % (Ban Ki-Moon, 2013). This is attributed to limited renewable water resources and anticipated high population growth.

In fact, climate change and poor water management have been implicated as contributing causes to both the Syrian and Yemeni civil wars. Unrest, instability and conflict can all be triggered or worsened by water scarcity. Besides being inefficiently managed, water is also distributed unevenly across the globe, making some regions significantly more stressed than others. The Middle East will be one of the regions most affected by water shortages in following years. According to an analysis by the World Resources Institute, 33 countries will face extremely high water stress in 2040, of which a shocking number of 14 will be in the Middle East. In addition, water availability and quality are threatened by pollution, the impacts of climate change, population growth and increasing consumption.

Overcoming the already expected water deficit in 2025 will require an estimated 237 bn m^3 to make it necessary to augment supply through increased dependency on desalination, increased water reuse of adequately treated wastewater sources and the mining of the non-renewable groundwater.

Desalination is becoming increasingly important as a solution to the water challenges and a serious climate change adaptation option in the region, and also an important strategic technology to fulfill the sustainable development goals (SDGs), mainly the SDG 6 (Ensure availability and sustainable management of water and sanitation for all) and SDG6-a: “By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies”.

Desalination offers several advantages over other water supply options because it taps a virtually infinite resource that is more immune to political or social claims than conventional hydraulic works. Moreover, desalinated seawater is insensitive to climate change and may reduce tensions between and within countries struggling over shared water resources. About 80 % of the population in this region live within 100 Km from the sea (AFED, 2009).

Desalination is growing rapidly worldwide, but also presents essential drawbacks:

- High financial costs and energy costs needed to transform seawater into potable water to the point that for some are a source of “mal-adaptation” to climate induced water scarcity;
- Environmental impacts from concentrate disposal;
- A complex, convoluted and time-consuming project permitting process;
- Limited public understanding of the role, importance, benefits and environmental challenges of desalination;
- The fact that it is still virtually ignored in many critical pieces of national legislations. Likewise, the multiple dimensions of this resource (technical, social, environmental, geopolitical) tend to be approached in isolation from each other.

Many water-stressed countries in MENA are increasing their water supplies with desalination to meet the needs of the continuous growth of population and industrial, tourism and agriculture developments. Desalinated water can no longer be considered a limited resource because some countries such as Qatar and Kuwait rely 100 % on it for domestic and industrial use, whereas Saudi Arabia (KSA) reliance is nearly 60 % (GWI, 2018). The reason behind these vast capacities in the region is the technological improvements which led to a drop in the cost of desalination. Former King of Saudi Arabia stated that: “Water security is no less important than the national security” (King Abdullah of the Kingdom of Saudi Arabia, 2011).

Therefore, to ensure water security and face the increasing water scarcity, the MENA region has not many options, and one of the most important options is undoubtedly adopting sustainable desalination technologies. However, the separation of salts from seawater requires large amounts of energy which, when produced from fossil fuels, can increase environmental pollution and exacerbate the earth's climate-related problems. There is, therefore, a need to employ environmentally friendly energy sources such as renewables to desalinate seawater.

Since the energy requirements in desalination processes play a decisive role, it appears attractive to consider renewable energies (RE), because it offers a sustainable and secure way to desalinate water. There is a great potential to develop solar desalination technologies especially in the MENA region where the solar source is abundant and the installed photovoltaic (PV) costs are declining. However, several issues related to this technology at large scale are yet to be solved out.

Policy makers in the MENA region need to consider the different choices for desalination based on locally available renewable energy sources.

MEDRC proposes to prepare a regional study covering the whole MENA region on the deployment of desalination as a solution to face water scarcity.

The objectives of this study are to:

- Give insight into the state of the art of desalination in the MENA region as a valuable alternative for water supply in front of an increasing water scarcity exacerbated by climate change and economic and population growths;
- Zoom on some countries with relevant desalination projects;
- Discuss the significant challenges and gaps facing the further implementation of desalination, the environmental impact, financial model, CO_2 footprint, the technology choice and the innovation potential;
- Provide a state of the art of the deployment of renewable desalination in the MENA region;
- Discuss the potential use of renewable desalination and the most promising areas of development;
- Discuss the costing and financing of this technology;
- Provide some success stories and case studies from the region;
- Provide recommendations to policy makers and investors of this sector.

II. Water scarcity in the MENA region

“Water is the driving force of all nature”, claimed Da Vinci. Water scarcity, which is the shortage in water supply, is one of the biggest concerns in the MENA region, considered the most water scarce area of the world. Twelve of the world’s most water-scarce countries are located in the MENA region. This shortage is not only considered an environmental challenge but also a significant socio-political problem in these countries as it could lead, for instance, to an increase in migration out of the region (Trumbull, 2010). For example, different countries in the region, such as Jordan and Israel or even Lebanon and Syria, share some water resources which lie on their borders. Others entirely depend on resources controlled by their neighbouring countries which is the case of Palestine and Israel (Mason, 2012). The trans-boundary nature of the water resources in the Middle East makes cooperative management of these resources critical as they have the potential to induce economic and social development and reduce the risks of conflict.

Many countries in the MENA region are dependent on water resources that lie beyond their borders. For example, Syria, Jordan and Palestine rely on trans-boundary water resources. Palestine is almost entirely dependent on water mainly controlled by Israel. The trans-boundary nature of the water resources in the Middle East makes cooperative management of these resources critical as they have the potential to induce economic and social development and reduce the risks of conflict.

For decades, many solutions to this problem have been brought up trying to find an effective and sustainable way to provide freshwater. However, because of the rapid economic and demographical growth, renewable water resources are expected to drop significantly in the next coming years to reach a worrying level. Populations are consuming water faster than the usual hydraulic renewal cycle in addition to the pollution and contamination of water over the years. Moreover, because of the extensive pumping of fresh water for agriculture mainly in the Middle-Eastern coastal areas such as the Libyan coast as well as the Nile Delta, the freshwater level is considerably reduced on the surface and is being replaced by the sea because of seawater intrusion (Mughram, 2008).

In response to increasing water scarcity, over the last 40 years desalination, has evolved into a viable alternative water supply. It allows us to tap non-conventional water resources with great potential to provide a sustainable, drought-proof water supply. Desalination provides only around 1 % of the world’s drinking water, but this percentage is growing year-on-year. An expected significant increase in investment in the next years would double the capacity by 2030.

Across the MENA region, desalination is increasingly being considered as a technical, supply-side solution that can meet current increasing water demands and buffer against the negative impacts of climate change on water resources. Despite being energy intensive technology, the Intergovernmental Panel on Climate Change (IPCC) lists desalination as an ‚adaptation option‘ which may be particularly important in arid and semiarid regions such as the MENA region (Bates et al., 2008).

While climate change is considered as a main driver of conflict in the MENA region, it cannot be overlooked as a threat multiplier of conflict. The implications of water, energy and food insecurity along with subsequent social and economic burdens indicate these issues are interlinked; and likely to be even more so in the future. But as the MENA region is one of the most varied economically in the world − GDP per capita range from USD 1,000 in Yemen to more than USD 20,000 in the Gulf Cooperation Council (GCC) countries − , there could be enormous variations in the adaptation capabilities to climate risks within the region (Abouelnaga, 2019). In this regard, desalination could be considered as a climate change adaptation only in countries with higher GDP and where water security can justify investments in desalination technologies. In fact, GCC countries may have the financial capabilities needed for adaptation measures, the rest of the region is more vulnerable to risks.

The concept of water security has gained traction in the global political agenda and garnered attention from national governments at the highest level, specifically as a result of its relation to all forms of security including peace and state security, but also for its implications for development issues (United Nations, 2013). The term was used by the Global Water Partnership (GWP) at the 2nd World Water Forum in The Hague in 2000 under the banner of 'Water Security in the 21st Century', to describe a similarly integrative approach to water management. The term has since become increasingly used by academics and practitioners (Cook and Bakker, 2012).

Water insecurity means that levels of consumption exceed levels of available water, renewable or else. A water-rich country that uses water haphazardly can be insecure. Hence, being water-scarce, as many countries in the MENA region are, does not make water insecurity necessarily inevitable (Baconi, 2018). It illustrates the centrality of water for all forms of security, whether related to more traditional forms of geo-political military security, or newer ones such as sustainability, development and human security. The concept of water security has gained traction in the global political agenda and garnered attention from national governments at the highest level, specifically as a result of its relation to all forms of security including peace and state security, but also for its implications for development issues (United Nations, 2013).

Therefore, an accident for instance at any Iranian nuclear facility could bring "environmental catastrophe" to the neighboring countries with considerable desalination capacities such as Saudi Arabia and UAE. Depending on the severity and circumstances, such an event could not only affect international trade, but it could also temporarily jeopardize the gulf's capacity as a water source for the Gulf citizens. In addition, any terrorist attack or malicious act on a major desalination plant would put water security in the region in doubt. To not forget the drones attack on Saudi Arabia's biggest Aramco oil plant in September 2019 added urgency to the kingdom's push to shore up water supply as key vulnerability. The country's daily water consumption exceeds its storage capacity, and millions of people could go thirsty if the sprawling desalination plants on which the desert nation depends were put out of action. Saudi authorities plan a building spree of reservoirs to ensure security of supply as well as manage periodic surges in demand. The government will seek bids in the first quarter to install new water tanks at major cities, said Amer Al Rajiba, vice president for capacity planning and analysis at state-run Saudi Water Partnership Co. The plan calls for a six-fold increase in storage capacity by 2022. Saudi Arabia's reliance on desalinated water has concerned policy makers for years (Ratcliffe, 2019).

On the other hand, climate change has been recognized for its security implications (United Nations Department of Public Information, 2011) with water being the medium through which climate change will have the most direct consequences. In similar way, water issues carry implications on human security issues: either as a trigger, a potential target, a contributing factor or as contextual information. Recognizing that water plays a role in security acknowledges that water is in itself a security risk , that addressing water insecurity could act as a preventative measure in regional conflicts and tensions, and that achieving water security could contribute to achieving increased regional peace and security in the long term (United Nations, 2013). In addition, water security is embedded in sustainable development goals (SDGs) and explicitly in SDG6. Moreover, water scarcity and water insecurity have the potential to exacerbate the current problems and to increase instability in the MENA region.

Heightened geopolitical tensions in the Gulf region have intensified concerns over the potential risk to Saudi water supply for example. By dispersing storage and distribution facilities more widely around the country, the government would make it harder for an adversary to paralyze the entire water system (Ratcliffe, 2019). To face such risks, the Gulf Cooperation Council (GCC) work on a regional solution to water security.

For all these different natural and human reasons behind water scarcity, a sustainable solution had to be adopted by the regional countries, and this solution happened to be desalination for most of them.

Proponents and critics of desalination have for the most part emphasised availability and costs approaching desalination as a purely technical-economic issue. However, the development of desalination is also impregnated with social, environmental and political and geopolitical factors. Such factors defy both the cornucopian view of desalination as the ultimate solution assuring reliable and sufficient water supplies to future generations and helping the countries of the region ensuring their water security, and also the more pessimistic view of desalination shifting scarcity towards energy, adding extra carbon footprints and polluting marine environments with the rejected brine.

While these are of course relevant and legitimate concerns, other aspects of desalination remain much less explored: for instance its role in changing power relations around water; in introducing new geopolitical configurations with potential for both peace and conflict in areas such as the Middle East (e. g. Red-Dead sea project and Gaza Desalination Plant); in reframing the very notion of scarcity creating “relative scarcities” among those (i. e. farmers, the urban poor) that cannot afford the high costs of desalted water; in questioning the nature of water (“produced” vs “naturally available”) or in reinforcing the water- energy nexus in sustainable ways.

In addition, we notice in Israel for example that the intense capitalisation of the desalination projects and the work done to justify privatisation and profit making as a necessity (e. g., Feitelson and Rosenthal, 2012) are indications of a shift in water politics. Moreover, the long sought objective of efficiency and savings in water use may become compromised by an appeal to the endless supply of water coming from the oceans provided that the price constraint of desalted water can be brought to manageable levels and the environmental impact can be significantly reduced.

Hence, one of the most effective solutions to water scarcity is desalination. The MENA region is the world’s largest market for this technology. Indeed, half of the world’s desalinated water is consumed in countries there, and more than 350 million (M) people survive thanks to this technology.

III. Overview of desalination technologies

The ocean makes up 70 % of the earth's surface and accounts for 96 % of the water on the planet. The problem is, this water can't be consumed. It's filled with salt. The desalination process is the large-scale efforts to remove salt or freshwater from seawater trace back to the 1950s, and today almost 20 000 facilities producing almost 100 Mm^3 of freshwater to sustain burgeoning populations (GWI, 2018).

Desalination is nothing but a technical process to get fresh water from the salty water. Ever since desalination was initially invented in antiquity, different technologies have been used. Back in the 4th century BC, Aristotle, the Hellenic philosopher, described a desalination technique by which non-potable water evaporated and finally condensed into a potable liquid. Likewise, Alexander of Aphrodisias in the 200 AD described a technique used by sailors, as follows: seawater was boiled to produce steam, and that steam was then absorbed by sponges, thereby resulting in potable water (Kalogirou, 2005). 18th century sailors experimented with capturing this vapour in sponges to ease their thirst on long journeys. Modern desalination began similarly: boiling seawater (by burning oil or natural gas) and recovering droplets of fresh water in a process known as thermal desalination. More energy-efficient technologies such as reverse osmosis (RO) − passing seawater through polymeric membranes to remove salt and other impurities − have become more prevalent. It boomed and flourished again during the mid-20th century and became very popular throughout the world as the second generation of desalination technologies, especially in the MENA region where the energy cost is relatively lower than in other parts of the world.

As of 2018, more than 100 Mm^3 of desalinated water is produced per day, roughly 1 % of the world's need. Saudi Arabia produces the most significant share of desalinated water, about a fifth of the world total, followed by the US, the United Arab Emirates (UAE), China, Spain and Kuwait. Because Gulf countries use most of their limited groundwater for agriculture, they depend heavily on desalination to supply populations and industries. Governments and companies spend as much as USD 14 bn a year to make the ocean and brackish water drinkable (Stanley, 2019).

The most reliable desalination processes that can currently be exploited at the commercial scale and that have been widely used to separate salts from ocean water are:

- Thermal processes: like multi-stage flash distillation (MSF), multi-effect distillation (MED), thermal vapour compression (TVC), or distillation processes such as mechanical vapour compression (MVC); and
- Membrane processes: reverse osmosis (RO) and electrodialysis (ED) processes. ED is mostly used for brackish water installations, while RO can be used for both, brackish and seawater (Koroneos et al. 2007).

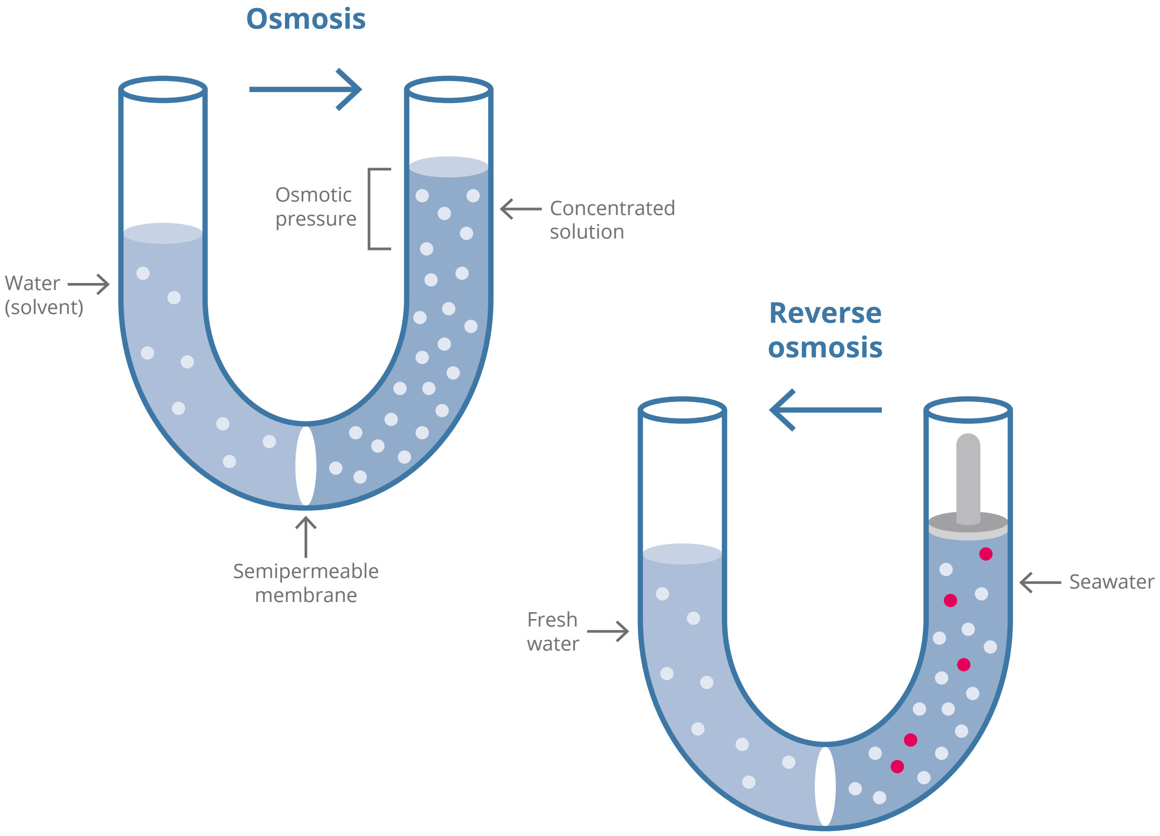
There are also other minor processes which are either limited by unit size or they are still under development at pilot scale among other limitations, such as freezing desalination, humidification / dehumidification, adsorption desalination (AD), membrane distillation (MD), capacitive deionisation (CDI), and electro deionisation (EDI).

Depending on the desalination process in use, energy might be required either as heat, power or even a combination of both energy forms. Choice of desalination process is dependent on many factors, but mainly its cost.

In the last 10 years, RO technology has come to dominate desalination markets, due mainly to recent improvements in membrane technology and its low investment and total water costs achieved by lowering the energy consumption to about 3 KWh/m^3 (Ghaffour et al., 2013).

RO is a technology that is used to remove a vast majority of contaminants from water by pushing the water under pressure through a semi-permeable membrane to overcome the natural osmotic pressure of saline water (Figure 1). In reverse-osmosis desalination systems, seawater is pressurized using high-pressure pumps. The pressurized water is forced through the membrane, producing low pressure freshwater and high-pressure brine. Energy-recovery devices have been developed to re-capture some of the hydraulic energy of the high-pressure brine.

Figure 1: Reverse Osmosis (RO) process



Source: MEDRC training material

RO membranes can be supplied in both flat sheet and HFF (Hollow Fine Fiber) structural formats. The flat sheet RO membrane is composed of three layers.

RO membrane are typically thin film composite. There is a nonwoven polyester support layer, a polysulfone layer, and on top of the polyamide barrier layer. However, RO membranes have a limited life-cycle and are often disposed of in landfills. Another type of RO membrane consisting of fine hollow fibres made of cellulose tri-acetate (CTA), a mix of Di and Triacetate cast on non-woven polyester support is also used in seawater desalination application.

Membranes can usually operate well for a couple of years but they will last up to five or more years under right conditions. The impacts caused by the disposal of thousands of tons per annum of RO membranes have grown dramatically around the world. Waste prevention should have a high priority and take effect before the end-of-life phase of a product is reached. There are many on-going research projects including in MEDRC to deal with this challenge and extend the life-cycle of RO membranes for other uses as an example, but ending with the same disposal issue when they are completely damaged. RO membranes are a consumable, and represent a large part of the O&M budget, the third section after energy and chemicals. According to the feed water source, on seawater, and the pretreatment, RO membrane expected life ranges from 5 to 8 years.

RO works by using a high-pressure pump to increase the pressure on the salt side of the RO and force the water across the semi-permeable RO membrane, leaving almost all (around 95 % to 99 %) of dissolved salts behind in the reject stream. The amount of pressure required depends on the salt concentration of the feed water. The more concentrated the feed water, the more pressure is required to overcome the osmotic pressure.

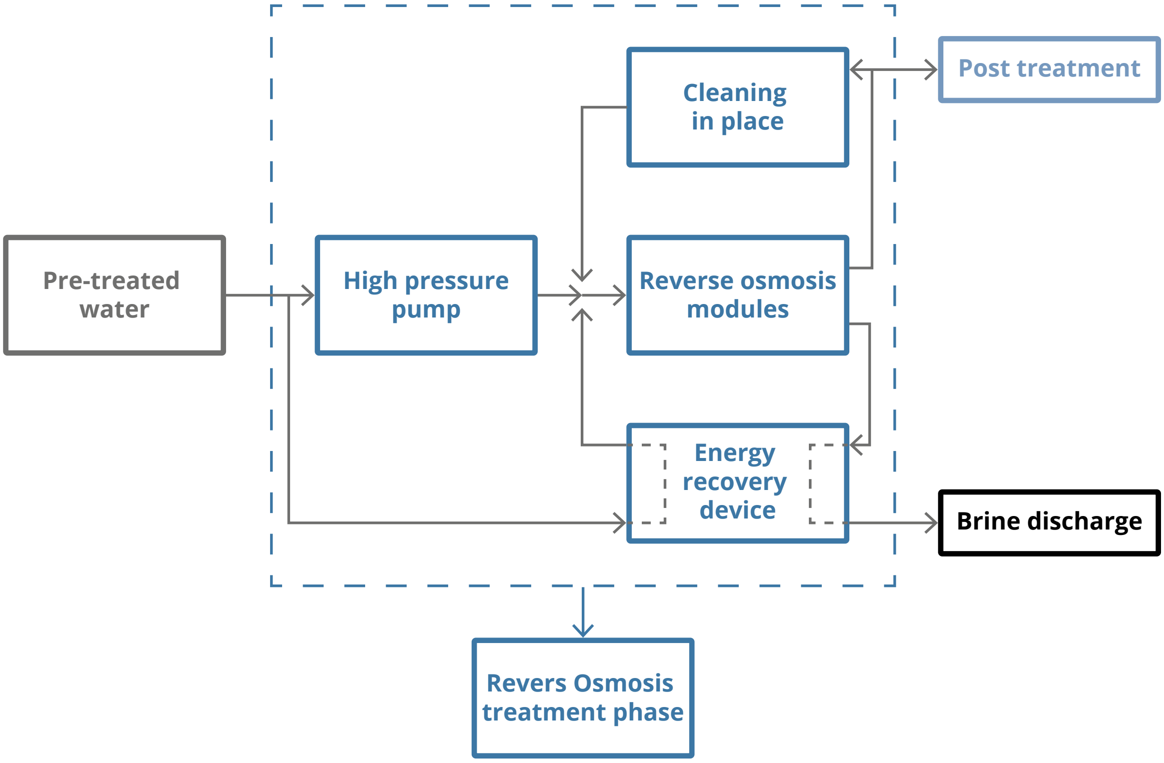
Table 1 presents the most essential technologies in use today. The motive power in the phase-change or thermal processes is a thermal energy source, whereas in the membrane or single phase processes, electricity is used. An exception is membrane distillation (MD), which is classified as a phase change process but needs membranes to operate. All processes presented in Table 1 require the chemical pretreatment of seawater to avoid foaming, fouling, scaling and corrosion as well as chemical post-treatment, mainly for disinfection.

Table 1: Commercially available desalination processes

Major processes	**Minor processes**
Thermal: › Multistage Flash Distillation (MSF) › Multi Effect Distillation (MED) › Vapour Compression Distillation (VPC)	Freezing Membrane Distillation (MD) Solar Humidification
Membranes: › Reverse Osmosis (RO) › Electrodialysis (ED) › Forward Osmosis (FO)* › Nanofiltration (NF)	

* FO needs another step for DS (distant selection) regeneration, e. g. heat.

Figure 2: Reverse Osmosis (RO) system



Source: MEDRC training material

Table 2: RO advantages and practical limitations

Advantages	Practical limitations
› Suitable for desalinating is both seawater and saline groundwater › Requires less energy than the MSF, MED and VC technologies › Lower investment and total water costs than other technologies	› Desalinated water quality ranges between 250 – 500 mg/L salinity (suitable for drinking purposes) › Membrane replacement › High operating pressure (electrical energy) › Continuous membrane cleaning › Limited recovery rate › Essential extensive pretreatment and post-treatment (chemical additives) › Significant capital investments, and has relatively high operational cost › Brine disposal (environmental impact)

The process diagram shown in Figure 2 corresponds to a conventional RO treatment phase for Sea water. Figure 3 shows the RO Pilot Plant at MEDRC facilities. It is producing up to 4 m^3/h of desalinated water, and it includes all components of a commercial RO desalination plant. RO potential problems are mainly: scaling (accumulation of salt particles on the desalination plant components), fouling (clogging of the membrane pores and feed spacer by feed water suspended substances and/or sticky polymeric precipitates) and chemical attack (chemical destruction of the membrane surface). RO advantages and practical limitations are listed in Table 2.

For the membrane technologies, pretreatments are necessary to protect the membranes by removing some contaminants and controlling microbial growth on the membrane (except in MD, where membranes are hydrophobic), as well as to facilitate membrane operation. Suspended solids are removed by filtration, pH adjustments (lowering) are made to protect the membrane and control precipitation of salts; anti-scaling inhibitors are added to control calcium carbonates and sulfates. Iron, manganese and some organics cause fouling of membranes. A disinfectant is added to control biofouling of the membrane. Disinfection can involve chlorine species, ozone or UV light and other

Figure 3: MEDRC RO pilot plant (RO System – 2 stages)

Source: MEDRC

agents. Marine organisms, algae and bacteria must be eliminated, and if chlorine is used, it should be neutralised before contact with the membrane (Gilbert, 2019).

Post-treatment of the water produced is required in all technologies, especially in distillation processes that require mineralisation of the distilled water produced. The post-treatment aims to stabilize the produced water and make it compatible with the distribution network. Adjustment of pH to approximately 8 is required. Carbonation or use of other chemicals such as lime may be applied, and blending with some source water may be done to increase alkalinity and TDS and stabilise the water. Addition of corrosion inhibitors like polyphosphates may be necessary (Dariva and Galio, 2014).

Post disinfection is also necessary to control microorganisms during distribution, as well as to eliminate pathogens from the blending process. Degasification may also be necessary. Many systems blend back a portion of the source water with the desalinated water for mineralisation.

In terms of energy consumption, RO demonstrated in the last decade to be more energy efficient than thermal desalination processes. Based on current processes, the share in the world desalination market and their respective published specific energy consumptions, seawater reverse osmosis (SWRO) 60 % at 3.5 kWh/m^3 and thermally driven processes 40 % at 17 kWh/m^3 (Shahzad et al., 2019).

This report is meant to cover the state of the art of desalination technologies in the MENA countries, and highlight its role as a climate change adaptation option, and also its strenghts and constraints. We will also cover the advances in the technology and the efforts to make it more environment friendly and the aspects related to water policy and legislation. Finally, we will also talk about the capacity building efforts in this field and the need of localising the technology in the region.

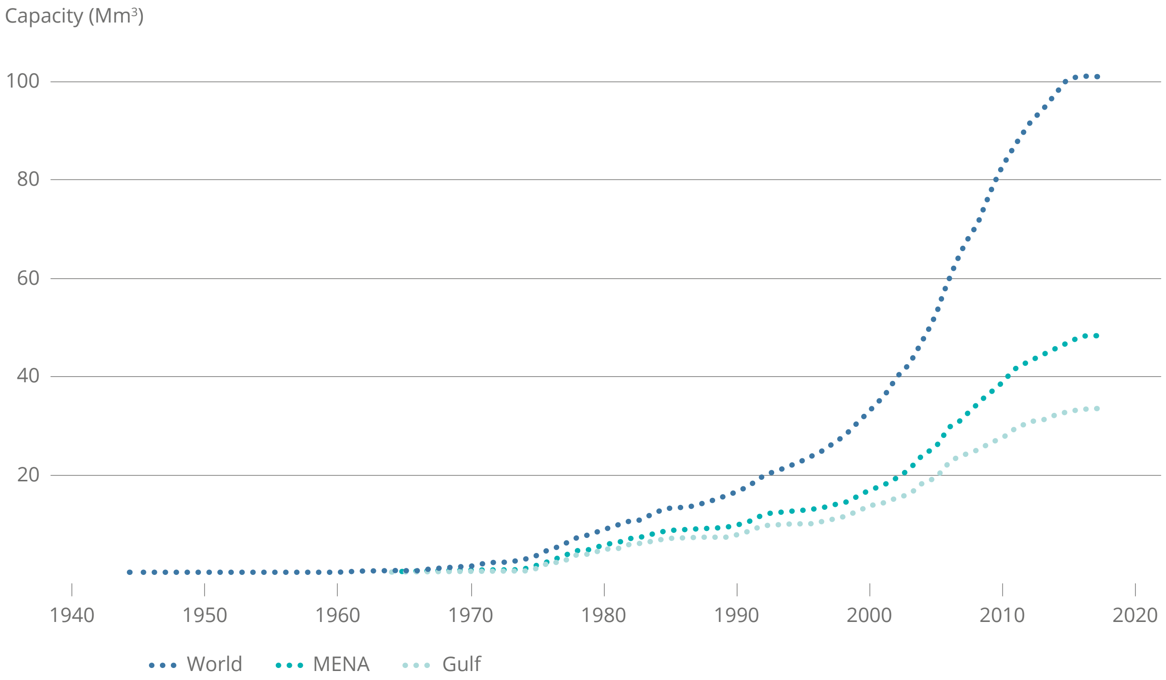
State of the art of desalination deployment in MENA

I. Desalination capacity in MENA

The MENA region becomes nowadays so dependent on desalination technology for sustainable water supply that thousands of additional technical experts of various professional levels will be needed to service the desalination industry.

The Middle East has been a leader in desalination so far. Saudi Arabia, the United Arab Emirates, Kuwait, and Israel rely heavily on desalination as a source for clean water. Israel gets 60 % of domestic water from desalination (D'Souza, 2017), mainly from five seawater desalination facilities: Ashkelon, Palmahim, Hadera, Sorek, and Ashdod and the rest comes from other facilities for desalinating salty groundwater, mostly in the Arava (Avgar, 2018). These countries also have hardly any groundwater or fresh water sources, so desalination is a case of innovation by necessity. These countries make up the 1 % of the world currently relying on desalination to meet water needs. However, the UN predicts

Figure 4: Cumulative contracted capacities globally and per region since 1944 (m³/d)



Source: Desal Data/GWI

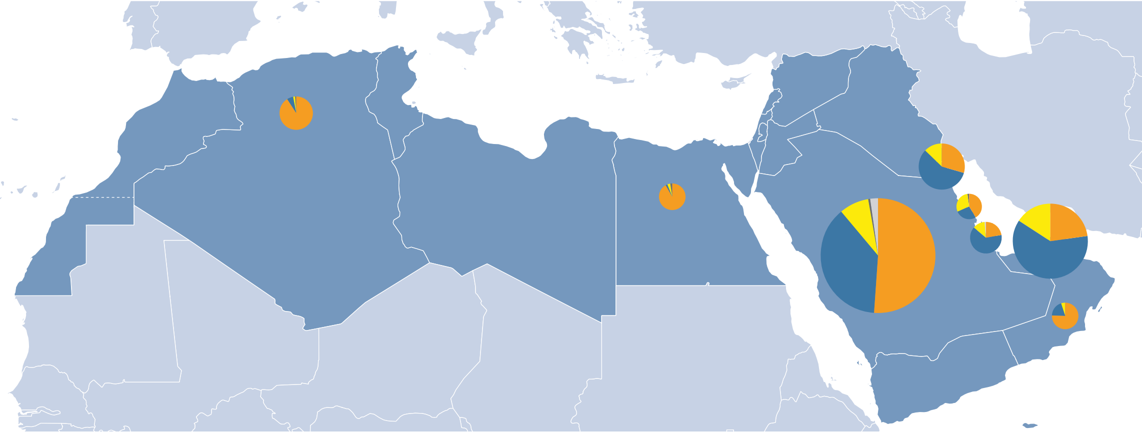
that by 2025, 14 % of the world will rely on desalination to meet water needs (Werft, 2016).

Desalination is becoming increasingly important as a solution to the region's water problem. Many water-stressed countries in MENA are increasing their water supplies with desalination to meet the needs of the continuous growth of population and industrial, tourism and agriculture developments. Desalinated water can no longer be considered a limited resource because some countries such as Qatar and Kuwait rely 100 % on it for domestic and industrial use, whereas Saudi Arabia reliance is nearly 60 % (Ghaffour, 2009).

The reason behind these huge capacities in the region is the technological improvements which led to a drop in the cost of desalination. Currently, the global market is led by Saudi Arabia with a total cumulative capacity of 15,378,543 m^3/d followed by the United States (US) producing 11,815,772 m^3/d and the United Arab Emirates (UAE) with 10 721,554 m^3/d (GWI, 2018).

2019 has seen the desalination market return in force after a relatively weak 2018. 4 million m^3/d in new capacity was contracted in the first half of 2019 alone. This increase was primarily driven by very large awards in the GCC, with just four independent water projects (IWPs) making up almost 60 % of this top-level figure: Taweelah (909 000 m^3/d) and Umm al Quwain (680,000 m^3/d) in the UAE, and Rabigh 3 (600,000 m^3/d) and Shuqaiq 3 (380,000 m^3/d) in Saudi Arabia. The wider MENA region (excluding the Gulf) is also bouncing back after a quit 2018: its 226,000 m^3/d total contracted capacity in the first half of 2019 is a 32 % increase on its 2018 year-end total. While political uncertainty in Algeria has stalled two 300,000 m^3/d SWRO projects under procurement, water scarcity in Morocco and Tunisia is driving a healthy project pipeline in North Africa (GWI, 2019).

Figure 5: Symbol map of the MENA desalination capacities and the technology used



Indicators (in per cent)

Saudi Arabia: RO (51.5), MSF (38.2), MED (8.3), ED (0,6), Others (2.0)
UAE: RO (22.8), MSF (61.6), MED (15.6)
Oman: RO (75.7), MSF (19.4), MED (4.9)
Quatar: RO (22.4), MSF (63.8), MED (12.5), Others (1.3)
Bahrain: RO (41.6), MSF (26.8), MED (29.5), ED (2.1)
Kuwait: RO (29.7), MSF (57,7), MED (12.6)
Egypt: RO (91.8), MSF (2.2), MED (3.6), ED (2.4)
Algeria: RO (91.1), MSF (6.0), MED (2.0), ED (0.9)

Technologies

🟧 RO 🟦 MSF 🟨 MED ■ Electrodialysis □ Other

Scale

● 1,000,000 m^3/day

Source: Desal Data/GWI

Figures 4 and 5 show consecutively the cumulative capacities globally and per region (MENA and Gulf) since 1944 and the mapping of the capacities and technologies used. The bigger the circle, the bigger the desalination capacity. The data used were provided by the Global Water Intelligence (GWI) desal data.

Subsequently, we note that the MENA region occupies nearly half of the global desalination activity in 2017 with a cumulative total contracted capacity equal to 48,972,069 m^3/d and a global cumulative contracted capacity of 100,949,442 m^3/d. Therefore, desalination is an indispensable and inevitable source of fresh water in the region, given those huge quantities of fresh water produced daily.

According to Desal Data (GWI, 2018), more than 90 % of all desalinated water in the MENA comes from Membrane desalination (Reverse Osmosis). Furthermore, the desalination plants in countries such as Syria, Morocco, Republic of Djibouti and Palestine completely depend on this technology. Other technologies such as MSF desalination and MED account for less than 10 % of the production in the MENA region.

Membrane desalination technologies have been dominant over thermal for some years now. One of the few thermal awards is a 62,500 m^3/d multi-effect distillation (MED) unit furnished by Veolia for the Abu Dhabi National Oil Company. The world's operating thermal capacity is declining. The decommissioning of 90,840 m^3/d of MSF capacity at Jeddah 3 (commissioned 1979) in 2015,191,000 m^3/d at Al Ghubrah, Oman and 227,100 m^3/d at Jeddah 4 in 2019 took 2 % of the world's running thermal desalination capacity offline. These are likely to be joined by thermal units in Abu Dhabi, as the UAE's department of Energy plans to build large-scale SWRO plants to replace thermal production capacity (GWI, 2019).

The above graphs and the map support the idea that the MENA region is responsible for a big part of the desalination activities in the world regardless of the technology used. Nevertheless, the repartition of these activities remains unequal between the countries. A big gap is observed between the capacities of most Gulf countries and that of Yemen or Jordan. This disproportion is mainly due to the big capital costs required to build desalination plants as well as the essential future operation and maintenance (O&M) costs which will be discussed later in this report.

Tables 3 and 4 show the biggest desalination plants (both in operation and planned) in MENA. The tables also give information on their capacities, the type of technology, the type of feedwater, operation day and also the cost per m^3 or the estimated project cost, as the cost per m^3 is not always indicated. The largest plants are built in Saudi Arabia and the UAE. The lowest cost per m^3 corresponds to Magtaa plant in Algeria with USD 0.56 per m^3 and Al Shuaiba 3 plant in Saudi Arabia with USD 0.57 cost per m^3. As shown in tables, all the newest plants are RO technology based.

Table 3: The largest desalination plants (in operation) in the MENA region: The KSA and the UAE

Location	Capacity (m^3/d)	Process	Feedwater	Operation year	Cost (USD)
Al Jubail, KSA	800,000	Thermal (MED)	Seawater	2007	0.827/m^3
Al Shuaiba 3, KSA	880,000	Thermal (MSF)	Seawater	2009	0.57/m^3
Jebel Ali M Plant, UAE	636,440	Thermal (MSF)	Seawater	2013	EPC cost: USD 1.07 bn
Soreq, Israel	540,000	RO	Seawater	2013	0.585/m^3

Table 3 (continued): The largest desalination plants (in operation) in the MENA region: The KSA and the UAE

Location	Capacity (m³/d)	Process	Feedwater	Operation year	Cost (USD)
Magtaa, Algeria	500,000	RO	Seawater	2014	0.56/m³
Ras Al-Khair, KSA	1,025,000	RO	N/A	2016	-
Ras Al-Khair, KSA	728,000	Thermal (MSF)	Seawater	2016	EPC cost: USD 4.2 bn
Yanbu 3, KSA	550,000	Thermal (MSF)	Seawater	2017	EPC cost: USD 1 bn

Source: Desal Data/GWI

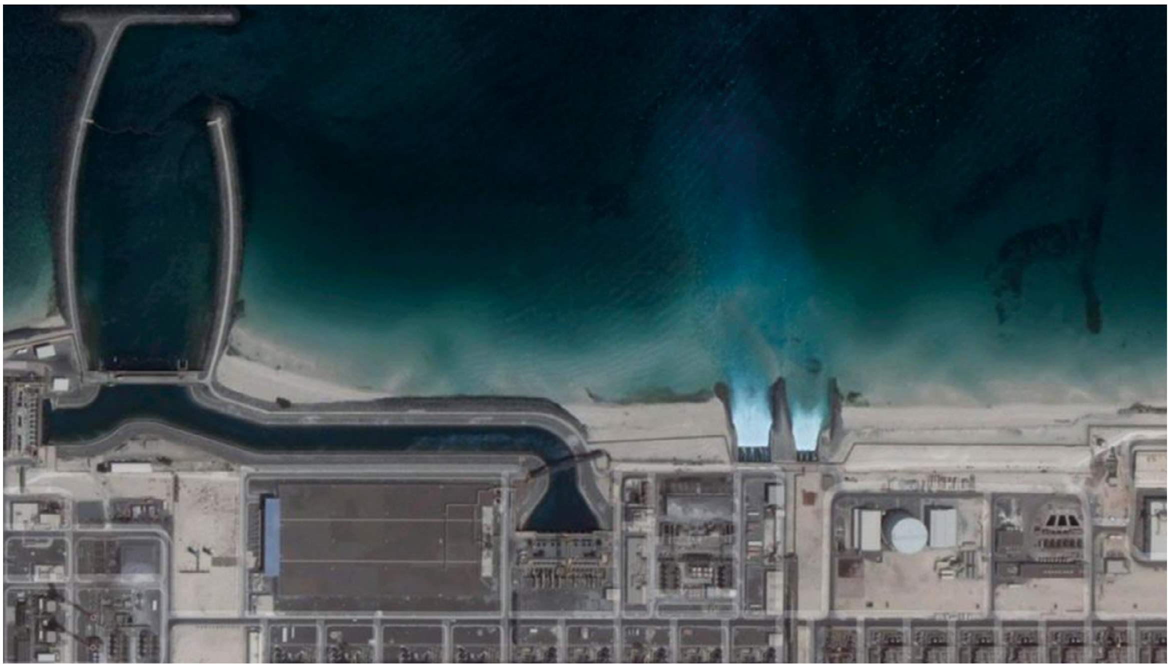
Table 4: The largest desalination plants (planned) in the MENA region: The KSA and the UAE

Location	Capacity (m³/d)	Process	Feedwater	Operation year	Cost (USD)
Umm al Quwain IWP, UAE	681,900	RO	Seawater	2020	EPC cost: USD 250M
Rabigh 3 IWP, KSA	600,000	RO	Seawater	2021	-
Khobar 2 replacement SWRO, KSA	600,000	RO	Seawater	2021	EPC cost: USD 650M
Taweelah IWP, UAE	909,200	RO	Seawater	2022	EPC cost: USD 840.5M
Rabigh, KSA	600,000	RO	Seawater	2022	-
Jubail 3b IWP, KSA	600,000	RO	Seawater	2022	EPC cost: USD: 3 bn
Jubail 3a IWP, KSA	600.000	RO	Seawater	2022	EPC cost: USD: 3 bn
Shoaiba 6 IWP, KSA	600,000	RO	Seawater	2029	-
Hassyan SWRO, UAE	545,520	RO	Seawater	Planned	-
Haradh BWRO, KSA	800,000	RO	Brackish water or inland water	Planned	-

Source: Desal Data/GWI

On the other hand, the International Energy Agency (IEA) has estimated energy requirements of desalination in the MENA region, ranging from a low of 2.4 % in Algeria to a high of 23.9 % in UAE or even 30 % in Bahrain of total energy use. In the world's largest oil exporter, Saudi Arabia, desalination and electricity generation alone currently requires burning approximately 1.5 million barrels per day of crude equivalent. The trend is similar for other GCC countries as well as in the North African countries, to whose water supply portfolios desalination contributes a significant share (Asaba, 2019).

Figure 6: Jebel Ali MSF plant, UAE, power and water cogeneration plant, positively buoyant discharge



Source: Google Earth

A Gulf region (GCC)

In GCC, MSF is still dominating the market in UAE, Qatar and Kuwait, while RO started dominating in Saudi Arabia, Oman, and Bahrain (Figure 7) and several thermal plants have been shut down to be replaced later by RO plants (e. g. Ghubrah Plant in Muscat, Oman in 2018). The trend will likely confirm the dominance of RO in GCC as many planned desalination projects are almost RO.

B North African countries

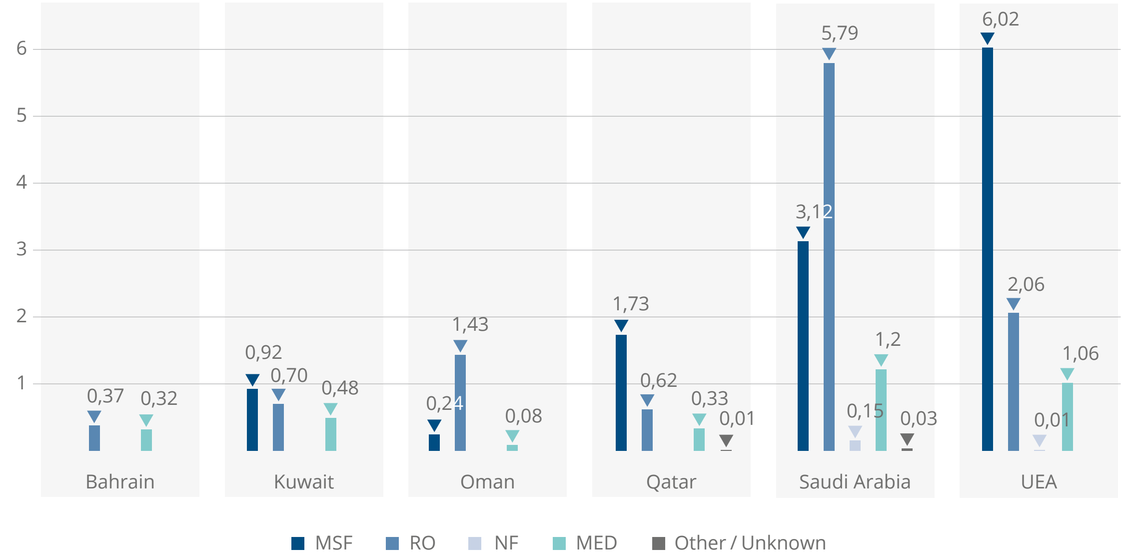
Figure 8 shows that in North African countries RO technology is dominating capacities in all North African countries except in Libya, where MED technology is still the primary technology followed by MSF and RO technologies. Algeria has the largest capacity followed by Egypt.

C The use of desalinated water

In the MENA region, desalination is a solution for water scarcity allowing the production of reasonable quantities of freshwater to meet the increasing water demand. The main sector of use is the domestic (municipal) mainly in GCC where there are no other options than desalinated water, and we can witness cities fully relying on desalinated water such as: Muscat, Doha or Dubai. Figure 9 shows the total desalination capacity by customer type (sector) in the MENA region. Almost 3 fourths are for domestic use, while the rest is distributed mainly on industrial use, followed by touristic use, power stations, military and agriculture.

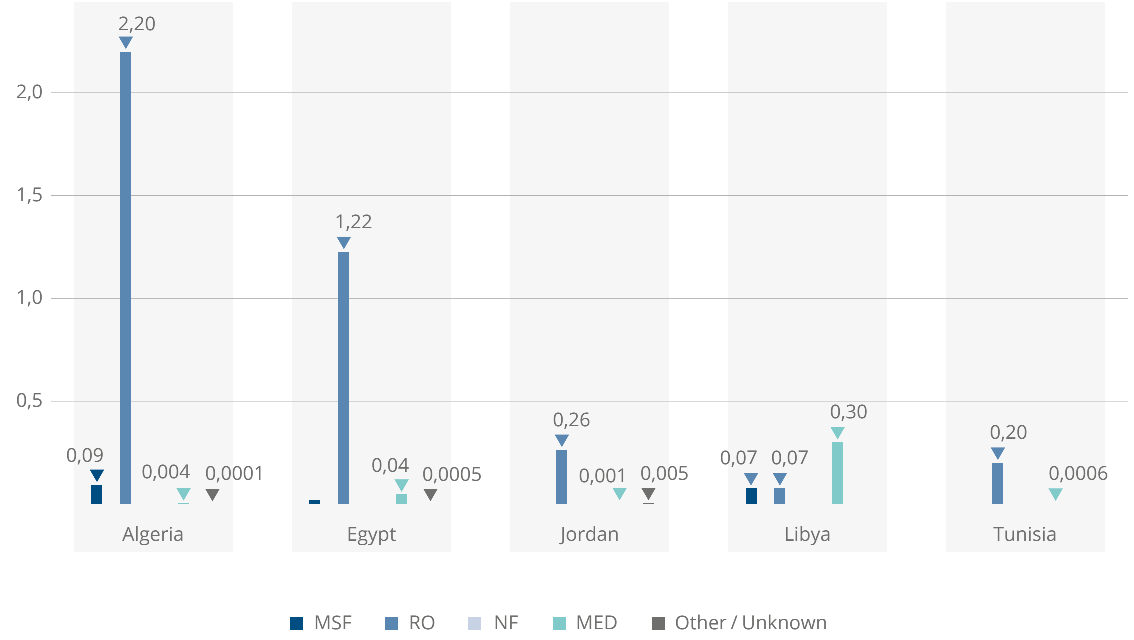
Almost in all countries, the maximum usage of desalinated water is used in municipalities as drinking water, followed by industries and power stations (cooling).

Figure 7: Desalination technologies distribution (Capacities in Mm³/d) in GCC



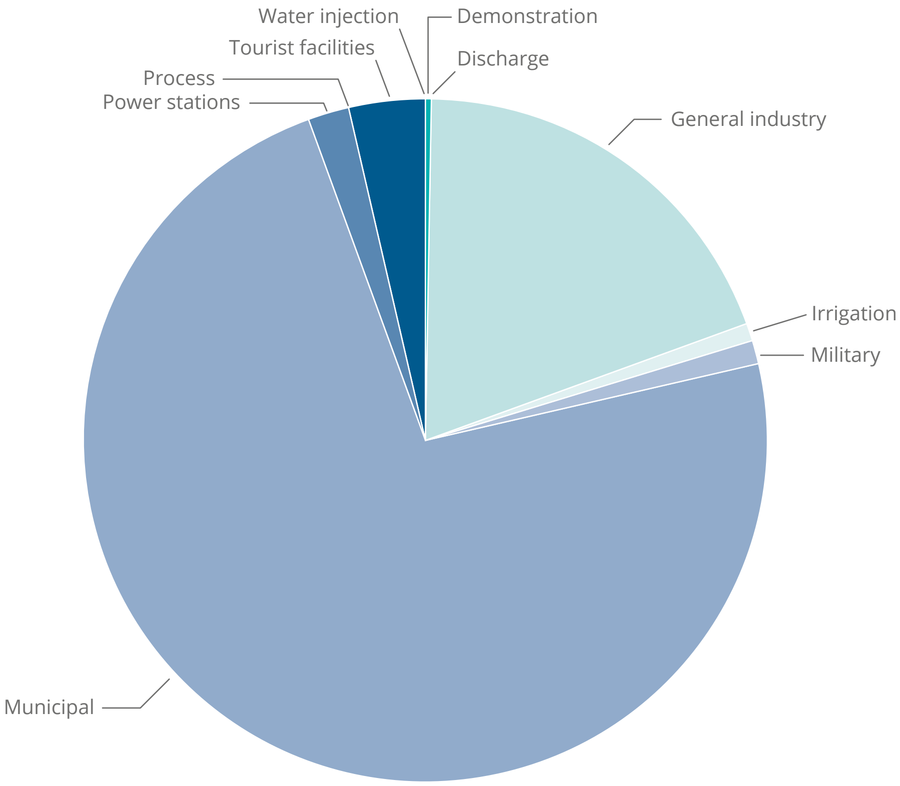
Source: Desal Data/GWI

Figure 8: Desalination technologies distribution (Capacities in Mm³/d) in North African countries



Source: Desal Data/GWI

Figure 9: Total capacity by customer type in the MENA region



Source: Desal Data/GWI

II. Zoom on some MENA countries

A Desalination in Tunisia

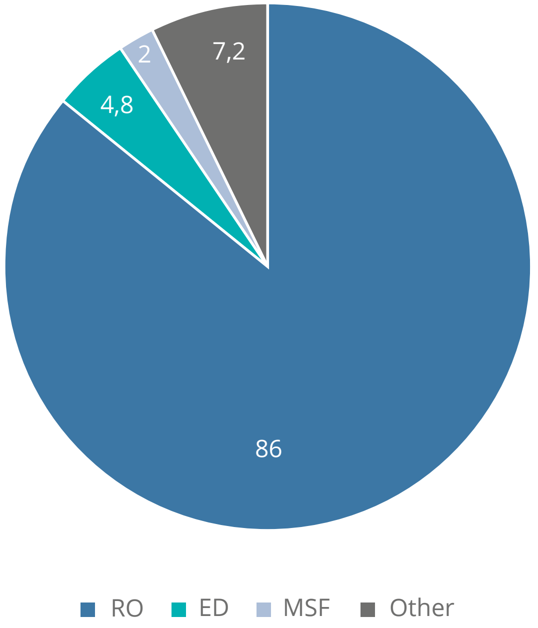
Water resources in Tunisia are inventoried and well identified: 4,840 Mm³ (Surface water: 2,700 Mm³ – Groundwater: 2,140 Mm³). In 2014, the water availability per capita/year was 440 m³ (the minimum considered by United Nations is 1,000 m³). In addition, in the same year, about 93 % of resources were mobilised.

When it comes to the development of non-conventional water resources in Tunisia, the main undertaken measures are:

- Increase the rate of waste water reuse;
- Considering artificial aquifer recharge (AAR) by treated waste water (TWW) in some water aquifers;
- Support wastewater recycling in the industry sector;
- Development of brackish (BW) and seawater (SW) desalination program.

The production capacity of desalination plants in June 2016 is about 200,000 m³/d, and the number of desalination plants by the end of 2016, was 110. Desalination is playing an increasing role in water supply mainly in the South of Tunisia. Figure 10 shows desalination technologies used in Tunisia.

Figure 10: Desalinated water in Tunisia by desalination processes (in %)



Source: SONEDE

1 Desalination plants in Tunisia

Table 5 shows some of the desalination plants locations and characteristics (capacities, conversion rate, salinity, date of operation, etc. These plants are operated by SONEDE (National Water Distribution Utility).

To be noted that Bengardene desalination plant is a photovoltaic-powered RO desalination plant with a production capacity of 1,800 m³/d, and it is associated with an evaporation pond of 11.9 ha.

Apart from the water supply by desalination, Tunisia has adopted desalination programs to improve water quality (brackish water desalination). Lower salinity is registered in the north while the highest salinity is registered in the middle and south of Tunisia. Those programs have been carried out in two phases:

Table 5: Some Tunisian desalination plants with its capacities, year of operation, and characteristics of feed water

Plant	Gabes	Djerba*	Zarzis	Kerkennah	Bengardene	Total
Nominal Capacity (m^3)	30,000	17,000 – 50,000	15,000	3,300	1,800	67,100 – 100,100
Maximal Capacity (m^3)	34,000	17,000 – 67,000	15,000	3,300	2,000	71,300 – 121,300
Conversion rate	74 %	75 %	75 %	75 %	70 %	75 %
Raw water salinity	3.2 g/L	6 g/L	6 g/L	3.7 g/L	14 g/L	-
Osmosis water salinity	300 mg/L	300 mg/L	500 mg/L	300 mg/L	300 mg/L	-
Lines number	4	7	3	4	3	21
Modules number	1,584	756 + 162	756	144	100	3,502
Operation/ Online date	1995	1999 – 2007 – 2018	2000	1983	2013	-

* Djerba first plant was put online on 1999 with a capacity of 12,000 m^3/d, the second one was put in operation on 2007 with a capacity of 5,000 m^3/d, and the third one on 2018 with a capacity of 50,000 m^3/d.

- The first one refers to regions with population over 4,000 inhabitants and where water salinity is greater than 2.0 g/L. Operation date end 2016 and first 2017. Table 6a shows corresponding desalination plants.
- The second phase refers to regions where water salinity is between 1.5 g/L and 2.0 g/L and population over 4,000 inhabitants. Achieved study, preparation of tendering procedure is in progress and some drilling startup works. Table 6b shows corresponding desalination plants.

Another example of Tunisian desalination plants is the Desalination plant of Djerba. Hereafter some characteristics:

- Contracting method: Turn-key;
- Seawater intake, desalination plant and brine discharge;
- Desalination capacity of 50,000 m^3/d expandable to 75,000 m^3/d using RO technology;
- Storage of produced water after being mixed with brackish water;

- Deferrisation of the mixed water;
- Connection of the desalination plant to the distribution network;
- Work progress: about 95 % in January 2018.

It is worth also to mention Ksour Essef desalination plant, which is a PPP project to be implemented as a complementary potable water resource by means of a new sea water desalination plant covering five governorates along Tunisia south-east coast. The project's goal is to cover expected potable water consumption increase by year 2030. The needs to cover are mainly population increase, development of industry and tourism activity along the coast, increase in living standard, and development of potable water networks in the countryside. The project estimated costs of the project is USD 134.4 M (SONEDE, 2018).

From year 2025 a new deficit is expected that should be balanced by the addition of 100,000 m³/d issued from a new seawater desalination plant, the present Ksour Essef seawater desalination plant. In Year 2035, a new deficit of 100,000 m³/d is expected and shall be covered by the extension of the Ksour Essef plant.

B Desalination in Saudi Arabia

The main challenges facing water security in Saudi Arabia as in almost all MENA countries are:

- the limited natural water resources;
- the elevated per-capita consumption;
- the rapid increase in population and unsustainable growth in water demand;

Table 6a: Desalination plants of the first phase

Governorate	Station	Capacity m³/d	Technology	No. lines
Tozeur	Tozeur	6,000	RO	3*2000
	Nafta	4,000	RO	2*2000
	Hezoua	800	RO	1*800
Kébili	Kébili	6,000	RO	3*2000
	Souk Lahad	4,000	RO	2*2000
	Douz	4,000	RO	2*2000
Gabès	Matmata	4,000	RO	2*2000
	Mareth	5,000	RO	2*2500
Médenine	Béni Khédache	800	RO	1*800
Gafsa	Belkhir	1,600	EDR	2*800
Total		36,200		

Table 6b: Desalination plants of the second phase

Governorate	Station	Capacity m³/d	Technology	No. lines
Tozeur	Dégueche	2,000	RO	2*1000
Kébili	Kébili extension	2,000	RO	2*1000
Sidi Bouzid	El Meknassi-Mazouna-Bouzian	3,000	RO	2*1500
Médenine	Ben Guerdane	9,000	RO	3*3000
Gafsa	Gafsa Mdhila-Gtar-Metlaoui Redayef-Moulares	9,000 6,000	RO	3*3000 2*3000
Total		31,000		

- the high costs of water coupled with low tariffs making the sector unsustainable;
- the limited private sector participation in the kingdom's water sector; and
- the substantial investments required in the near future for new capacity to offset planned decommissioning of existing desalination plants.

In the vision 2030 of the water sector in the kingdom, the key objectives are:

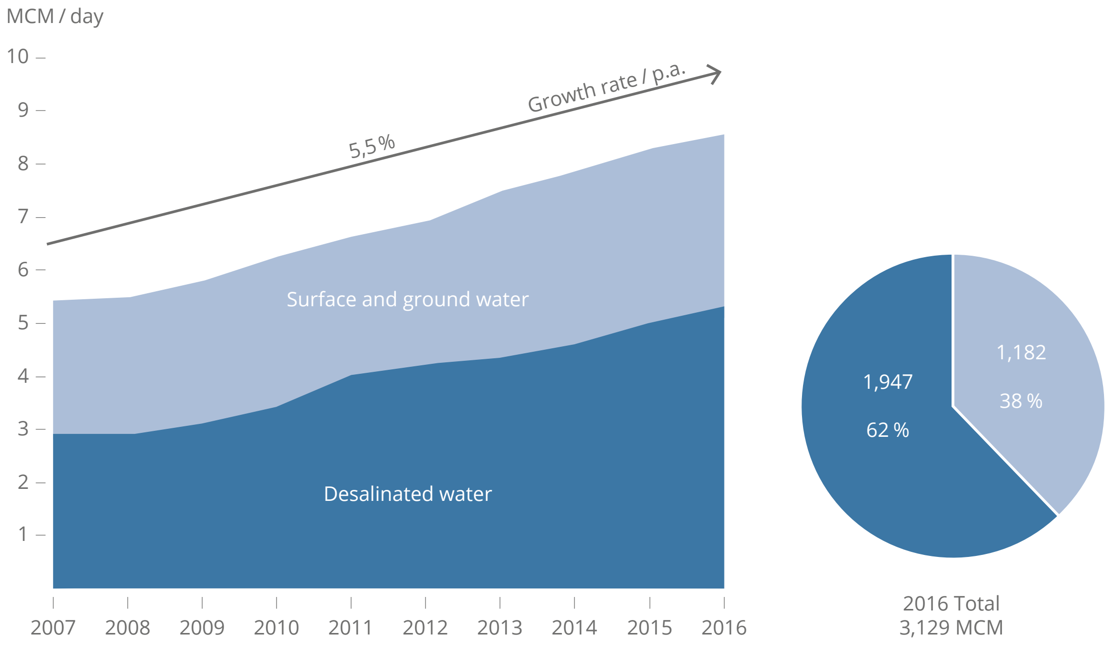
- Promoting sustainable water supply sources and improving service coverage;
- Reducing excessive water consumption;
- Achieving customer satisfaction by providing high-quality service and reducing waste;
- Reduce the sector dependence on state funding by taking steps toward privatisation;
- Improving financial and operational efficiency.

In Figure 11, we show the water supply growth in the kingdom.

Saudi Arabia is the world's largest producer of desalinated water, and its plants are vital to easing a chronic water shortage that has reached acute levels. Of the country's gross domestic product (GDP), 65 % is in activities exposed to the risk of water shortage, while 64 % of the population is vulnerable to it.

The largest desalination plant is the Ras Al-Khair, which uses both membrane and thermal technology with a capacity of over 1,000,000 m^3/d, in operation since 2013. The Ras Al-Khair plant supplies Maaden factories with 25,000 m^3 of desalinated water and 1,350 MW of electricity. It also supplies with water, the capital city of Riyadh and several central cities with a total need of 900,000 m^3/d (Construction-WeekOnline 2013, desalination.biz, 2013). Another example is the 880,000 m^3/d MSF Shuaiba 3 desalination plant that is located along the east coast of Saudi Arabia and supplies with potable water, the cities of Jeddah, Makkah, and Taif. Saudi Arabia also hosts the Ras Al-Zour unit, producing 800,000 m^3/d of water (Henthorne, 2009).

Figure 11: The growth in water supply in Saudi Arabia up to 2016



Source: SWCC 2018

Nine new desalination plants along the Red Sea coast are planned and will cost USD 530 million and further increasing the amount of fresh water produced with this technique (SWCC, 2018).

In terms of desalinated water producers in the kingdom, the private sector is producing 38 % while 62 % is produced by the Saline Water Conversion Corporation (SWCC), which is responsible for: water desalination, power generation and water transmission in the kingdom.

SWCC was established in 1974 as an independent government organization. It is considered the World's largest desalination entity (Production & Transmission). It is a key player as an electricity producer in the Kingdom, and main contributor to research activities in the desalination sector, as well as a leading desalination training center.

On the other hand, SWCC has procured three floating (mobile) desalination units to provide a total capacity of 150,000 m^3/d (50,000 m^3/d each) of drinking water over 20 years. A contract has been signed with the Norwegian company OWD (Offshore Water Desalination). The three units will be installed on barges off the Red Sea coast, initially opposite the desal facilities at Al Shaqiq in the southwest, feeding the tanks there, and supplying Jazan and Asir provinces. This project is considered for emergency cases to provide additional capacity where needed. The three units are expected to be operating by October 2019.

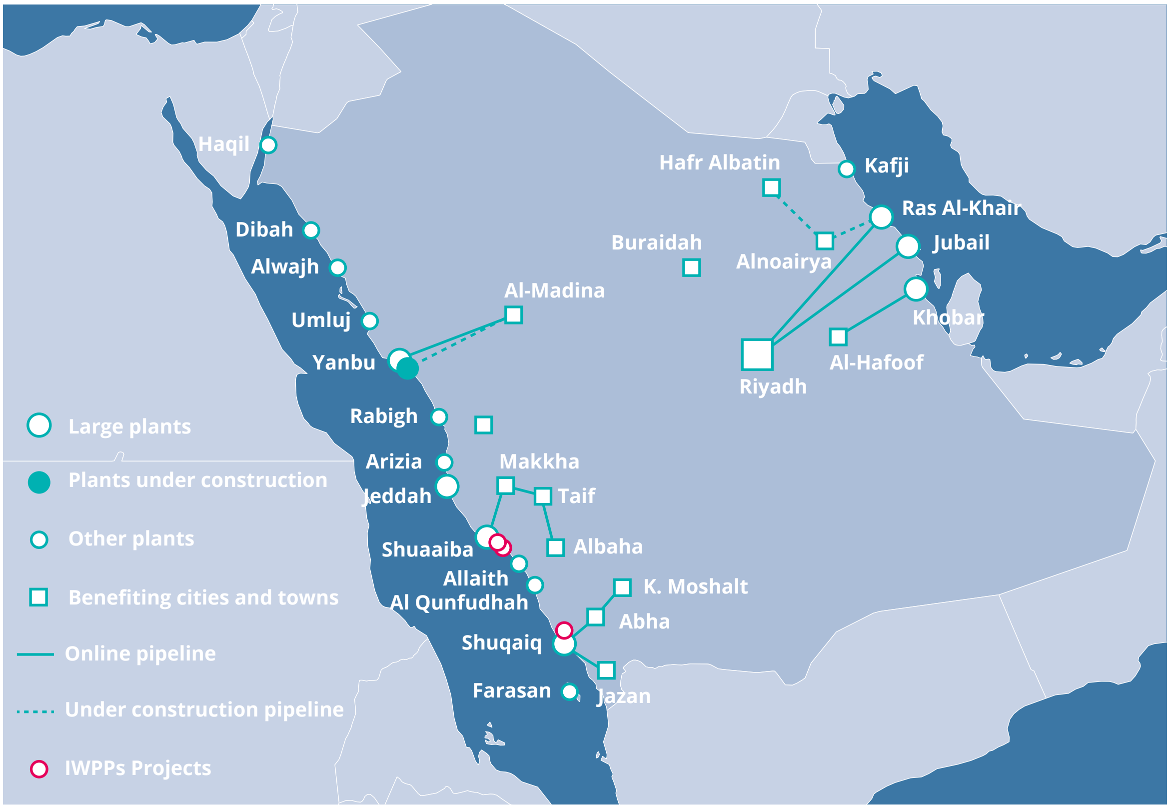
Research, development, and constant innovation are necessary to compete in such a strategic sector, and to reduce the severe impact that water scarcity could have on people's lives and the economies of entire nations. Hence, Saudi Arabia is increasing significantly its investment in R&D among other efforts by boosting research and innovation in prestigious research centres and universities such as King Abdullah University of Science and Technology (KAUST).

Figure 12: SWCC main assets

Desalinated Water	Power Generation	Water Transmission	Plant	Storage
4.7 MCM/Day Total instaled capacity **62 %** of desalinated water in the Kindom	**7,305** MW Total instaled capacity **12%** of production capacity in the Kingdom	**7,175** KM total length **21** Transmission systems **56** Pumping stations **12** Mixing stations	**29** Plants **18** Different locations	**285** number of storage tanks With capacity **12.7** MCM

Source: SWCC 2018

Figure 13: Main desalination projects in Saudi Arabia



Source: SWCC 2018

C Desalination in Jordan

Jordan is classified between the arid and semi-arid countries, and is considered one of the most water-stressed countries in the world, with less than 145 m^3 annual per capita of fresh water resources, while the world water poverty line is 1,000 m^3. The country is divided into 15 surface water basins and 12 ground water basins, some of which extend to neighboring countries. The annual average of surface water, is 411 Mm^3 and of safe groundwater abstraction is 275 Mm^3.

Water resources depend on rainfall which varies in quantities, intensity and distribution from year to year, with most of it falling between the months of October and May.

Trans-boundary surface and ground water resources contribute to an important share of the water resources of the country. These resources are governed by bilateral treaties and agreements for their mutual management and utilization.

In terms of water uses, Table 7 shows the uses per sector.

Historically, municipalities were responsible for water distribution, and the Ministry of Health was responsible of water quality monitoring in the early fifties in the last century. In 1960 the Central Water Authority was established to conduct water studies and obtaining water resources for municipalities. In 1959 the East Groh Establishment was created to implement the first stage of King Abdullah Canal (KAC). The Jordan Valley Authority (JVA) was created in 1977 according to JV Dev, low no 18, 1977.

The Ministry of water and irrigation (MoWI) was established in 1988 as an umbrella for both authorities to improve drinking water services and to lighten the financial burden on the Jordanian government, the MoWI established three main water companies working commercial biases.

Miyahuna is the leading company established in 2007 providing water. Miyahuna is fully owned by the Water Authority of Jordan (WAJ). The main desalination plants are shown in Table 8.

Table 7: Distribution of water uses in Jordan (considering: surface water, groundwater and treated wastewater "TWW")

	Sectors (Mm^3)				
Sources	**Municipality**	**Industrial**	**Irrigation**	**Live-stock**	**Total**
Surface	123.75	3	155	7	288.75
Ground	333.15	27.37	257.8	0.63	618.95
TWW	0	2.1	134.24	0	136.34
Total	456.9	32.46	547.04	7.63	1,044.03
%	43.7	3	52.4	0.9	100

Table 8: Jordanian desalination plants

Desalination/ Water treatment plant	Raw water resources	Capacity m³/d	Technology	Cost USD /m³
Zarqa Ma'aen	Zarqa Ma'aen spring surface water sources	130,000	Pretreatment sand filters RO, UV, CL_2 Disinfection	0.85
Abu Zighan	Abu Zighab brackish (12) wells	60,000	Pretreatment sand filters RO	0.60
Zarqa	Zarqa brackish (3) wells	9,400	Pretreatment sand filters RO, CL_2 Disinfection	0.33
Mashtal Faisal	Mashtal Faisal brackish (8) wells	9,000	Aeration tank, ceramic microfiltration (MF) filters, RO, CL_2 Disinfection	0.37
Other minor desal plant	Ground water (wells)	50 – 120	Mobile RO	Cost is varied because its operated by the private sector (O&M)

1 Aqaba

A seawater desalination plant to be built to supply the Aqaba Special Economic Zone Authority (ASEZA) in the southern port city in Jordan. The plant will supply 20 million m³/y of desalinated water (55,000 m³/d). The bid submissions deadline was 1st April 2019. A water desalination plant opened in Aqaba on March 2017, set to work at a capacity of 12,000 m³/d at the cost of USD 1.1/m³. The desalination project was implemented on the principle of build-operate-transfer (BOT). This formula of public-private partnership (PPP) allows the state to recover its investment after a set period. In this case, it is seven years, and when the firm transfers it to the government, it will be helping the Ministry of Water and Irrigation run the facility. The clean water generated is estimated at around 5 Mm³ annually, are used for drinking purposes, agricultural and industrial needs. This plant will meet Aqaba's water needs until the year 2035, and is fully supplied with renewable energy resources, with solar energy generating electricity for the entire project. A large portion of water is pumped into the Aqaba Water Company network to be distributed to its consumers. In addition, the plant provides the same amount of water as the Disi project, the main water conveyance project that brings water to Amman from Disi aquifer in the southern desert.

2 Red-Dead Sea

The second big desalination plant is pending yet, which is the so-called Red-Dead Sea water project. A total of 85 – 100 Mm³ of water will be desalinated every year, while the seawater will be pumped out from an intake located in the north of the Gulf of Aqaba. Jordan signed a memorandum of understanding (MoU) with Israel and the Palestinian Authority in December 2013 to implement the first phase of the Red-Dead project.

Under the first phase, a total of 300 Mm^3 of water would be pumped each year. Eventually, up to 2 bn m^3 of seawater will be transferred from the Red Sea to the Dead Sea annually, according to the Jordanian Ministry of Water and Irrigation. In addition, a conveyor will be extended to transfer desalinated water and a pipeline will be installed to dump the brine into the Dead Sea to stop its constant decline, estimated at one meter every year. The Kingdom will receive an additional 50 Mm^3 of water from the Lake Tiberias Reservoir annually to be added to its share from the desalination station to provide Aqaba with water.

The Red-Dead project‘s main components will include a seawater intake structure; an intake pump station; a seawater pipeline; a desalination plant with a capacity of 65 – 85 Mm^3 per year; a desalination brine conveyance pipeline; two lifting pump stations; hydropower plants; and discharge facilities at the Dead Sea. Under the signed MoU, the Palestinian Authority will receive 30 Mm^3 of freshwater to cover its water deficit, while Israel will buy its share of 50 Mm^3 of desalinated water from the project at cost value, and sell Jordan the same amount of water in the northern Jordan Valley at a cost of USD 0.38/m^3.

3 Challenges and lessons learnt on desalination in Jordan:

The main challenges facing the sector in Jordan are:

- A severe shortage of saline water sources and dispersed with limited quantities;
- Jordanian Inhabitants are concentrated at far distances from sources;
- Costly power generation which influences the cost of desalination.
- The only reliable saline water source is the Red Sea which is at a far distance from the populated area in the main cities which has adverse effect on:
    - Desalination cost;
    - Water transportation cost;
    - Cheap and affordable technology;
    - Funding desalination projects;
    - Political challenges.

The lessons that could be learnt from the Jordanian experience are:

- Desalination plants in Jordan operated in high efficiency (80 – 90 %);
- Pretreatment cost in Jordan is effective because of efficient operation (adding suitable chemical dosages);
- To bridge the gap between demand and supply of water desalination will be the possible solution.

D Desalination in Palestine

The main water player in Palestine is the Palestinian Water Authority (PWA), which has been established in 1995 as a Governmental Organization attached to the Prime Minister. Its main mission is to develop and protect water resources and infrastructure in a just, integrated and sustainable manner to provide water suitable for different purposes which guarantee environment protection and achieve development objectives. Its geographical and thematic area of intervention includes East Jerusalem, Gaza Strip and the West Bank.

In Gaza, the water situation is critical in quantity and quality, and its coastal area aquifer suffers from high salinity and sea water intrusion (Figures 14a, b, c).

Desalination is a must in Gaza. The EU-funded Southern Gaza Desalination Plant will bring fresh water to nearly 14 % of the population by 2020

Figure 14a: Gaza ground level map in 2016

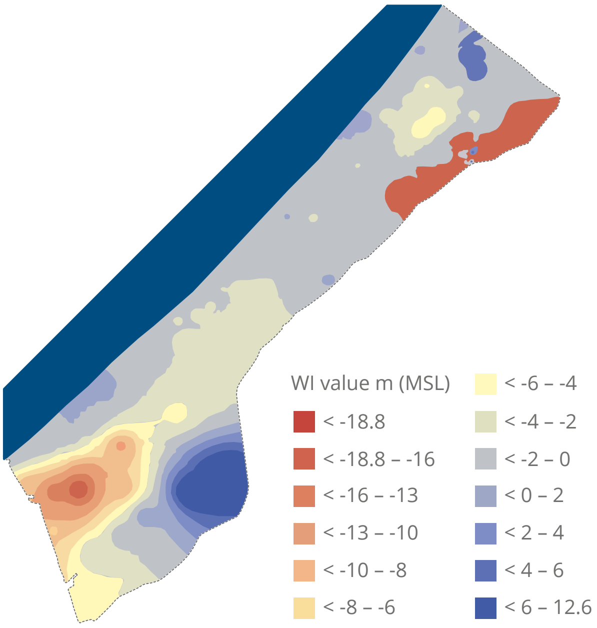


Figure 14b: Gaza chloride mapping in 2016

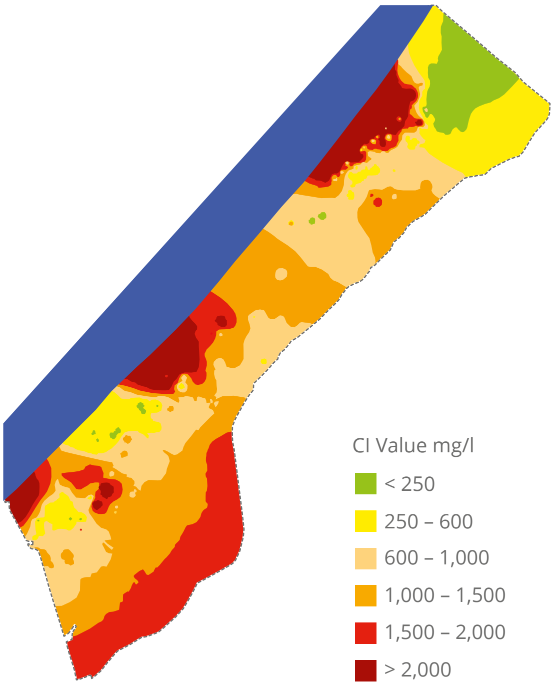
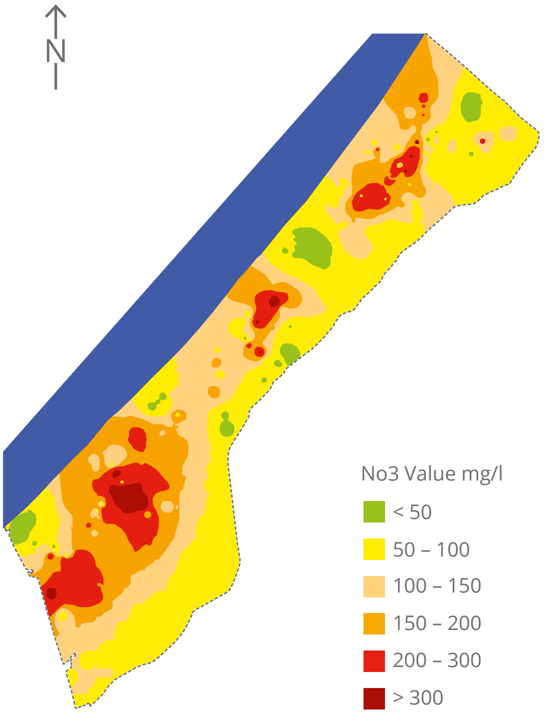


Figure 14c: Gaza nitrate mapping in 2016



Source: Al-Sheikh, PWA 2018

(the plant currently provides water to 75,000 people; 250,000 is the target by 2020) and has the potential to mitigate societal and political tensions in a highly vulnerable area, where 97 % of water resources are unfit for consumption. We list hereafter the main desalination projects:

1 Gaza Central Sea Water Desalination Plant

Table 9 shows the profile of Gaza desalination facility project. This project was labelled by the secretariat of the Union for the Mediterranean (UfM).

- 55 Mm^3/y phase 1 to be doubled in phase 2;
- ESIA completed, conceptual design furnished including energy options;
- Associated works detailed design completed;
- Total Cost Estimate USD 600 M;
- USD 60 M committed, 65 % of total costs pledged;
- The Palestinian Water Authority (PWA) has developed a feasibility study on natural gas (NG) supply from Israel.

a. Khan Younis Short Term Low Volume Desalination Plant

This plant (Figure 15) has a capacity of 6,000 m^3/d. In addition an expansion to 20,000 m^3/d is under tendering.

Solar Energy:

- Existing: 130 KWp contributes to 10 – 12 % of energy demand. In addition; 7 KW provides the full needs of the administration building;
- In process: 560 KWp to be able to operate one line (2,000 m^3/d).

Table 9: Desalination Facility for the Gaza Strip

Promoter	Palestinian Water Authority (PWA)
Result	> 55 Mm^3/y of drinking water › North-South water conveyance system › Non-revenue water (NRW) reduction programme
Beneficiaries	1.7 M Gaza inhabitants
Duration	2014 – 2017
Partners	› European Investment Bank › Islamic Development Bank › World Bank › European Commission
Budget	USD 347 M

Figure 15: Khan Younis Short Term Low Volume Desalination Plant

Source: Al-Sheikh, PWA 2018

2 Deir Al Balah Short Term Low Volume Desalination Plant

- 2,600 m³/d seawater desalination plant exists (Figure 16);
- Expansion to 6,000 m³/d under construction;
- Solar Energy: PVs with capacity 400 KWp to cover the needs of administration and laboratory.

3 North Gaza Short Term Low Volume Desalination Plant

- 10,000 m³/d seawater desalination plant under construction;
- Solar Energy: PVs with capacity 7 KWp to cover the needs of the administration building.

In terms of brackish water, there are 154 desalination plants with a total of 3 Mm^3/y of produced water distributed as follows:

- 26 North
- 51 Gaza
- 29 Middle
- 35 Khan Younis
- 13 Rafah

PWA accumulated considerable experience and knowledge in fixing price limits of desalinated water sales, and in what comes to incentives to the private sector. While on the other hand, there is still a need in terms of the legal framework, commitments to the public sector, and improving revenue collection under severe political and socio-economical situations.

A partial solution to the Gaza water crisis resides in the development of a new desalination facility,

Figure 16: Deir Al Balah Short Term Low Volume Desalination Plant

Source: Al-Sheikh, PWA 2018

which is labelled as an UfM (Union for the Mediterranean) project. Its aim is to provide safe drinking water for more than 2 M people and to decrease the pumping demands on the aquifer, which in turn can help the small Gazan agricultural and tourism sectors.

E Desalination in Oman

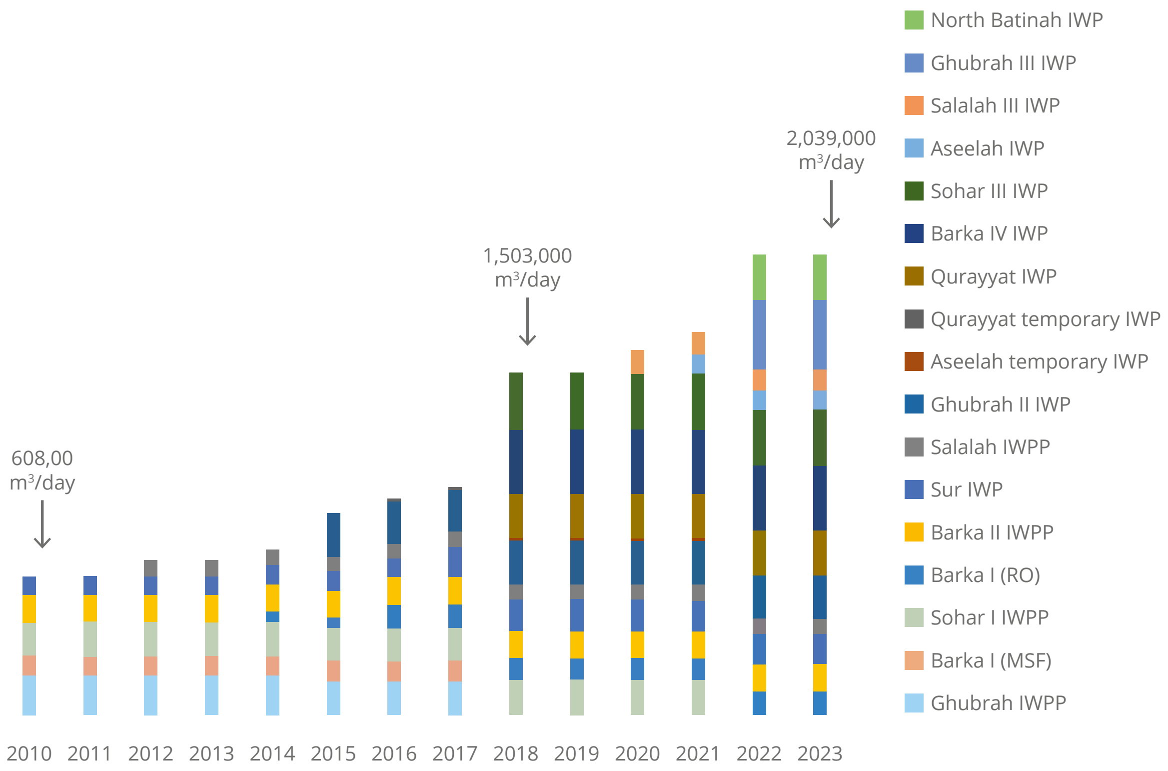
In Oman, Oman Power and Water Procurement (OPWP) is the entity that develops desalination projects requirements of power and water capacities through the fair and transparent competition process. The private sector investment in the desalination sector is about USD 2.6 bn up to 2019. The current capacity is around 1.5 Mm^3/d and will reach 2 Mm^3/d by 2023 (Figure 17).

Figure 18 shows the type of feedwater used in desalination plants in Oman. More than 60 % is seawater. On the other hand, the impact on water tariffs is shown in Figure 19 provided by NAMA / OPWP (NAMA is the highest governmental entity in charge of delivering safe, reliable and efficient electricity and water services, and OPWP is the Oman Power and Water Procurement Company).

In the near term to 2020, the tariff is expected to decline by 40 % due to:

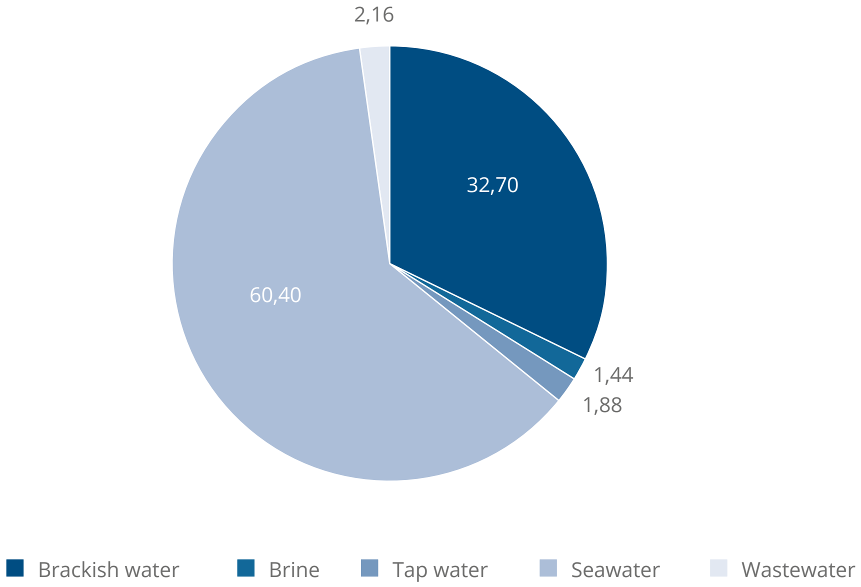
- Retirement of Ghubrah IWPP (MSF Technology);
- Shifting other MSF plants to standby mode (Barka I, Sohar I); and
- Lower expected tariffs of upcoming large IWPs (Qurayat, Sohar III, Barka IV).

Figure 17: Desalination capacity in Oman from 2010 to 2023



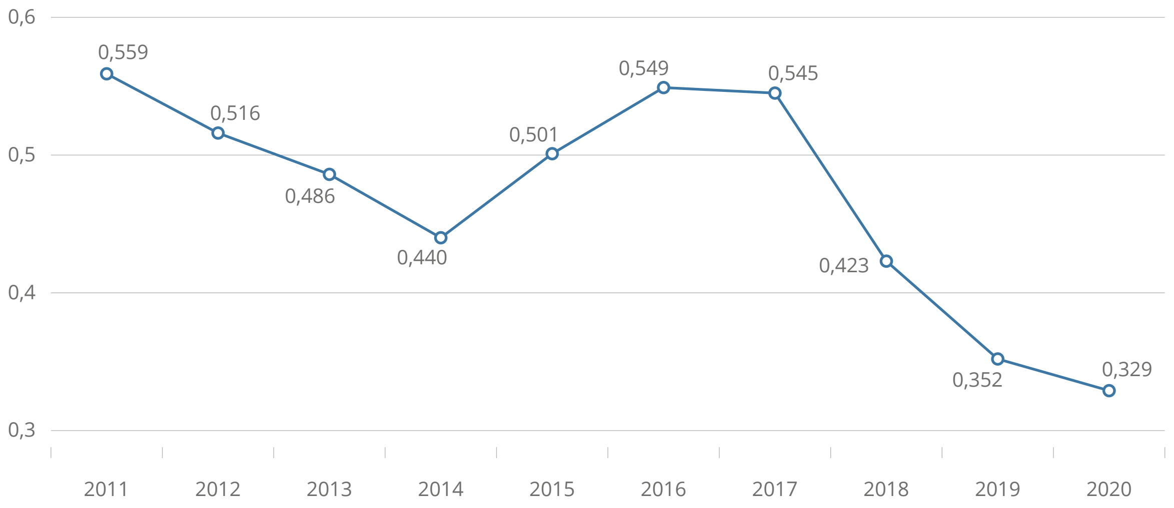
Source: OPWP 2018

Figure 18: Type of feed water used in desalination plants in Oman



Source: OPWP 2018

Figure 19: Impact on Oman water bulk supply tariff (BST)



Source: OPWP 2018

The following map (Figure 20) shows the new planned projects. The following ones are under construction:

- Barka IV IWP: equipped by a combination of dissolved air floatation (DAF) and dual media gravity filtration (DMGF) for pretreatment, which is quite efficient to deal with the harmful algal blooms (HABs) which threatens the production when it invades the costs;
- Qurrayyat IWP: with a combination of dissolved air floatation (DAF) and dual media filtration (DMF) for pretreatment;
- Sohar IV IWP: with a combination of dissolved air floatation (DAF) and dual media gravity filtration (DMGF) for pretreatment.

It is noticeable that future SWRO plants will use DAF as an additional pretreatment step further to the severe membrane fouling experienced in these regions observed especially during red tide events, which forced several plants to shut-down in the past.

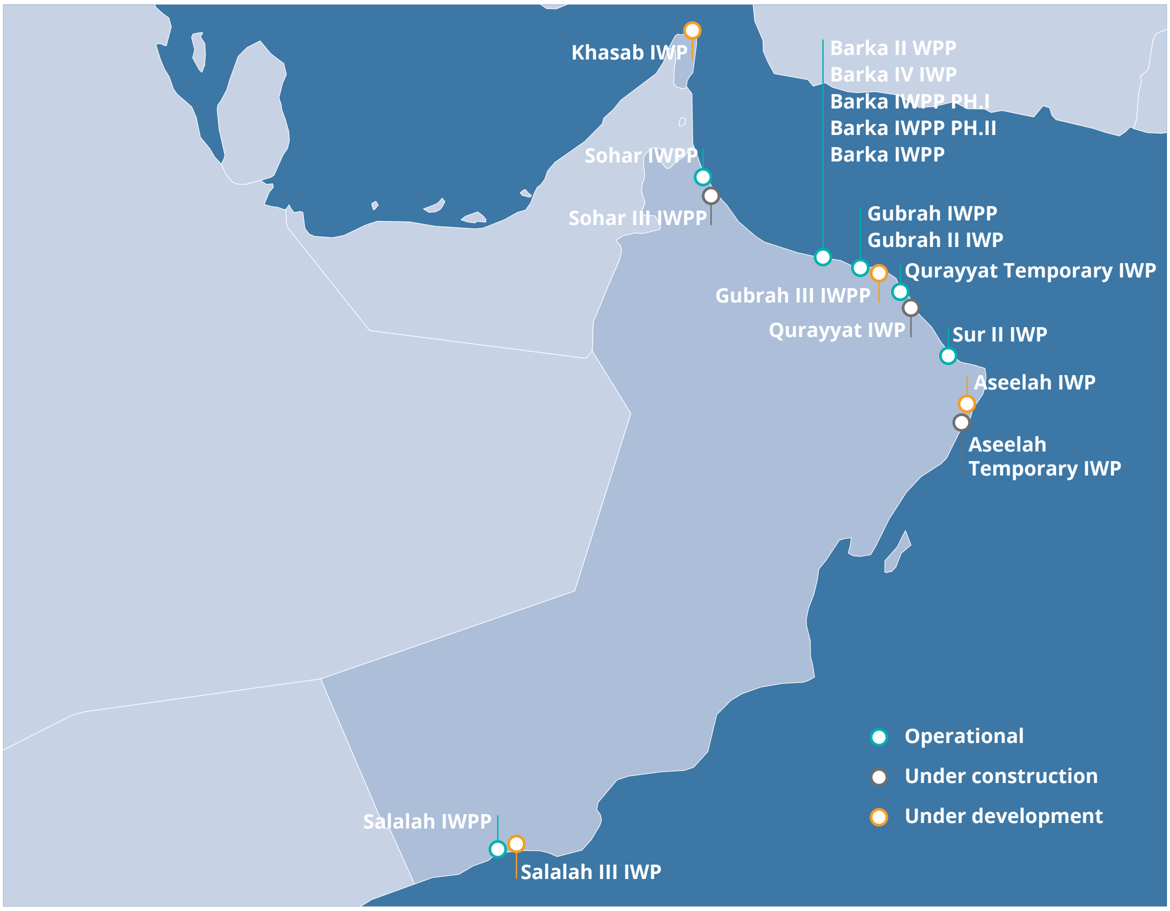
Table 10 presents some characteristics of some Omani desalination plants in operation. Moreover, the following ones are under development in 2019:

- Khasab IWP: 16,000 m^3/d
- North Batinah IWP: 150,000 m^3/d
- Al Ghubrah III IWP: 300,000 m^3/d
- Sharqiyah IWP: 80,000 m^3/d
- Salalah II IWP: 100,000 m^3/d
- Wadi Dayqah IWP: 90,000 – 120,000 m^3/d

In terms of procurement models used in Omani desalination projects, almost procurements are EPC, which is a particular form of contracting arrangement used in some industries where the EPC contractor is made responsible for all the activities from design, procurement, construction, commissioning and handover of the project to the end-user or owner.

In Figure 21, we show the main private sector players in the Omani desalination industry (holding companies). Data were provided by desal data (GWI, 2018). In Oman, it was found that seawater is the most used feed in desalination plants; due to its availability. The leading holding company and supplier is Veolia.

Figure 20: Oman new planned desalination plants

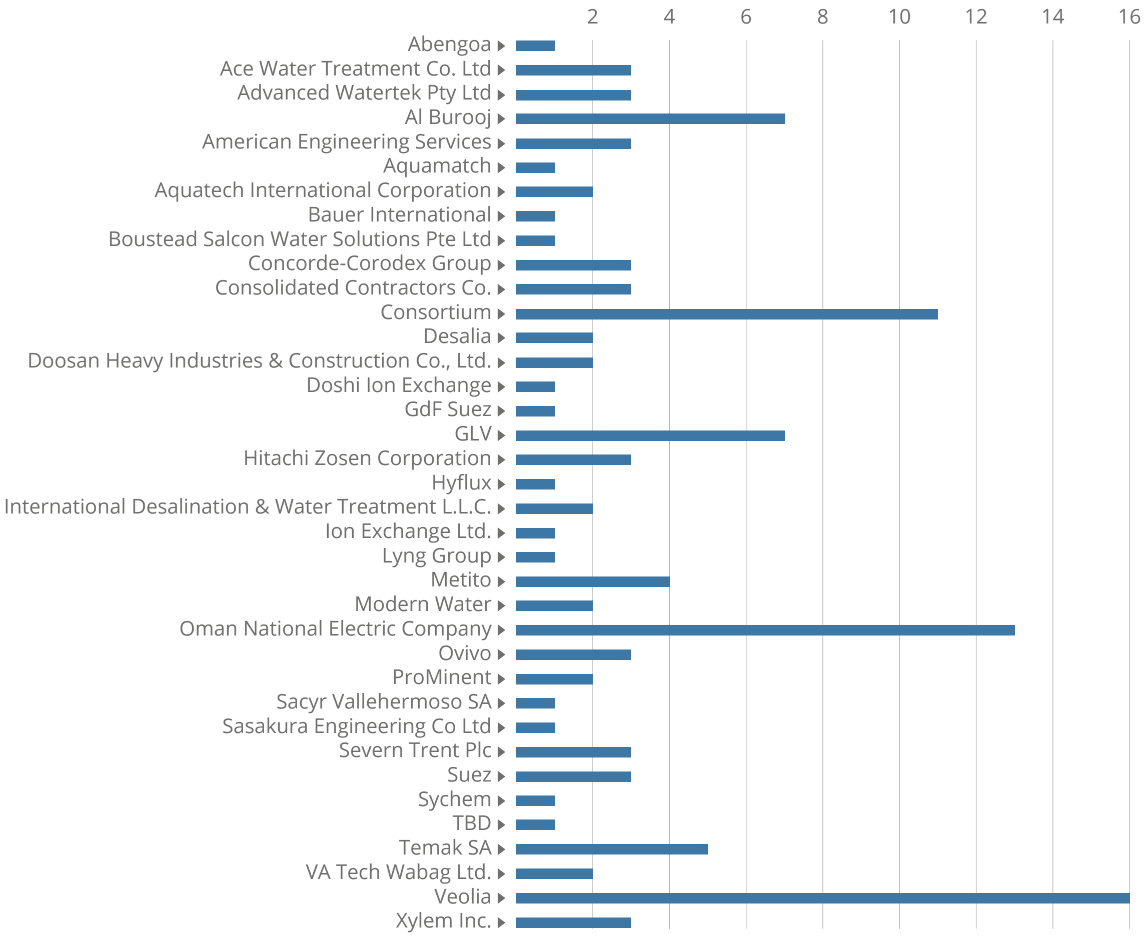


Source: OPWP 2018

Table 10: Characteristics of some Omani desalination plants in operation

Operation Date / Desalination Plant	Characteristics
2009: Barka II IWPP	First RO desalination plant
2009: Sur IWP	Extract water from Beach wells
2010: Salalah IWPP	Cylcone filtration system
2014: Barka PH I IWP	8 units of Ultra filtration 0.01 – 0.1 microns
2015: Al Ghubrah II IWP	Combination of dissolved air floatation (DAF) and dual media filtration (DMF) for pretreatment
2016 : Barka PH II IWP	14 units of Micro-filters 0.1 – 0.2 microns

Figure 21: Operators of desalination plants in Oman



Source: Desaldata/GWI

Brackish water desalination is also widespread in Oman mainly for agricultural use. At the North of Oman (the Batinah region) groundwater over abstraction is causing seawater intrusion and salinisation of soils along the Batinah coast, while there is an essential agricultural activity in this area. In 2019, more than 250 farms are using desalination to provide irrigation water.

F Desalination in Morocco

Morocco's exploitable groundwater reserves have dwindled over recent decades and it is today one of the world's most drought and climate change affected countries. The situation is expected to worsen in the future due to the continuing decline in rainfall (10 % less precipitation is predicted between 2021 and 2050). At the same time socio-economic development and tourism is creating more water demand. Existing infrastructure that supplies drinking water to 900,000 inhabitants in the areas of Agadir, Inezgane and Aït Melloul, as well as water for irrigation, needs to be upgraded and expanded to cope.

The Moroccan desalination experience implemented by the National Office of Electricity and Drinking Water (ONEE) was 20 years ago closely related to the water supply in south Moroccan areas which lack fresh water and have limited brackish water resources. In Morocco, the objectives of water desalination are mainly:

- Drinking water supply in areas that lack conventional water resources;
- Securing the supply of drinking water to face the impact of climate change.

In terms of capacity, Morocco is planning 13 desalination plants, and contracted already a capacity of seawater desalination of 275,000 m^3/d, which is Agadir desalination plant (under construction). Morocco has accumulated considerable experience and know-how in desalination since 1976. This can be resumed as follows:

- Study and choice of feed water intake modes;
- Awareness on the environmental aspect;
- Choice of piping materials and equipment;
- Control of operating ratios;
- Control of energy ratios: from 7 to 2 kWh/m^3;
- Acquisition of expertise in desalination;
- Technology watch;
- Desalination costs: from USD 3.4 to less than USD 1.1.

The main desalination projects in development are:

- Agadir desalination plant: 150,000 m^3/d of drinking water in its first phase;
- Al Hoceima desalination plant: 17,300 m^3/d;
- Sidi Ifni desalination plant: 8,600 m^3/d.

ONEE (Office National de l'Electricité et de l'Eau Potable), Morocco's main water utility, together with the country's Ministry of Agriculture and Fishery, launched a public private partnership (PPP) to finance, design, construct, operate and maintain a 275,000 m^3/d desalination plant in Agadir. SEDA (a joint-venture company formed by Abengoa Water and InfraMaroc) and the SPV Aman El Baraka will construct and run the plant – which will use state-of-the-art ultrafiltration pretreatment systems and RO technology – under a 30-year build-operate-transfer contract. The global capacity at term will be of 400,00 m^3/d of which: 1st phase: 275,000 m^3/d (150,000 m^3/d for drinking water needs and 125,000 m^3/d for irrigation water). This is an RO plant to be built under PPP agreement (BOT of 20 years), and commissioning is expected for 2020.

The plant will meet domestic demand for drinking water in addition to demand for irrigation water in the region, contributing to the development of the tourism and agricultural sectors, and preventing the over-exploitation of aquifers. The plant's capacity has the potential to be increased by an additional 125,000 m^3/d, providing even greater water security. This is the first privately financed contract that ONEE has introduced. Its successful financial close is expected to lead to further PPP projects, unlocking new sources of investment and helping to deliver more desalination plants, which have previously been unaffordable due to their high CAPEX and OPEX costs.

The project involves construction of three storage tanks with a cumulative capacity of 5,500 m^3 and pumping stations to facilitate the delivery of water to households in Laâyoune. It is projected to have a capacity of 26,000 m^3/d in the future.

A new desalination plant is set to be developed in Laayoune in a bid to boost the drinking water supply in the Western Sahara. According to ONEE, which is implementing the project, the desalination plant will be operational by June 2021 and is expected to meet the city's drinking water needs until 2040. The project will require an investment of USD 41 M. The project is also in support of the 2020 – 2027 Priority Drinking Water Supply and Irrigation Programme, which is now being rolled out in Morocco.

Some other projects are in the pipeline, mainly:

- Casablanca desalination plant: 300,000 m^3/d;
- Safi desalination plant: 26,000 m^3/d;
- Agadir extension: 50,000 m^3/d;
- Sidi Ifni extension: 8,600 m^3/d.

Table 11 summarizes the planned desalination plants with a total capacity of 319,345 m^3/d.[1]

Morocco has developed a water/sanitation strategy, including the development of non-conventional water resources. Desalination is one of the proven

Table 11: State of the art of Moroccan desalination plants

Project	Capacity m^3/d	Technology	Current status
Casablanca desal plant	/	/	Conceptual stage: potential capacity options under study
Chbika desal plant	/	/	Financial close and start of construction: The timeline for the tendering remains unclear.
Dakhla Municipal SWRO	17,300	RO	The plant is scheduled to be developed in 2020.
Dakhla SWRO	74,845	RO	Consultant/client issues RFQ/RFP: A contract for a 5,000 ha irrigation scheme with a 74,845 m^3/d seawater desalination plant (of which 2,200 m^3/d would be for drinking water), twenty 500m-deep boreholes with a supply capacity of about 15,000 m^3/d, and a 26 MW wind-powered plant power around 130km north of Dakhla.
Essaouira	50,000	RO	This project is a long-term proposal and will not be commissioned until 2020 or 2025.
Jorf Lasfar extension	30,900	RO	Professional advisor / consultant mandated
Laayoune SWRO	26,000	RO	To be operational on 2021
Safi	75,800	RO	This plant is part of OCP's long-term strategy to reduce demand for groundwater resources at its phosphate production facility at Safi, south-west of the city of El Jadida.

[1] Table 11 also lists desalination plants in Western Sahara. The claim to the Western Sahara is the reason of state and a central concern of Moroccan politics. The status of Western Sahara is unsettled under international law.

Table 11 (continued): State of the art of Moroccan desalination plants

Project	Capacity m³/d	Technology	Current status
Safi municipal SWRO	26,000	RO	To build a 26,000 m³/d seawater reverse osmosis desalination plant to serve the city of Safi. This project is a long-term proposal, and any plant which is constructed will not be commissioned until after 2025.
Sidi Ifni phase 1	8,600	RO	These two seawater desalination plants in the south of Morocco are part of ONEE's long-term desalination strategy.
Sidi Ifni phase 2	8,600	RO	Phase 2 of a 34,560 m³/d SWRO, a growing tourist destination. ONEE plans to build the plant in phases, with the first phase of 8,640 m³/d designed to meet the local population's needs awarded in 2018. The second phase of 8,600 m³/d is likely to be awarded in 2020/2021.
Tan Tan port desalination	/	/	Conceptual stage: Morocco's national port agency, Agence Nationale des Ports, is considering a desalination plant to supply the port of Tan Tan in southern Morocco. The plant would be powered by renewable energy.
Tarfaya SWRO	1,300	RO	To build a new 1,300 m³/d seawater reverse osmosis plant in the town of Tarfaya. The capacity will eventually be doubled.

Source: GWI 2018

and safe solutions for mobilising additional water resources. The effects of climate change require rethinking desalination at the heart of water supply alternatives: Between types of use and different resources.

On the other hand, the Water-Energy Nexus aims to strengthen the synergies between the two sectors in the context of sustainable development. In addition, continuous training, regional and international cooperation, maintaining a technological and institutional watch are undeniable levers for the sharing of best practices, with the aim of mastering technology, optimising costs and setting up an adequate acquisition mode. ONEE is a key player actively involved in knowledge sharing in the field of water desalination.

G Desalination in Algeria

In Algiers since 2006, urban water supply is managed by a public company SEAAL in cooperation with a private partner SUEZ environment. The company provides drinking water services to approximately 3 million people. In 2011, the Algerian authorities renewed and extended the contract with SUEZ for five years to help modernise the water and wastewater management services for Algiers.

On the other hand, Algerian Waters (ADE) is a national public establishment of an industrial and commercial character endowed with the good personality and financial autonomy. It was established by Executive Decree No. 01-101 of 27 Moharem 1422 corresponding to 21 April 2001. The establishment is under the supervision of the Minister in charge of water resources, and its head office is set in Algiers. It must ensure the implementation of the national drinking water policy throughout the national territory through the management of production, transport, treatment, storage, supply, distribution and supply of drinking water and industrial water and the renewal and development of related infrastructure;

The ADE has 15 zones and 44 units; each zone manages 2 to 4 units (ADE, 2018).

1 Context

The droughts during 2004 triggered the choice to invest in large-scale seawater desalination. Thus, the extent and severity of droughts which are exacerbated by climate change, will be critical factors driving desalination investments. According to the Algerian minister of energy, the specifications for the implementation of two seawater desalination plants in Zéralda (Algiers) and El-Tarf are under preparation.

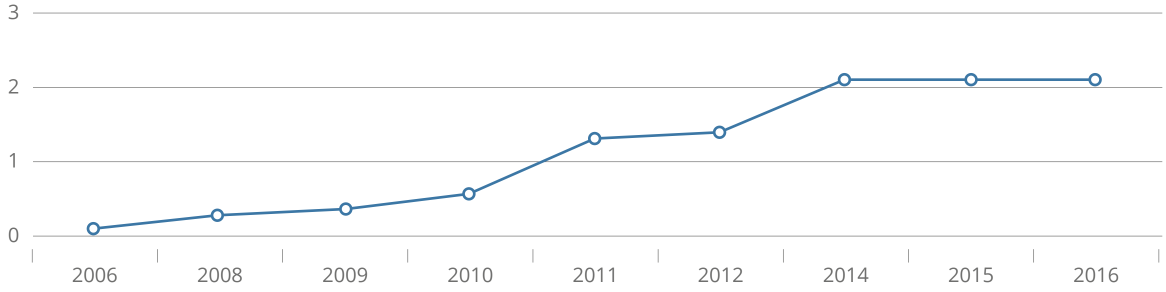
Despite having 11 large scale desalination plants, freshwater availability in the country is rapidly falling far below the UN's water poverty threshold (less than 300 m^3/y), which is 1,000 m^3 per capita per year. In the 1960s, Algeria's annual per capita availability was more than 1,000 m^3. Currently, it is 292 m^3.

Desalination production accounted for approximately 17 % of water consumed in 2017, and it is increasing considerably in the last decade as you can appreciate in Figure 22.

2 Desalination plants

Oran was the first major city to use desalinated water for drinking water supply through Kahrama project which is an independent water and power

Figure 22: Desalination capacity (Mm^3/d) in Algeria since 2006 and up to 2016



Source: Desaldata/GWI

project (IWPP). The facility produces a net power output of 314 MW coupled with an average annual water production of 88,000 m³/d, and by 2008 Algiers became the second city in using desalination for drinking water supply.

Nine other large-scale SWRO plants are in operation at several locations to supply drinking water Desalination plants in Algeria have a cumulative capacity of about 2 Mm³/d. Later on, the largest plant was Magtaa. Its construction started in October 2008, and was completed to begin operations in November 2014. The plant features the world's largest ultrafiltration (UF) membranes with a total production capacity of 500,000 m³/d. Table 12 shows the most important desalination plants in Algeria.

According to the Algerian ministry of energy, the specifications for the construction of two seawater desalination plants in Zéralda (Algiers) and El-Tarf are under preparation. These specifications should lay down, the cost price of the desalinated seawater and the deadlines for completion of these two plants with a capacity of 300,000 m³/d each.

On the other hand, in terms of brackish water, the application of a solar-powered desalination system to treat it is resulting in high-quality desalinated water that could provide water for irrigation in arid regions of Algeria.

In 2019, there are several municipal brackish groundwater desalination facilities in Algeria, with capacities ranging from 9,000 to 40,000 m³/d.

Twelve brackish water desalination plants are operational in the North Western Sahara Aquifer System (NWSAS), with average electricity consumption in the range of 0.5 – 2.5 kWh/m³. Integrating solar power to existing desalination facilities could generate a high-value product from low-value resources.

Table 12: Desalination plants in Algeria have a cumulative capacity of about 2 Mm³/d

Project	Capacity m³/d	Commissioning	Partners
Kahrama	88,000	since 2006	J. Burrow Ltd: 50 %
Hamma	200,000	since 2008	GE Ionics, US: 70 %
Skikda	100,000	since 2009	Geida (Befesa / Sadyt), Spain: 51 %
Beni Saf	200,000	since 2010	Obra, Spain: 51 %
Souk Tlata	200,000	since 2011	TDIC (Hyflux / Malakoff), Singapour: 51 %
Fouka	120,000	since 2011	AWI (Snc Lavalin / Acciona): 51 %
Mostaganem	200,000	since 2011	Inima / Aqualia, Spain: 51 %
Honaine	200,000	since 2012	Geida (Befesa / Sadyt), Spain: 51 %
Cap Djinet	100,000	since 2014	Inima / Aqualia, Spain: 51 %
Tenes	200,000	since 2015	Befesa, Spain: 51 %
Magtaa	500,000	November 2015	Hyflux, Singapore: 47 %; ADE, 10 %

3 Gaps and Needs in the desalination sector

The desalination plants are actively collaborating with Algerian universities:

- Students of different specialties do their practical internships at the desalination plants;
- Signed an agreement with universities to create new specialties of engineering in seawater desalination.

That is said, there is still a need for a desalination platform that could gather national facilities to improve capacity building among operators, engineers and technicians. Therefore, it is important to allocate resources to capacity building programs. To achieve this, it is required to create a basis for cooperation between the academic and research communities at a national and regional level. Sharing of best practices in the region would contribute to demonstrating that openness and collaboration can lead to innovation in such a vital sector.

At the research level, some cooperation agreements exist between the ADE, the National Sanitation Office (ONA) and research institutions for the water-related issues.

Algeria and the European Union (EU) signed the Prima agreement on scientific cooperation to increase research in the key sectors of water and agriculture. The PRIMA initiative (2018 – 2028), aims to develop new solutions for sustainable water management and food production.

In terms of cost, the lowest cost case is Magtaa plant: USD 0.55/m^3 of water and a total investment cost of approximately USD 468 M, while the most expensive case is Hamma plant: USD 0.75/m^3 of water and a total investment cost of approximately USD 200 M. It is worth to mention that before Hamma desalination plant became operational almost 11 years ago, all citizens of Algiers city lived with water delivered for only a couple of hours every second or third day. Today, the city has reliable and constant water on tap.

What is probably needed in Algerian desalination sector, is more data to assist decisions and strategies to mitigate brine disposal and its impact on the marine ecosystem. Other options to bridge the water gap in Algeria include rationalisation of virtual water trade and the use of renewable energy (RE) for desalination.

The Algerian government is currently implementing a series of desalination plants strategically placed in other water scarce coastal cities that also had high competing demands from industry. Given the high energy requirements of water desalination, some projects also included co-located power plants.

From the aforementioned information, it is clear that desalination capacity will continue increasing in the whole MENA region and not only in oil producing countries, and there will be an increasing need of training on O&M of desalination plants and an increasing concern about the environmental impact and ways to make desalination more environment friendly. One day is to use renewable energies, which will be detailed in the following section.

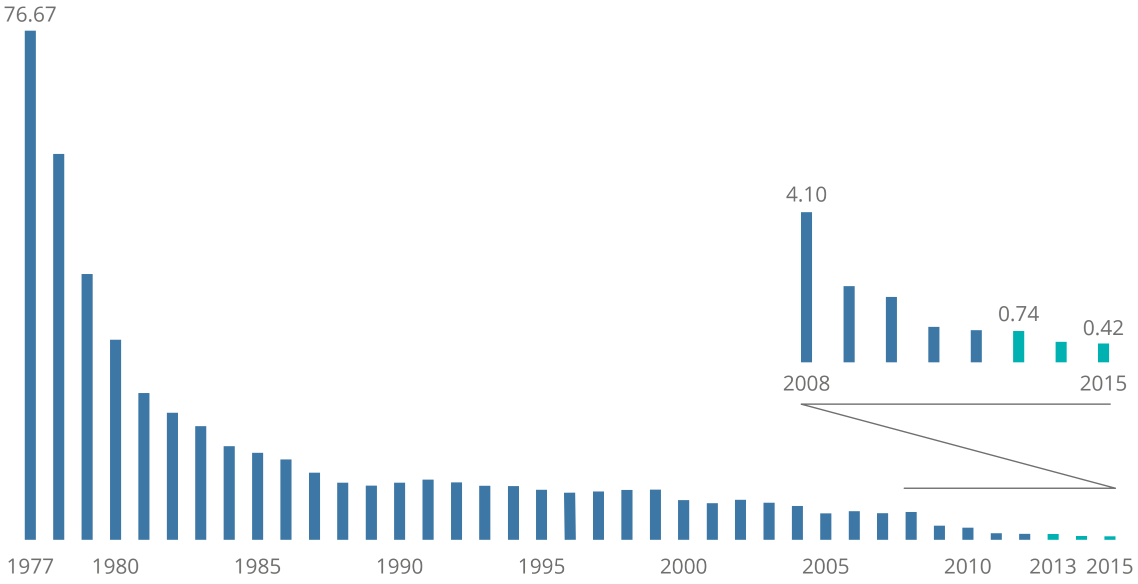
III. Renewable Desalination in MENA

Taking into account the climate protection targets and significant environmental concerns, future desalination technologies worldwide will be increasingly powered by solar, wind and other renewable energy sources. As conventional energy costs will expectedly increase in the short term and water availability will decrease due to the implications derived from climate change, the future of RE-powered desalination is very promising for environmental and economic reasons; it is, in fact, already a competitive alternative where water costs are very high (Cipollina et al., 2014).

In an attempt to lower carbon footprint resulting from energy-intensive desalination processes, attention has shifted to using renewable energy sources to power desalination. Renewable energy technologies offer increasingly attractive solutions to power desalination, a vital issue for many countries in arid and semi-arid regions, including the countries of the MENA region.

With solar irradiation quite ample in the MENA region that heavily rely on desalination, solar-powered desalination provides one of the most successful renewable energies options and a sustainable solution to meeting water needs. The compatibility of each desalination process with solar technology is driven by whether the kind of energy needed is thermal or electrical, as well as its availability. A number of different technologies allow the exploitation of renewable energy

Figure 23: Price of crystalline silicon PV modules: 1977 – 2015 (USD/watt)



Source: Ferreira 2018

resources, providing energy as heat (solar thermal, biomass, geothermal), power (wind power, wave power, solar photovoltaic) or even a combination of both energy forms (solar thermal electricity).

With rapid advances in solar energy technologies – both photovoltaic and solar thermal, there has also been growing interest in coupling solar energy with desalination, with a focus on improving energy efficiency.

The main challenge of renewable energy desalination is that desalination technologies generally work in steady-state conditions, but renewable energy sources are usually non-stationary (intermittent):

- Renewable energy generation needs adjustments for continuous supply (energy storage);
- Desalination technologies can adapt to variable operation.

In addition, land cost and size are also challenging renewable desalination. That is said, there is excellent potential to develop solar desalination technologies especially in MENA where solar energy is abundant and the cost of photovoltaic (PV) declining.

PV powered desalination has previously been regarded as not being a cost-competitive solution when compared with conventionally powered desalination; however, the decline in PV costs over the last few years (Figure 23) has changed this outlook.

Over the next few years, we will witness a huge number of desalination projects in MENA to respond to the increasing demand of domestic, industrial, agricultural and touristic sectors (5 to 6 % annual increase). In addition, there is an increasing interest in the region to localise desalination technologies to cut the full dependency on the international market (desal elements such as membranes, etc.). Moreover, policymakers in the MENA need to consider the different choices for desalination based on locally available renewable energy resources or consider the real cost of desalination projects.

Since the energy requirements in desalination processes play a decisive role, it appears attractive to consider renewable energies, because it offers a sustainable and secure way to desalinate water. Until recently, only small desalination plants in remote areas with no grid electricity and no skilled manpower used renewable energies, but as R&D has intensified, several pilot desalination plants in the MENA region have operated successfully using mainly solar energy (Ullah, I. and Rasul, M. G. 2018).

Moreover, the combination of desalination with renewable energies generation, even if not directly powered by it, can facilitate its penetration in the grid (compensation). This can not only enhance the renewable component of energy generation by absorbing its surplus and storing it in water but can be crucial in weak grids that otherwise could not accommodate the renewable component, like in the case of small islands (Tzen et al. 2012). Increasing efforts are devoted to improving the efficiencies of the RE conversions, desalination technologies and their optimal coupling to make them viable for small and medium scale applications.

Concentrated solar energy (i. e., sunlight focused by lenses and/or mirrors) can be used to desalinate by focusing solar radiation into a receiver that collects energy from the sun as heat; this heat can then be used to desalinate water by evaporating pure water from a saline source (Ghaffour et al., 2015).

On the other hand, there is an excellent potential for solar desalination to grow further in the MENA region. There are several ambitious projects in Saudi Arabia and the UAE to develop large solar desalination plants, including a project in the area of Al-Khafji on Saudi Arabia’s eastern coast and one in the area of Ras Al-Khaimah in the UAE. Both plants are set to become operational by 2020 and will be among the largest in the world (the initial phase of Al-Khafji solar desalination plant will produce 30,000 m^3/d, and this capacity will double in the next few years). The Al-Khafji one will be a disassociated RO and PV system. RO will take energy from the grid and PV will be injected in the grid, compensating the energy load. In fact, this plant will be the world's largest desalination plant of its kind thanks to a new kind of concentrated solar power (CSP) technology and new water-filtration technology, which King Abdulaziz City for Science and Technology (KACST) developed with IBM.

In such a concentrated solar system, lenses or mirrors focus sunlight on ultra-efficient solar cells that convert the light into electricity. The idea is to cut costs by using fewer semiconductor solar cell materials. However, multiplying the sun's power by hundreds of times creates a lot of heat. The Al-Khafji desalination plant is the first of three steps in a solar-energy program launched by KACST to reduce desalination costs. The second step will be a 300,000 m^3 facility, and the third phase will involve several more solar-power desalination plants at various locations.

A similar principle but this time with CSP is behind the desalination plant that is under construction currently by Abengoa in Agadir (Morocco). The benefits are clear: not only does it cut costs, but it also reduces carbon dioxide emissions and fossil-fuel dependency.

Several different technologies allow the exploitation of renewable energy (RE) resources, providing energy as heat, power or even a combination of both. Possible combinations with desalination technologies are shown in Table 13.

RO coupled with solar PV, is one of the most popular combinations in the MENA region. Therefore, it follows that:

- RE generation needs adjustments for continuous supply (energy storage), or compensation by connecting solar energy output to the existing grid, feeding the desalination plan directly from it as in Al-Khafji and many other medium scale plants;
- Emerging desalination technologies have an advantage that can adapt to the variable operation or operate under variable energy input like membrane distillation and adsorption desalination or hybrid systems (Ghaffour et al., 2015);

Table 13: Coupling options of solar energy with the different desalination processes

Solar Technology	Conventional Desalination processes			
	MSF	MED	MVC	RO
Concentrating Parabolic Collectors (Solar thermoelectric station producing both electricity and eventually heat through a cogeneration arrangement)	X	X	X	X
Flat Plate / Evacuated Tubular Collectors	X	X		
Salt Gradient Solar Pond	X	X		
Photovoltaic (PV)			X	X

Source: GWI El Kharraz 2015, Al-Karaghouli et al. 2011, IRENA 2012

Several MENA research institutions like MEDRC in Oman, Masdar in UAE, KAUST in Saudi Arabia (KSA), Khalifa University in Qatar, and CIEMAT in Spain, are heavily involved in developing novel RE integrated systems.

Solar still is one of the explored options for RE desalination. Many modifications to improve their performance have been made. These include adding solar energy collectors, incorporating a number of effects to recover the latent heat of condensation, improving the configurations and flow patterns to increase the heat transfer rates, and using less expensive materials of construction to reduce the cost. The solar still has many advantages like the low water cost, simplicity and durability. According to the literature, its production rates are 5 to 8 L/m^2 day. A glasshouse of 1,000 m^3 will have a water production between 5,000 to 8,000 L/d. This is 1,825 to 2,920 m^3 of fresh water per year. The water production costs can be estimated at 1.09 to USD 1.74/m^3 of freshwater, quite competitive and not much higher than the cost of water produced by conventional ways, yet here we are comparing very small to very large scales costs. A solar still pilot is installed at MEDRC facilities in Oman under the framework of a research project funded by the Dutch government and coordinated by the Dutch company Kascade.

Several successful solar desalination projects have been implemented in the MENA region but on a small scale. In Oman, solar energy has been a key area for the Research Council, Sultan Qaboos University (SQU) and MEDRC, and as an example desalination plants using concentrated solar power (CSP) technologies have been evaluated for Wilayat Duqum in Oman.

The MENA region has vast solar energy potential. Developing solar-powered desalination technologies, producing energy from the brine water salinity and reducing the energy required for desalination should be a top priority in MENA countries. R&D partnership and investments to identify optimal technical solutions and products for desalination and cogeneration powered by RE could improve the region’s social, environmental and economic condition.

For PV, battery storage remains costly, and for CSP, thermal energy can be stored relatively inexpensively. Intermittent operation is a particular concern when dispatchable power is required. For water production, the situation is more complicated. While water storage is relatively inexpensive, intermittent use of a desalination plant to meet base-load water demand requires oversizing the plant relative to what would be needed under steady operation. There is also another concept of electricity and water production mismatch in GCC countries.

On the other hand, when power tariffs vary during the day, energy cost savings through intermittent operation may offset the high capital cost of a larger plant.

The prices of PV electricity have been significantly reduced over the last decade to levels in parity with unsubsidized electricity rates in areas of high solar irradiation in the MENA region mainly where there is a need to expand desalination capacity.

The assessment made by Fthenakis (Fthenakis 2015) shows that PV powering RO desalination plants results in significant cost savings when both the direct and fuel subsidy costs of electricity generation are considered.

Recently, several utility-scale PV projects in high insolation regions have been bid at prices ranging from USD 0.03 to USD 0.06/kWhe, and further price decreases are expected. These systems do not include storage and are not designed to be dispatchable. Utility-scale PV systems at a scale of hundreds of megawatts are situated in arid regions with high insolation and relatively flat, barren land. While favourable local factors, including financing, have enabled this pricing, the potential to use this technology cost-effectively, if intermittently, to desalinate water with a near-zero carbon footprint is promising (Lienhard et al., 2016).

Furthermore, attention was paid by researchers in the last years to two different options for possible coupling between the solar system and a desalination unit (PV/RO and CSP/MED), to:

- accurately estimate the production cost of desalinated water; including ways to single out the possible factors to fill the gap between the production cost by solar and conventional technologies; and
- address other fundamental aspects of a solar system such as the initial investment and required area.

Overall water production cost is influenced by several local factors, like the market status of solar systems, financing conditions, labour and pre-treatment cost, fuel and electricity price. The selection of the appropriate solar desalination technology (Solar stills, Solar Collectors, Solar Pond, and PV with its three types: Stand-alone systems, Grid-connected systems, and Hybrid systems) depends on several factors. These include plant size, feed water salinity, remoteness, availability of grid electricity, technical infrastructure and the type of solar technology available.

IV. Case studies and innovative projects from MENA

Solar desalination projects implemented in the MENA region at a small scale:

- Autonomous Desalination System Concepts for Sea Water and Brackish Water (BW) in Rural Areas with REs – ADIRA project (2003 – 2007): Four PV-RO systems have been installed subsequently in 4 locations of Morocco, where feed water was brackish water (BW) from inland wells (salinity 2.5 – 8.7 g/L). Such systems produce 5 m³/d (PV capacity: 8 kWp), sufficient for 100 people, covering their food and sanitation needs;

- Autonomous PV-RO unit in Tunisia (since 2006): The village of Ksar Ghilène first African location with 2 years' operating PV-RO system. This project targeted 300 inhabitants with no access to the electric grid (nearest at 150 km) or fresh water. The system desalinated raw water with a salinity of 3.5 g/L, and operated more than 3,100 h producing 6,000 m³ of drinking water in 27 months;

- King Abdullah Initiative for Solar desalination - KSA: The initiative is expected to reduce production costs of desalinated water from USD 0.67 – 1.47/m³ to USD 0.27 – 0.40/m³. It is the world's first large-scale desalination plant to be powered by solar energy in Saudi Arabia;

- Ben Guerdan solar powered BWRO in Tunisia: with a capacity of 1,800 m³/d, in operation since 2013;

- A solar–MED plant built in Umm Al Nar, Abu-Dhabi has a desalination capacity of 120 m³/d. The thermal energy required for MED is provided by solar thermal collectors;

- The Layyah plant in Sharjah (UAE) integrates RO with MSF and MED thermal systems (Almulla, 2005).

In Dubai also, solar-powered RO desalination is expected to become the new trend to produce water and meet renewable energy targets. The UAE depends on desalination for its potable water, with a water production capacity of 2.14 Mm³/d. But now, the Dubai Electricity and Water Authority (DEWA) is working on powering its desalinated water plants with solar power to generate 1.15 Mm³/d by 2030. By using lower cost renewable energy to power desalination plants, Dubai's main utility will save USD 13 bn between now and 2030, according to DEWA.

PV-RO will now become the new trend as DEWA aims for 100 % renewable energy desalination in Dubai. This supports their efforts to boost water production in the UAE.

In this regard, it is worth to mention the Ghantoot case study. In 2016, Suez launched its pilot 100 m³/d RO desalination plant in Ghantoot, Abu Dhabi that showcases newer solutions to optimise energy at every stage of the water desalination process. The new technologies were expected to lay the ground for the implementation of cost-competitive large-scale seawater desalination plants powered by renewable energy in the UAE and beyond.

The idea has been to create an environment in which desalination components could be tweaked, tested and pushed. On a live, large scale plant, this is not possible as any equipment failure inevitably leads to potential downtime. Ghantoot became a desalination expert's playground – a chance to play and reconfigure components treating challenging high salinity waters. Pilot technologies from four companies were chosen. Later on, French company Mascara Engineering joined the site as the fifth company. This latest addition trial was designed to test off-grid, solar-powered desalination for remote, rural locations.

Riding on what it considers success in Abu Dhabi, the company has now signed projects in Tunisia and Bora Bora in the Pacific Islands.

In Tunisia, a 1,000 m^3/d plant has been confirmed with Tunisian water utility SONEDE, with 50 % of the USD 1.3 M project cost fronted by Mascara and hope that the remaining 50 % will be provided by partner Masdar. This project will use a hybrid approach – so water filtration is powered by solar panels during the daytime but reverts to grid power during the night. Meanwhile, a separate solar-powered RO unit is also currently being shipped to Bora Bora, a small South Pacific Island. This will be a smaller, 80 m^3/d demonstration project designed to test the system in a very remote location, without grid access.

Unlike the Tunisian project, which will be a grid / solar hybrid, Bora Bora will be purely off-grid designed to test system reliability in very remote, challenging conditions.

US firm Trevi System has a much lower energy target of 1 kWh/m^3, and it achieved 1.3 kWh/m^3 to 1.4 kWh/m^3. This trial ended by April 2017 and consists of a 50 m^3/d forward osmosis (FO) installation using a thermos-solute draw solution to create the osmotic pressure needed to desalinate the water. Waste heat causes phase separation of the ‘draw solute’, producing water and a concentrate draw solute.

Spanish firm Abengoa has been operating a more extensive operation at the site, producing 1,060 m^3/d of water. A hybrid process consists of RO membranes in combination with a membrane distillation system. The aim is to optimise membrane distillation (MD) to treat brine.

Meanwhile, the third French company on the site – SUEZ – has been testing dissolved air flotation (DAF) and membrane pretreatment adapted for challenging Gulf conditions, together with a double pass RO system. The company has also cited a 3 – 3.6 kWh/m^3 energy usage but is also working on a second trial, using liquid-to-liquid ion exchange resin technology to increase the volume of water produced without raising seawater intake.

For water, Masdar says it plans to co-create special purpose vehicles (SPVs) with the Ghantoot partners to bid on desalination projects.

One of the efforts led by MEDRC to boost innovation in desalination sector is the Oman Humanitarian Desalination Challenge (Box 1).

The MENA countries have no choice other than investing in innovation, and as far as desalination is impacting its water security, they will need to invest in the localization of desalination technologies.

Box 1

تحدي
عمان لتطوير أنظمة
التحلية الفردية لحالات
الكوارث الإنسانية

OMAN
HUMANITARIAN
DESALINATION
CHALLENGE

The Oman Humanitarian Desalination Challenge is a global water prize worth USD 700 000 for the individual or team that delivers a hand-held, stand-alone, low-cost, desalination device suitable for short-term use and rapid deployment in the event of a humanitarian crisis. There are no commercial products on the market that meet this challenge. While inexpensive marked-based water purification products can be purchased, they are unable to remove salt. The Challenge is a joint initiative led by MEDRC and The Research Council in Oman (TRC) with funding provided by the Sultan Qaboos Higher Center of Culture and Science. The Challenge looks to stimulate innovation and technical performance in small scale desalination technology. It will be held once a year for four years, or until the Prize is won.

In parallel and in support of the Oman Humanitarian Desalination Challenge, MEDRC are partnering with USAID on a second track of funding. This will support a new Desalination Challenge Research Call supporting pathway research, aimed at the delivery of an innovative family sized desalination unit. The funding aims to deliver an innovative family-sized (120 liters of water per day) brackish desalination device as a precursor or earlier generation to a hand-held device that the Oman Humanitarian Desalination Challenge Prize looks for. MEDRC will award up to four Pathway Research Grants up to a maximum of USD 90,000 each in 2020. Applications will be evaluated and awarded based on their ability to show how innovations can lead to meeting the Challenge Prize criteria. Down-scaling existing large-scale reverse osmosis and electrodialysis technologies will not be considered innovative and so will not be awarded funding.

www.desalinationchallenge.com

Desalination as a climate change adaptation option

I. Desalination as adaptation option

Rising temperatures will put intense pressure on crops and already scarce water resources, potentially increasing migration and the risk of conflict. In order to cope with those impacts, adaptation will be required. Whereas climate change mitigation has a global focus, climate change adaptation needs careful tailored local planning.

One way in which policies can contribute to successful adaptation is by enhancing the overall capacity of people to adapt to climatic change. Measures that improve the socio-economic conditions of poorer people also improve the baseline capacity for people to autonomously cope and adapt to changes in their environment. Such measures can also reduce or mitigate conflicts by making resources available for conservation or substitution (imported or artificially generated, e. g. desalinated water) of scarce resources. Measures which increase the adaptive capacity of rural households include income generation schemes, insurance schemes for climatic risks such as drought or floods, or broader social security schemes and social.

Therefore, desalination plants and irrigation with properly treated wastewater are considered good climate change adaptation options, which will make up for the lack of natural water availability. But it is not restricted to that, we can also consider raise awareness about water scarcity to facilitate adoption of unconventional techniques such as water reuse and desalination, in parallel with improvement of infrastructure efficiency and reduction of consumption.

In addition, infrastructure investments that ensure the sustainable and fair distribution of water as well as water use efficiency are needed. Desalination plants using properly treated wastewater and taking care of environmental impacts may become a useful option for some case studies located in coastal regions (Gerstetter et al., 2012). In Spain for instance, to face climate change and its impacts on water resources, adaptation measures included increasing desalination capacity mainly in the southern areas where the agriculture activity is intensive and the water scarcity is acute.

On the other hand, adaptation measures may hinder mitigation, e. g., desalination or pumping of (ground) water for drinking water and irrigation purposes requires energy, possibly generated from fossil fuels. Increasing water use as a result of climate change leads to aggravating droughts that can trigger forest fires or wetland destruction leading to loss of stored carbon. Moreover, it may increase the demand for water, leading to a negative feedback of aggravating drought. Improved water management, in contrast, can improve agricultural practice, help to store carbon through forestation, maintain wetlands and reduce heat spells (UNECE, 2015).

Examples from the region include (Kloos et al., 2013):

- Coastal desalination – Adapting to water scarcity: Droughts in the 1990s, increased stress on aquifer resources and increased urban water use. Desalination plants are still in the process of being implemented, but are a policy-attempt to adapt to water scarcity in the region which could reduce water and therefore human insecurity;

- Red Sea Dead Sea Water Conveyance: The jointly managed rehabilitation of the dwindling state of the Dead Sea can mitigate cross border water scarcity crisis and increase multilateral cooperation. The multi-lateral project aims to construct a pipeline that would transport 1.8 billion cubic meters of water from the Red Sea to the Dead Sea. The freshwater obtained from the desalination plant would be used to augment the water supplies of Jordan, Israel and the Palestinian Territories. It is an ambitious infrastructure project to connect the Red Sea and the Dead Sea, in order to counteract the shrinking of the Dead Sea, produce additional drinking water by the means of desalination and produce energy through hydropower development;

- North-Western Sahara Aquifer System (NWSAS), shared by Algeria, Libya and Tunisia: Being located in an arid and semi-arid area, the NWSAS basin is threatened by climate change with a probable temperature rise between 2.5 to 4.5°C and an expected decrease in precipitation by 5 to 20 % by the end of the twenty-first century, as well as an increase in the occurrence of extreme events. The expected impacts of climate change are likely to increase the existing stress on the aquifer system. The Sahara and Sahel Observatory (OSS) supports the three countries in better understanding and managing the NWSAS groundwater resources. In this regard, OSS carried out demonstration activities in six pilot projects in the three countries from July 2010 to December 2013, with the objective of providing the NWSAS users and policymakers with efficient solutions for increasing water productivity while ensuring the efficiency of investments, the improvement of farmers' income and the conservation of the NWSAS basin. A set of techniques have been adopted, one of them is aimed to give value to alternative water resources through the desalination of brackish water (Medenine-Tunisia) and to make better use of geothermal water (El Hamma, Gabes, Tunisia). In all pilot projects, solutions for more efficient use of water were introduced, for example, localized irrigation systems combined with sustainable agricultural practices such as the introduction of adapted varieties and intercropping. The pilot projects were successful in showing that more water-efficient agriculture helps to reduce the risks of saltwater intrusion and salinization, loss of artesian pressure, the depletion of natural outlets and the lowering of the water table, while at the same time raising farmer incomes. The demonstration projects therefore made it possible to define "low-regret" adaptation measures that can be included in the strategic adaptation documents (NAPAs and National Adaptation Plans) developed by the countries sharing NWSAS (OSS, 2013).

II. Desalination in policies

When it comes to adaptation policies, they have not yet been properly developed at national level in the MENA region, while at the moment few national and local water management plans take climate change impacts adequately into account. The mix of existing approaches and instruments to address adaptation of water resources to climate change impacts and in particular to floods and droughts include a wide range of options from water demand and supply-side measures and proactive policies to engineered solutions, options provided by ecosystems' services and response to damage measures. Desalination is therefore an alternative of climate change adaptation on the supply side.

Desalination as a potential solution to water scarcity has been for long time controversial, because many policy makers and policy documents advocate this option while others show more skepticism and prefer other solutions. Since desalination is present in the water supply mix of an increasing number of countries, promoting the debate on its merits and problems not just from a technical point of view but including also social, geopolitical and environmental dimensions, is relevant and timely, and more so when the progression of large scale plants appears to depend on political factors.

During the last few years, desalination has appeared in several policies and strategy documents and recommendations at national, regional levels and even in Europe.

In 2012, for example, it was cited in a document on scenarios for the protection of water resources in Europe (Ad de Roo et al., 2012), the Joint Research Center of the European Union introduced a so-called desalination scenario under which the Water Exploitation Index or Environmental Flows (helping to satisfy the requirements of the water framework directive - WFD) showed noticeable improvements mainly in Spain and Italy. It estimates the effects of installing several desalination plants along the coastlines. Moreover, the European Union, who contributed substantially to fund Spanish desalination plants in the 2000s largely for environmental reasons but also internal geopolitical factors, continues to provide financial support for the construction of these plants.

Early in 2017 the largest desalination plant in the Gaza strip, funded by the EU, was inaugurated. It is also true. However, that desalination was not mentioned in the Water Framework Directive as an alternative and that other policy documents such as the Council of the European Union Conclusions on Sustainable Water Management (2016) emphasise water reuse above desalination.

Moreover, private participation in the MENA region began with desalination projects in the first decade of the 21st century, exemplified by emblematic programs such as the one developed by the government of Algeria and led by Sonatrach. Saudi Arabia seeks to increase the proportion of desalinated water produced by private operators between 16 – 52 % by 2020 and to expand drinking water and sewerage services by 42 – 70 % of its cities (Revolve, 2017).

The question now is how desalination can intersect with other alternatives to provide more just and sustainable water policies at all scales from local to global? Moreover, how does desalination relate to climate change discourses and policies both in mitigation and adaptation?

When it comes to climate change adaptation, among the measures which should be handled with care at the level of increasing supply is desalination, which may be legitimate if no other adaptation measures are feasible. However, we need to highlight the high energy consumption, adverse environmental effects, and low social acceptance as the downsides.

Desalination is rapidly ascending worldwide both as a source of freshwater and as an adaptation measure to climate change-related water stress. Although proponents of desalination are cautious about its potential to solve many of the water problems of the world, current technological advances, especially the decrease in energy costs; the possibility of using renewable sources; the improvement of membrane technologies, and new ways of disposing of brines thereby reducing environmental impacts, pave the way to perhaps the ultimate "technological fix" in water.

The brine is characterised by high salt concentration, hardness and containing heavy metals and chemical compounds used in the process (antiscalant, cleaning agent, etc.), and higher temperature than ambient (employed in thermal-based processes such as multi-stage flash distillation "MSF").

Figures on recent installed capacity around the world and on rates of expansion confirm the momentum of desalination and its promise to overcome the social, political, territorial and environmental problems of traditional hydraulic solutions and contribute to the emancipatory power of technology in ways that conventional solutions such as dams, reservoirs and water transfers are increasingly unable to achieve.

According to its proponents, desalination not only taps an inexhaustible resource but also has the potential of effectively removing water from political, territorial and ecological conflict. It is, therefore, an alternative with multiple "wins" and few losses at least in comparison to those of the more traditional alternatives. Thus desalination has been an option favoured by the EU at least in some member states which, as in the case of Spain, have received EU funding (more than USD 1.1 bn) for building desalination plants. Moreover, the EU also finances desalination plants in sensitive areas. In January 2017, for example, a large plant built with EU funds was inaugurated in the Gaza Strip.

While desalination occupies an expanding niche in water-related scientific and technical research, from a social science point of view it has not received much attention. However, interest on the social, political, geostrategic, and territorial dimensions of desalination is developing in a variety of geographical settings such as the MENA region; as well as several EU member states located in the Mediterranean basin (Spain, Malta, Cyprus, and Greece).

As a matter of fact, in several countries, such as the Gulf States, Spain or Israel, desalination constitutes a key pillar of water policy. From the early social science research on this topic research, a picture of desalination is beginning to emerge that challenges the favourable image presented by the more technical approaches. Beyond the concerns about energy costs and environmental impacts, issues that are being examined by social scientists are, for instance, the financing of desalination plants; the sometimes negative reactions of citizens to this new resource; the health dimensions of desalted water; the creation of relative scarcities given the higher costs with particular impacts on farmers and poor urban dwellers; the possibility of capturing cheaper water resources by mining or large agricultural companies; the perpetuation of the cornucopian imaginary (for those who can afford it) of plentiful resources making conservation needless; the geopolitical implications of strengthening through desalination; the reworking of the food-water-energy nexus in some regions of the world, the opportunities for capital investment after the exhaustion of other large water works, and the reinforcement of the attraction of people to coastal areas as well as the more well-known of environmental impacts (marine biota, higher carbon footprint if energy is derived from fossil fuel power plants).

On the other hand, desalination can eventually contribute to making treated wastewater drinkable again thus reversing water flows, which has profound implications in the architecture of hydro social cycles.

Regarding the more problematic aspects of desalination, high energy consumption is probably the main challenge. The choice between renewables, nuclear and fossil fuels will depend on technology and cost but also on the fact that desalination plants need a steady source of power which may not be guaranteed by renewables alone since the latter (solar, wind) tend to fluctuate according to meteorological conditions.

Hence, it is not surprising that the nexus desalination-renewable energy occupies a central place in much of the technical research on this resource. On the other hand, the environmental impacts of using fossil (carbon footprint) or nuclear (waste, among other problems) are pervasive and difficult to solve. At the same time, a great deal of research is devoted to increasing the efficiency of the desalination process to reduce energy requirements.

For example, the challenge of reducing energy consumption from 3 kWh/m^3 to 1 kWh/m^3 of water is targeted by the EU Innovation Action „NMP-24-2015 - Low-energy solutions for drinking water production“ (2013) under the Horizon 2020. One of the funded projects attempt to develop Electrodialysis (ED) to provide safe, affordable, and cost-competitive drinking water, using less than half the energy required by state-of-the-art brackish water RO plants.

Another funded project aims at Microbial Desalination Cells (MDC) to treat wastewater and generate energy for desalination. MDCs can produce around 1.8 kWh of bioelectricity from 1 m^3 of wastewater. Such energy can be directly used to remove the salt content in seawater without external energy input. The latter example also shows the synergies but also the competition between desalination and treated wastewater. That is said, MDC is still under development at lab-scale. Hence, the scale-up issue is needed even for more advanced processes in development such as pressure retarded osmosis (PRO) or reverse electrodialysis (RED), which could be coupled with conventional desalination processes (Amy et al., 2017, Ghaffour et al., 2015 and McGinnis et al., 2018). The PRO and RED technologies can harvest some of the chemical energy that is present in the highly concentrated brine that is left over from the RO. If managed properly, this type of integrated process can lead to an overall reduction in the energy required to desalinate water (Geise, 2018).

According to the Global Water Intelligence Unit, in 2010, overall water reuse from treated wastewater surpassed desalination and since 2013 demand for reuse with tertiary treatment stays ahead of desalination. However, water reuse is mostly addressed to agricultural, landscaping and environmental functions, and therefore, it does not represent a strict direct competitor for desalination.

When it comes to investments related to water infrastructure including desalination plants, it should be linked to vulnerability assessments as a prerequisite. So water infrastructure investments should be made “climate-proof”, i. e. it should be ensured that they will still be viable under changing climatic conditions (Martina Flörke et al., 2011).

As an example of regional strategies related to desalination, the 5+5 (including Algeria, Morocco, Tunisia, Libya and Mauritania from the MENA region) Western Mediterranean water strategy desalination highlighted as a technology offering a huge opportunity to mobilise resources in countries where chronic water scarcity strongly limits conventional resources availability. This strategy (EMWIS, 2015) insisted on the necessity of:

- Promoting the use of more efficient technologies that also minimize environmental impacts as well as the utilisation of renewable energies in the desalination plants;
- Encouraging the development of desalination programs from a legal and political scope;
- Allowing for private sector investments to adapt to the rapidly increasing demand.

III. Desalination for agriculture

One of the main challenges in MENA coastal agricultural areas is the growing salinity of groundwater, with water tables falling throughout the country because of seawater intrusion and the overexploitation of aquifers. This has pushed farmers in many countries such as in Oman, to use brackish water desalination to irrigate their crops.

Depending upon the desired quality of desalinated water, the running cost of chemicals and membranes is relatively low and costs of desalination can be regulated with the optimization of the seasonal crop water requirements. Moreover, inland desalination usually uses brackish water where salinity level (about 10,000 mg/L) is much lower than that of seawater; hence the cost of desalinating brackish water will be lower than that of seawater.

In spite of this development, the costs of desalinated water are still too high for the full use of this resource in irrigated agriculture, with the exception of intensive horticulture for high-value cash crops, such as vegetables and flowers (mainly in greenhouses), grown in coastal areas (where safe disposal is easier than in inland areas).

In Gulf countries, Kuwait uses 13 % of its desalination capacity for agriculture. Saudi Arabia uses only 0.5 % of its desalination capacity for agricultural purposes. Bahrain uses 0.4 %, Qatar 0.1 % (Al Jabri and Ahmed, 2017).

If we consider the example of Oman, due to the increased level of soil and water salinization along Al-Batinah region coast, an increasing number of farmers are using small-scale desalination units for producing irrigation water. Desalination technology remains still an expensive option for agriculture, and it has environmental challenges that includes energy requirements, water quality, and disposal means of rejected brine which end up in many cases by contaminating groundwater and increasing its salinity. However, it can still be an attractive option for sustainable agriculture if used within specific constraints.

Desalination remains an excellent technical option to increase the availability of freshwater both in coastal areas with limited resources and in areas where brackish waters – such as saline groundwater, drainage water and treated wastewater – are available. Greenhouse and hydroponic farmers are beginning to use RO to desalinate and purify irrigation water for greenhouse use (the RO product water tends to be lower in bacteria and nematodes, which also helps to control plant diseases). Small RO plants have been built in rural areas where there is no other water supply option. An increasing number of Omani farmers are changing the irrigation water supply from a contaminated surface water canal source to an RO-desalinated brackish groundwater source.

If we consider the example of Spain, it provides a significant example of the application of desalinated water in irrigation. Spain has more than 300 treatment plants (about 40 % of the total number of existing plants) and 22.4 % of the total desalinated water is used for agriculture. Most of these plants process brackish water (only 10 % of the total desalinated water for agriculture originates from seawater) and are located in coastal areas or within 60 km of the sea (FAO, 2004). In this country, small and medium-sized brackish-water desalination plants, with a capacity of less than 1,000 m^3/d, are common because they adapt better to individual farmer requirements and to the existing hydraulic structures.

There is no exclusive use of desalinated water for irrigation. Spanish farmers mix it with low-quality surface and groundwater in efforts to reduce the cost of desalination. Farmers own the desalination plants and their agriculture is practices within their organised societies to compete with local and international markets. The Spanish government has clear institutional framework that defines the use of desalination for agriculture. Farmers in Spain are able to maximize net returns through well-defined marketing schemes. On the contrary, farmers in Oman use small size desalination units to sustain low-income field crops.

Most of inland desalination plants (80 %) in Oman are RO type of small capacities (below 10,000 m^3/d). More than 50 % are desalinating brackish water or inland water (TDS 3,000 mg/L – <20,000 mg/L) (GWI, 2018).

Part of Omani farmers have greenhouses where "classical" crops, such as cucumber and tomatoes, are grown. With such low-income field crops, that indicates that they are not business oriented and most farms are meant to sustain existing agricultural practices among other purposes. Upon securing a new source of fresh water, farmers moved forward to add more facilities to their farms; mainly residential buildings (small resorts and / or swimming pools) or animal-raising facilities (Al Jabri et al., 2019).

The cost of desalination from small-size units in Oman (without electricity subsidy = USD 0.65/m^3) is 63 % more expensive than what farmers are paying in Spain (USD 0.40/m^3). Moreover, farmers in the Sultanate pay more for the water "bill" due to the fact that crop water requirements are higher than that of Spain for the surveyed crops (22,000 versus 5,600 m^3/ha. y). While all farmers in Spain mix the desalinated water with other sources of low -quality water, 78 % of surveyed farmers by Al Jabri and his team (Al Jabri et al., 2019) in Oman use purely desalinated water to irrigate low-income-value crops. All these factors contribute to make farming using desalinated water much less profitable than in Spain. Moreover, Spain uses medium-size central desalination plant with high recovery rates compared to low rates from small units that are used in Oman. The "economy of scale" and high recovery rates greatly reduce the cost of desalination. The economic analysis shows that, depending on unit size, the cost of desalination ranges between USD 0.46 – 1.32/m^3 with an average of USD 0.55/m^3. (Al Jabri et al., 2019).

One option to reduce the costs of desalination for agriculture associated with desalination for agriculture is to mix desalinated water with less low-quality groundwater and follow certain irrigation deficit schemes to irrigate high-value crops.

The cost of desalination of brackish water for agriculture in Spain is optimized through the utilization of pricing schemes for energy. Spain has six pricing schemes depending on time of the day, week, and year. They operate their desalination plants during the low-demand periods that correspond to the lowest price scheme. Furthermore, costs in Spain are reduced further by mixing desalinated water with other sources of water, such as low-quality surface and ground waters. Energy-pricing schemes do not exist in the Arabian Gulf countries, where the cost is fixed. Furthermore, energy is subsidized in Oman and farmers pay only 30 % of the original (total) cost (Zekri et al., 2014).

On the other hand, using seawater desalination for irrigation of rentable crops as tomato and berries and other vegetables crops could be a judicious solution to continue producing horticultural products and saving water.

Pumping cost for example in Souss Massa region in Morocco is about USD 0.3, and the average desalination cost is equal to USD 0.5 with a little change depending on desalination (Hirich et al., 2016). Half of the capacity of Agadir desalination plant in construction now will be used to respond to Souss Massa region needs of irrigation water. However, this is seawater desalination and not brackish water desalination.

Brackish water desalination is also used in Tunisia in some regions to improve the water quality of irrigation water. This is the case for example in Mahdia. In 2016 authorities set up a pilot project for a desalination unit for agriculture in Mahdia.

The EU-funded project aimed at reducing the salinity from 5.8 g/L to 0.2 g/L. Equipped with a 600 m^3

water reservoir, the USD 5 M project is used by 60 farmers to irrigate greenhouse crops. The project is capable of irrigating three times more land volume than traditional drip methods.

The assessment of the appropriateness of desalination for agriculture should be based on the net economic returns of agricultural products as well as environmental costs.

Therefore, the feasibility of the technology for agriculture in Oman should be explored on such concerns. In an international workshop on desalination for agriculture held in Oman in 2018 (OWS, 2018), it was recommended to the farmers to set up joint central desalination plants to provide water for agriculture according to the hydrological characteristics of groundwater aquifers to reduce energy consumption, O&M costs and optimize the management of return water, through cooperation between farmers and the private sector to build these plants by design, build, operate and own system and push for increased use of treated water in agriculture, and facilitate this for farmers while taking into consideration tariff reduction.

Among the recommendations also, to start introducing industries based on wastewater from desalination plants (high saline) as they are critical to minimising environmental impacts and safe disposal of the brine, as well as their economic benefits. It was also recommended to prepare a public database available to researchers and decision-makers that includes all data related to the number of agricultural desalination units, their capacities, sites and agricultural products produced and their efficiency and their disposal of the brine (OWS, 2018).

IV. Public-private partnership (PPP) in desalination projects

The involvement of the private sector in providing freshwater has proven to be a successful approach, able to provide the necessary capital, networks, technology, experience and human resources. Public–private partnerships (PPPs) have been much discussed during the last decade in the MENA region and worldwide, mainly its aspects related to the institutional and regulatory frameworks for private investment, market risk, off-taker risk, tariff structure and desalinated water charging, construction / technical / operational risk, financing structure, credit enhancements, environmental risk, etc.

The need for a market-based economy and an expanded role of regional banks has also been raised. Nowadays, many countries rely on the private sector for additional funding in investment projects.

Desalination projects are procured using different types of delivery models. These models vary depending on whether project financing is a public agency or involves a private entity. Other factors that can affect the choice of procurement model are project location, the size of the plant, the project risk profile, owner's experience with similar projects, the client, and the source of project funding – loans, grants, bonds, equity or a mixture of these funding sources. The main project delivery models are:

- Plant purchase: The client uses this delivery model when it wants to purchase the plant and retain ownership of the facility. This category includes engineering, procurement and construction (EPC), design-build (DB) and design-bid-build (DBB) delivery models. For all these models, typically the client appoints an engineer to prepare drawings and project specifications, which are then put out to bid to a contractor for construction. The client pays for the project during the construction period and takes responsibility for operations;
- Design-build-operate (DBO): The client requiring the desalination plant tenders both construction and operating and maintenance (O&M) contracts as a single package. Typically the two contracts of EPC and O&M are signed separately, and in some cases, responsibilities on the two contracts can be split between different members of the bidding consortium;
- Build-operate-transfer (BOT): This type of delivery model involves the participation of a private project development company in the project, which owns the assets. Other names for this delivery model, but with the same basic arrangements, are design-build-own-operate-transfer (DBOOT) and build-own-operate-transfer (BOOT). In all of these models, the assets are to be transferred to the client at the end of the contract period, which spans on average 20 years;
- Build-own-operate (BOO): This model is similar to BOT but without asset transfer. Independent water projects (IWP) are included in this category;
- Independent water and power projects (IWPP): This is basically a BOT contract type, which refers to the procurement of combined desalination and power projects. IWPP contracts are typically adopted in the Gulf region.

The main contract models used up today are: EPC, DBO (Design-build-operate) and BOOT (Build-operate-transfer). Other variants are DBB, Construction Manager at Risk and Alliance.

The build own operate transfer (BOOT) project delivery method has become the preferred method for municipalities and public utilities worldwide as it allows cost-effective transfer to the private sector of the risks associated with the costs of desalinated water. Some of these risks include: predicting plant performance due to variable intake-water quality; permitting challenges; startup and commissioning; fast-changing membrane technology and equipment market; and limited public-sector experience with the operation of extensive seawater desalination facilities (Voutchkov, 2004).

However, there are infrastructure constraints on the application of PPPs. For instance, desalination normally requires long-distance transport of desalinated water to its site of use. Furthermore, there are institutional constraints that need to be addressed in concert with PPPs, such as establishing a water pricing policy and incentives, investment in research and development, and integrated water resources management.

Other constraints relate to the public perception of private-sector involvement in PPPs. Public concerns regard potential price increases, inappropriate business practices, and insufficient information dissemination. The effect of water quality on socioeconomic growth has not been well quantified, and human resources and related organisations are still at a nascent stage.

All the above issues pose current challenges to the sustainable application of desalination for supplying both potable water and irrigation water. However, we can mention some successful case studies such as Agadir desalination plant in Morocco (Box 2).

Box 2

Agadir desalination plant, Morocco

The Agadir desalination project is part of Spanish operator Abengoa's strategic plan to solve water supply problems in those parts of the world most affected by water shortages. Moreover, it will be the largest capacity desalination plant in the region. A total of USD 92 M in financing has been arranged with a consortium of local banks led by Banque Marocaine du Commerce Extérieur (BMCE),

ensuring a high degree of integration and participation with the local business and financial sector. Furthermore, this is the first project that the National Power and Drinking Water Office (ONEE) has developed under a public-private partnership (PPP) system, putting Abengoa at the forefront of this model in Morocco.

The project is valued at USD 0.41 bn in its two components (drinking water and farm water) and ultimately aims to secure the drinking water supply of the Grand Agadir region and provide water for high value-added irrigated agriculture in the Chtouka area.

Overall, the project involves the construction of a desalination plant with a 275,000 m^3/d total production capacity, which will make it the most significant plant designed for drinking water and irrigation. The contract signed provides for the possible capacity expansion to up to 450,000 m^3/d.

In addition to the initial USD 0.27 bn investment for the drinking water component of the desalination plant, ONEE will dedicate additional investments of USD 62 M to: the installation of 44 km of pipes, the construction of a drinking water tank with a capacity of 35,000 m^3, the installation of three high voltage power lines measuring over 55 km from the source station of Tiznit to the solar complex Noor Ouarzazate, and the construction of two pumping stations and two loading tanks.

For the drinking water component, the seawater desalination project is expected to secure the supply of drinking water for 2.3 million inhabitants by 2030, 20 % of whom live in rural areas.

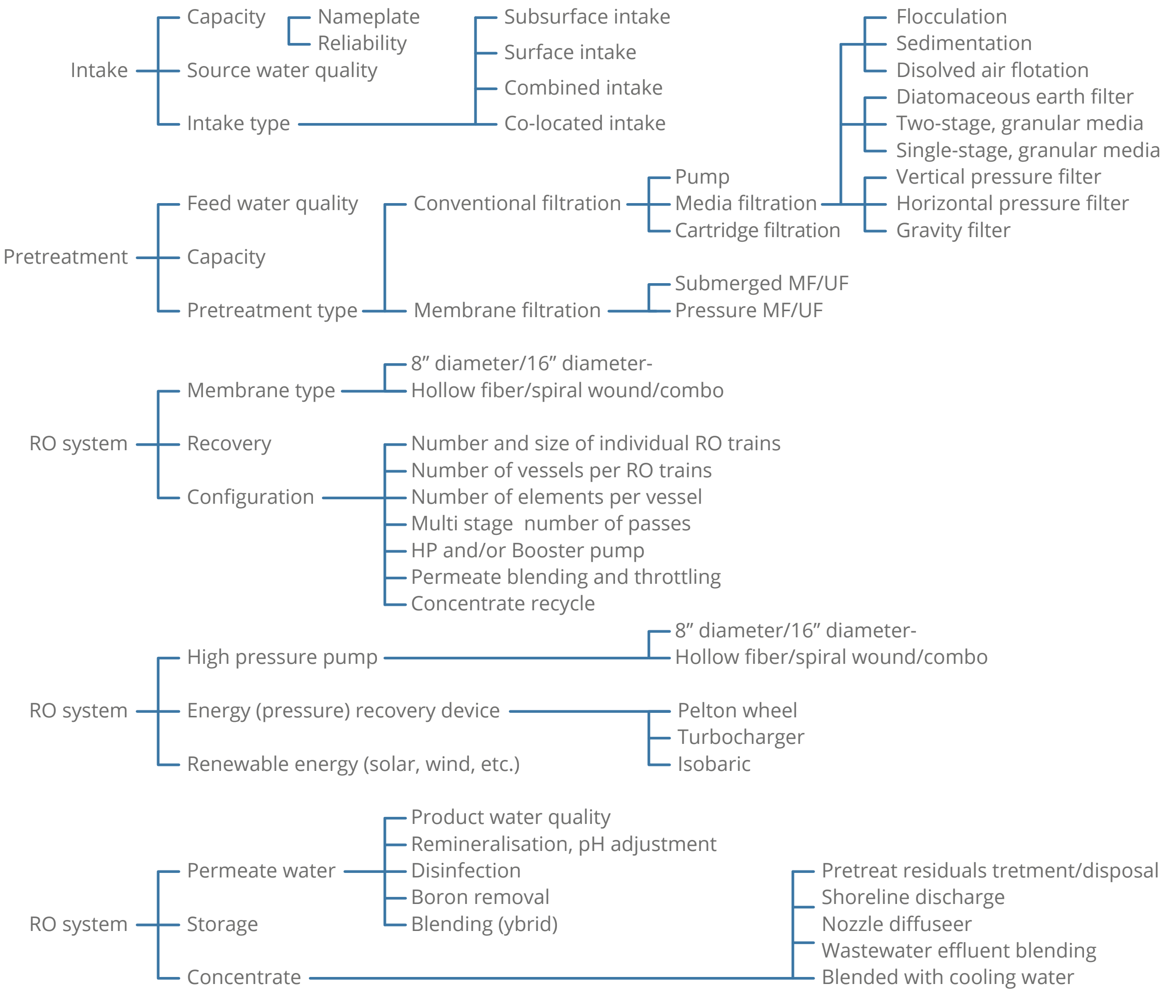
The implementation site has been chosen to allow a zero impact. The infrastructure has been designed to control the brine disposal through the use of modern technology. Marine cartography and mapping have been applied to minimize the impacts and risks as much as possible.

This large-scale project also presents the potential of being operated by wind power to meet the demand for water for domestic use, in addition to irrigation water needs in the Agadir area. At the same time, the project will contribute to the development of the region’s main economic drivers, the agricultural and tourism sectors, and the conservation of local aquifers, therefore preventing their over-exploitation.

V. Desalination costing

Experts usually talk about the different desalination processes, their pros and cons, the innovative technology, the desalination capacities. However, it's rare to find those who discuss detailed cost indicators that could allow a real benchmarking of the real cost of desalination projects overall the world. Researchers and scientists are starting to work on this critical issue to be able to trace and analyse the cost of this broad field taking into account so many parameters.

Figure 24: Seawater desalination whole elements



Source: Pankratz 2015

Desalination costs have decreased by more than half over the last 25 years thanks to improvements in technology and energy efficiency. The cost of producing 1 m^3 of treated water currently ranges from USD 0.5 to USD 0.9. Saudi Arabia and the UAE are among the cheapest places to desalinate water, given their comparatively low energy prices and the economies of scale at their large facilities. Increased use of renewable energies to run the desalination process may make it even cheaper. In fact, Dubai Electricity & Water reported in 2020 a \$0.306/m^3 water cost for 545,000 m^3/d Hassyan SWRO when online in 2023. This is world’s lowest water levelized tariff so far.

The overall cost of desalination can be divided mainly into investment or capital cost (CAPEX) and maintenance-operation cost (OPEX).

CAPEX involves land, edifices and equipment, as well as transportation cost, insurance, construction, legal fees and unforeseen costs, while OPEX is divided into energy cost, maintenance, repairs, personnel/staff, spare parts, and reconstruction when required.

If we want to go deeper in analysing the CAPEX and OPEX, we need to understand each part and a single component of the process. In the case of RO, for instance, we need to consider the different factors intervening during the intake, pretreatment, RO system, energy saving and the post-treatment (Figure 24).

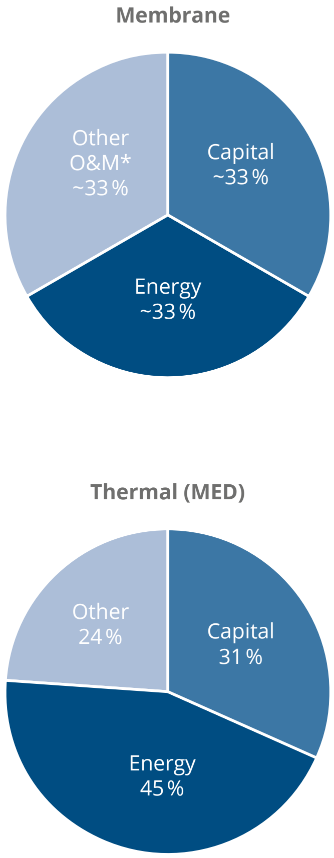
The current RO desalination is expensive because of the high energy requirements for equipment, such as pumps, and piping, as well as intake, pretreatment, outfall and pressure vessel desalination stages. Hence, Mr. on-going R&D is continuing for RO desalination, especially for seawater and brackish water sources. These on-going research efforts for brackish water and seawater RO desalination are important to increase potable water source diversification and availability, as well as potentially decrease water costs.

Energy cost is the highest contributor to operating cost and thus to the overall cost and this is valid for thermal and membrane desalination processes (Figure 25). In many cases, energy cost can reach almost 60 % of the OPEX.

A comparison of the total cost of the RO and MSF technologies is given in Table 14 (Al-Karaghouli, 2011).

The critical factors that influence policy / decision makers for appropriate technology selection are the total investment and produced water costs, the type of project contract, and other parameters such

Figure 25: Distribution of costs in both membrane and thermal desalination processes



* Membrane replacement, chemicals, labor maintenance

Source: MEDRC training material

Table 14: Cost percentage in conventional RO and multi-stage flash distillation (MSF) of the same capacity in Libya

Desalination technology	RO (membrane)	MSF (thermal)
Investment cost	31	42
Energy cost	26	41
Maintenance and repair cost	14	8
Membrane replacement cost	13	0
Personnel cost	9	7
Chemicals cost	7	2

as local incentives or subsidies (Khan et al., 2017). Desalinated water costs per m^3 can be substantially impacted by several factors like capacity and type of desalination plant, feed water (seawater or brackish water) and labour, location, and type of energy used whether conventional or renewable energy (Karagiannis et al., 2008 and Alkaisi et al., 2017). For example, phase change desalination processes that use traditional sources of fuel and energy generally have large production capacities and are very expensive compared to membrane plants due to the requirement of large quantities of fuel for vaporising saltwater. In the instance of the Ashkelon SWRO plant, the overall fresh water cost was US USD 0.52/m^3 (Water Technology Net. 2011). Similarly, membrane methods are more cost effective for brackish water desalination (Ullah and Rasul, 2018).

There is no global standard for reporting desalinated water costs, and a direct comparison is often meaningless. The scope and all technical and commercial aspects of the projects must be considered. The Global Water Intelligence (GWI) did an effort through their portal desaldata.com where they have a tool called "cost estimator" which gives an estimation of the CAPEX, OPEX and the cost per m^3 once we introduce some inputs such as the type of energy, capacity, location, etc. See an example of the interface in Figures 26a, b, c: As it is the case for costing software, there is no transparency in the methodologies used for cost estimations.

For comparing the cost between the different options, the reference value for the water production cost in the case of conventional desalination can be assumed equal to USD 1/m^3 for medium to small size desalination processes connected to the grid. The desalination system typically used in a stand-alone configuration is an RO process coupled with a diesel-powered generator; due to the additional charges for transporting and fuel storage, the water production cost can rise up to USD 1.5 /m^3. While in the case of solar (PV) coupled with RO, the water production cost is USD 2/m^3, and for MED/SGSP (solar-powered multi-effect evaporation/Thermal desalination by salinity-gradient solar ponds), the water production cost is USD 1.5/m^3.

Continued innovations will reduce the cost of MED and RO desalination. While desalination is a relatively small market for CSP, CSP can meet the large and growing energy demand. The cost of CSP desalination likely will decrease in response to technical innovation, new materials, and efficiency improvements, just as desalination did when RO was first introduced.

For MSF (Multi-Stage Flash) desalination, CSP energy source is not economically competitive due to

Figure 26a: Seawater desalination costing: CAPEX breakdown

Technology	SWRO
Capacity m^3/d	1000000
Seawater	40,000 mg/L
Seawater Min. Temp.	15°C
Seawater Max. Temp.	24°C
Pretreatment	Difficult
Second Pass	50 %
Remineralisation	Yes
Intake / Outtake	Onerous
Permitting	Onerous
Country	Oman

Basic Capex	$120,790,579
Basic Capex / Capacity	$1,208/m^3

Adjusted Capex	$202,109,817
Adjusted Capex / Capacity	$2,021/m^3

Delivery Time Estimate	104 weeks

Factors	**Basic ($)**	**Adjusted ($)**
Pretreatment	10,267,199	32,855,038
Civil costs	21,440,328	21,440,328
Pumps	10,395,105	11,642,518
Equipment and materials	26,875,904	32,519,844
Design costs	6,945,458	34,727,292
Legal and professional	1,207,906	6,039,529
Installation services	9,663,246	9,663,246
Membranes	6,341,505	7,102,485
Pressure vessels	1,811,859	2,029.282
Piping, High-grade alloy	15,702,775	15,702,775
Intake / Outtake	9,059,293	21,177,880
Energy Recovery Devices	1,080,000	1,209,600
Total	**120,790.579**	**202,109,817**

Source: GWI 2018

Figure 26b: Seawater desalination costing: OPEX breakdown

Capacity (m^3/d, set in Capex	100000
Country (set in Capex)	Oman
Annual production (m^3)	34,675,000
Utilisation rate (%)	95
Energy consumption (kWh/m^3)	3.5
Electricity price ($/kWh)	0.025
Labour factor	Determined by country

Factors	**Basic ($)**	**Adjusted ($)**
Parts	1,040,250	1,040,250
Chemicals	2,427,250	2,427,250
Labour	3,011,459	2,710,313
Membranes	1,040,250	1,040,250
Electrical energy	9,709,000	3,034,063
Total	**17,228,209**	**10,252,125**

Source: GWI 2018

Figure 26c: Seawater desalination costing: water cost per m^3

Capacity (m^3/d, set in Capex	100,000
Electricity price ($/kWh, set in Opex)	0.08
Utilisation rate (set in Opex)	95
Interest rate (%)	6
Equity Yield (%)	12
Loan repayment (years)	20
Debt equity split (%)	75

Factors	Value($/$m^3$)
Total capital cost and armotisation	0.58
Total variable costs	0.022
Energy costs	0.09
Labour	0.08
Overheads	0.05
Water Price	**0.92**

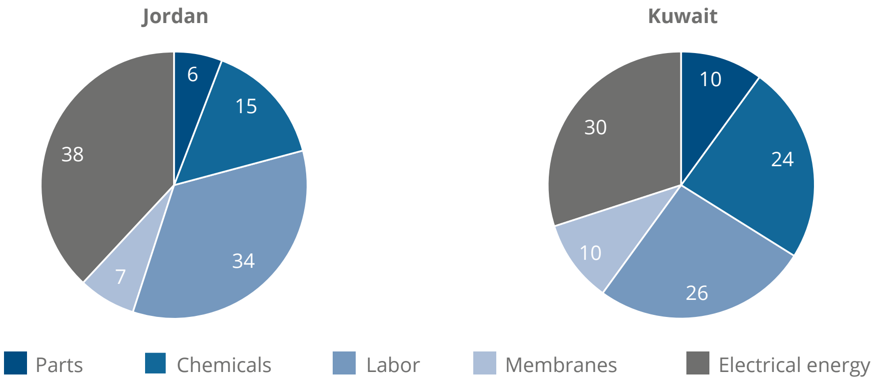
Source: GWI 2018

high capital costs for both energy and desalination technologies. It should be noted that CSP systems costs incorporate the costs of thermal storage capacity for up to 6 hours. This leads to capital costs of USD 6,300/kWe and USD 5,700/kWe for CSP parabolic trough and CSP tower, respectively (Bitar and Ahmad, 2017).

According to the International Desalination Association (IDA), Suez and Veolia Group of France and Doosan Heavy Industries & Construction Co. of South Korea are the biggest builders of installed capacity.

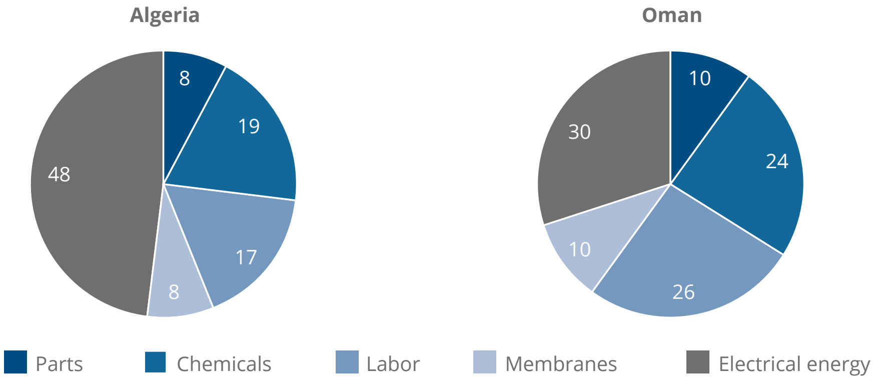
In Figure 27, we show comparisons of operational cost distribution between Jordan and Kuwait from a simulation using DesalData Costing model. As expected, energy and labour is more expensive in Jordan than in Kuwait. A similar comparison is carried out between Oman and Algeria in Figure 28. Operational costs of energy are costing more in Algeria than in Oman.

Figure 27: Detailed OPEX for Jordan and Kuwait respectively



Source: Desaldata/GWI

Figure 28: Detailed OPEX for Algeria and Oman respectively



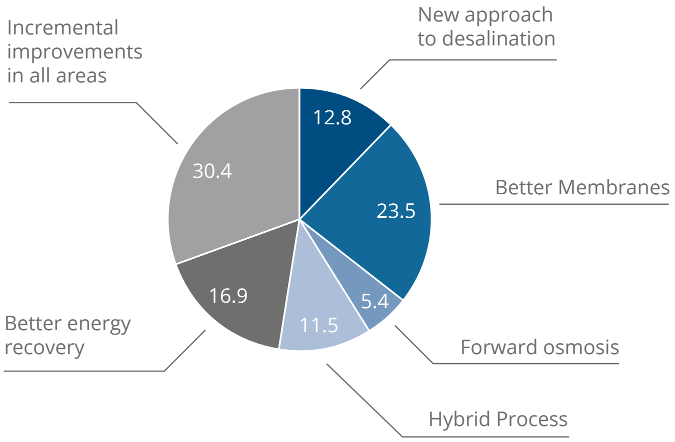
Source: Desaldata/GWI

The above graph combines capital and operating costs for a plant having a capacity of 100,000 m³/d for different countries in the MENA region. The four diagrams give us an idea about the detailed distribution of the average OPEX price in different countries. Our samples were taken from Jordan, Kuwait, Algeria and Oman in which the price varies according to the different parameters mainly the electrical energy, the parts, the chemicals used, the labour needed as well as the membranes. These

Table 15: Cost percentage in conventional RO and multi-stage flash distillation (MSF) of the same capacity in Libya

	MED	**RO**
CSP	› Continuous operation with storage, power production not considered, the cost for heat are related to system costs › Continuous operation, heat considered as free of charge	› Continuous operation with electrical power production and storage
PV		› 24h operation on grid back up › 24h operation off-grid battery storage › 7h operation off-grid small battery
Wind		› Off-grid discontinuous operation › 24h operation 12 to 24 % coverage by wind 88 to 76 % by grid

Figure 29: The future potential sources of decreasing desalination cost



Source: Pankratz 2015

diagrams confirm what we previously mentioned concerning the energy cost in oil-producing countries like Oman and Kuwait. The energy does not exceed 30 % of the total OPEX in Oman and Kuwait whereas it gradually increases in other countries to reach 38 % in Jordan and 48 % in Algeria.

Table 15 shows a comparison of 250 m^3/d plants in the case of renewable desalination.

To reduce the cost of sea water desalination, there is still a margin of improvement (Figure 29).

The reduction of desalination cost could take a form of:

- new desalination approaches (e. g. FO);
- better membranes such as graphene membranes (Abraham et al., 2017), carbon nanotubes, nanomaterials;
- Better energy recovery devices (e. g. Energy Recovery Inc. "ERI" is already of great efficiency);
- Incremental improvements in all areas.

Desalination impacts

I. Desalination and water security

In the MENA region, the dominant public discourse on water politics holds that water scarcities are of great, if often under-recognised, geopolitical importance. Pessimists and optimists alike tend to assume that water has, or soon will have, profound geopolitical implications. However, some experts such as Selby (2006) considers it a question of political economy; that water is structurally insignificant within the political economy of the modern MENA region; that in consequence water is generally unimportant as a source of inter-state conflict and co-operation; and that, notwithstanding this, water supplies are a crucial site and cause of local conflicts in many parts of the region. Hence, given the worsening state of economic development within the region, these local conflict dynamics are likely to further deteriorate.

In the last decade, many voices raised to talk about future water wars or at least very severe conflicts over water between states, mainly in the MENA region because of the shared water resources or what we call transboundary water resources. Therefore, cooperation or what we call water diplomacy was promoted as concept to avoid such wars or conflicts. But also we need to highlight that it is much cheaper to invest in more efficient water use systems, desalination technologies and the import of virtual water than to fight over water.

Transboundary water agreements and cooperation can act as a catalyst for development and stability. An example from the MENA region is the memorandum of understanding outlining pilot regional water-sharing initiatives signed between Israel, Jordan, and the Palestinian Authority. These include a desalination plant in Aqaba, Jordan, where the water produced will be shared with Israel, increased releases to Jordan from Israel's Sea of Galilee, and the sale of water from Israel to the Palestinian Authority. This agreement was facilitated by the World Bank, again highlighting the contribution that international organizations and donors can make in playing a constructive third party role and promoting cooperative transboundary water management as a tool for stability and prosperity.

Moreover, water security can both contribute to fragility and to stability and should therefore be considered as an integral part of broader strategies for escaping fragility. Ensuring water security in this region will necessarily rely in part of it on desalination to produce enough quantity of water for the needs of the population and the economic activities.

If we consider the case of Cape Town, which suffered from a severe water shortage last years. In fact, over the past four years the Western Cape Province was in the midst of the worst drought on record. One of the immediate measures taken by the water authorities was investing in more small desalination plants. The recently-installed desalination plants installed at Strandfontein, Monwabisi and the V&A Waterfront are the latest investments by the City of Cape Town to boost its potable water supply in the face of what's now not only the City's worst drought on record, but a national disaster. There's widespread consensus amongst both water technology specialists and municipal planners that a desalination mega plant is among the most viable long-term options for ensuring the City's long-term water security.

Other cities across the world – in Australia, Israel, elsewhere in the Middle East and the GCC – that have invested in desalination technologies to overcome similar supply challenges provide a model of how it should best be implemented. These plants don't get mothballed, even during periods of abundant rainfall. Critics might question this logic, citing the higher unit cost of desalinated water versus conventional potable water treatment should compel us to use desalinated water only during periods where conventional treatment cannot deliver the required volume of water. But it's precisely by keeping desalination plants running, constantly, that we can continually optimize their efficiency and thus operating costs – across energy; chemi-cals, equipment and other consumables; and plant and equipment processes – enabling a lower total cost of ownership and per unit cost of water. That's how today's leading large-scale desalination projects have been able to drive down the costs of desalinated potable water to even less than USD 1 per cubic metre – a price that's competitive with medium-term financial forecasts for many municipalities.

II. Energy Requirements & Carbon Footprint of Current Systems

In the climate change literature, mitigation refers to efforts to reduce greenhouse gas emissions, while adaptation refers to strategies to deal with climate change impacts. Adaptation and mitigation initiatives push for sustainable desalination alternatives able to produce minimal or negligible quantities of CO_2 to prevent climate change conditions. However, desalination is an example of conflict between mitigation and adaptation measures, as it is still the most energy intensive water treatment method and as most countries still power their desalination plants with fossil fuel. The energy required to desalinate water varies depending upon the technology used and system details, as well as the salinity of the water, is desalinated.

Desalination is an alluring adaptation strategy as it could provide a reliable, drought-resistant water supply to many coastal areas in the MENA region and the GCC. Desalination also has the potential to offer improved water quality compared to existing sources. In some MENA countries such as Libya, desalination offer better supply option than water transfer at least in terms of cost, because importing water to the northern areas of Libya from the southern oasis requires a great amount of energy, decreasing the total amount of water imported to the region could reduce the amount of energy used for water supply, thereby reducing corresponding GHG emissions.

That is said, replacing water transfers (mainly long distance transfers) does not guarantee a reduction in GHG emissions because desalination plants are also energy intensive. In addition, some desalination plants argue that they are not required to mitigate emissions associated with their energy use because they are not directly emitting GHGs (Kelly, 2011).

Electricity and heat generation accounts for about 25 percent of global emissions (IPCC 2014). Mitigation opportunities include replacing fossil-based electricity supplies with renewable sources and electrification, and reducing demand from end-consumers in the transport, industry, and building sectors, and from desalination plants.

RO technologies Current state-of-the-art RO plants for desalinating seawater may consume approximately 3.5 kWh/m^3 when all unit operations of the overall system are considered, and they were found to have lower CO_2 emissions than thermal desalination technologies as the estimated carbon footprint of seawater RO desalination (0.4 – 6.7 kg CO_2 eq/m^3) is generally larger than brackish water RO desalination (0.4 – 2.5 kg CO_2 eq/m^3) and water reuse systems (0.1 – 2.4 kg CO_2 eq/m^3). The variation of such values is due to: location, technologies, life cycle stages, parameters considered, and estimation tools, which were identified as major challenges to making accurate comparisons. Carbon footprint estimation tools could be more precise if we separate emissions by unit process, direct and indirect emissions, and if we consider the offset potential of various resource recovery strategies (Cornejo et al. 2014).

The direct carbon footprint of a desalination plant will depend upon the source of energy that drives it, in addition to the efficiency of the plant. As in most industries, desalination plants produce indirect greenhouse gas (GHG) emissions as well.

Fossil fuel-powered desalination plants have environmental impacts related to the emission of GHG or other pollutants associated with power generation (Einav et al. 2002), contributing to temperature increases due to the greenhouse phenomenon (Malla 2009).

According to Voutchkov (2008), the desalination unit carbon footprint is the quantity of CO_2 that is emitted in the atmosphere by electricity generating sources that provide the needed electricity for plant operation. Carbon footprint is usually calculated in tons of CO_2 per year. The total carbon footprint of the desalination plants depends on two basic factors:

- quantity of electricity used up by the plants for operation; and
- the emission factor of the specific power plants supplying desalination plants with electricity (Laspidou et al., 2012).

As a fraction of the world's energy consumption and GHG emissions, desalination is relatively small and estimated to be less than 0.2 % of global energy consumption in 2013. With RO, about 2.1 – 3.6 kg CO_2 are produced per m^3 of freshwater, depending strongly on the fuel used to produce the electricity (Lienhard et al., 2016).

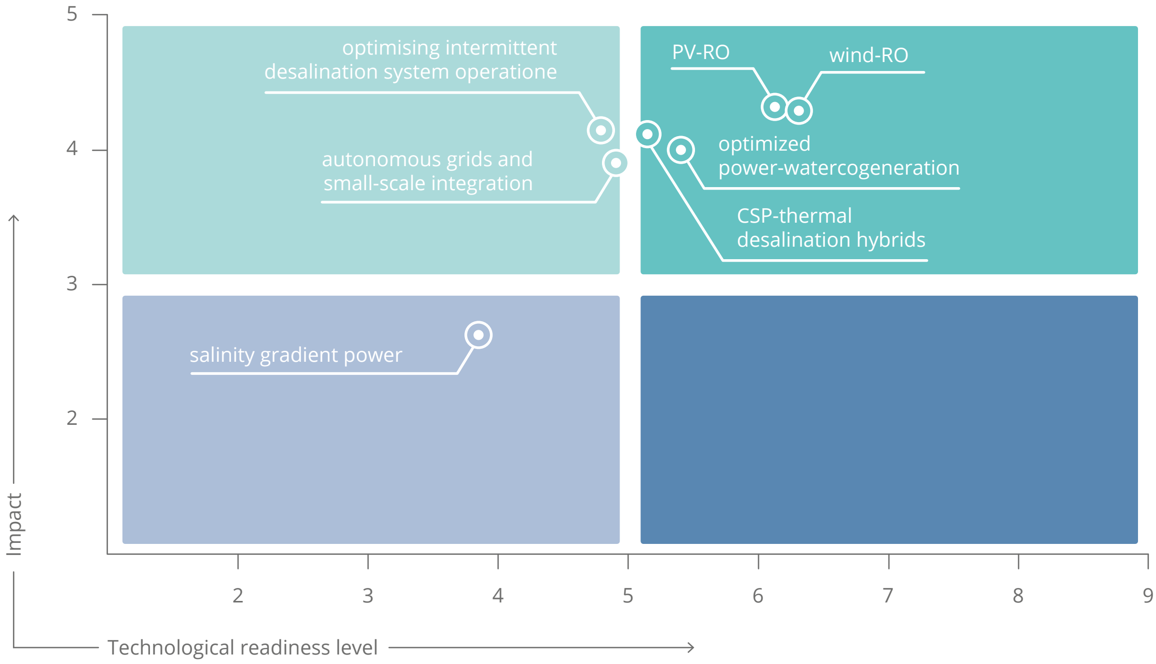
To reduce that negative impact associated with GHG, we need innovation breakthroughs. Some of the possibilities are: to couple desalination plants with carbon-free or low-carbon power sources such as solar, wind, or nuclear power plants, which could make it possible to gain the benefits of clean water without the climate impact.

However, some of these renewable energies do not deliver power continuously, and some types of desalination technology such as RO encounter difficulties when their operation is not steady.

In terms of GHG impact versus Technology Readiness Level (TRL) for several low carbon desalination systems, four areas were ranked high Technology Readiness Level (TRL), high impact (Figure 30).

1. PV-RO,
2. Wind-RO,
3. CSP-thermal desalination hybrids, and
4. Optimised power-water cogeneration.

Figure 30: GHG impact versus Technology Readiness Level (TRL) for several low carbon desalination systems



Source: Lienhard et al. 2016

Indirectly coupled arrangements or PV- and wind-RO were viewed as higher TRL than directly coupled arrangements (Lienhard et al., 2016).

It is obvious that when it comes to water supply in such scarce water region, we need more than any time to adapt our operations to prepare for a changing climate, reduce our own impacts through lowering our greenhouse emissions and generating more renewable energy. In fact, we need to adapt to less rainfall by harnessing alternative water sources like desalination, storm water and recycled water, and conducting controlled burns to protect water supply catchments from bushfires.

On the other hand, brackish water has less salt than seawater, so brackish water desalination most used for agriculture in some MENA countries requires less energy, and thus results in less GHG emissions than seawater desalination. It can be used also with recycled water recharge of underground aquifers.

In practice, the decision makers in the region should make it obligatory to prepare a GHG inventory for all aspects of the region's existing and planned water supply systems, including as much detailed and quantitative data as is feasible given time, expertise, and financial resources. Such an inventory could lead to a sort of guidelines that state which water supply technologies are lower-emission alternatives and which ones should be given the preference. This should lead to promoting further renewable desalination.

In addition, an effective climate change adaptation approach will require strategies to reduce GHG emissions, and consequently encouraging more renewable desalination.

III. Environmental impact

Desalination plants have been developed to deal with water shortage problems in the world. Therefore, desalination could hold the key for new freshwater resources. However, some argue against building desalination plants on the grounds of environmental impacts to the surrounding areas, especially to marine life due to the high concentrated brine discharge that diffuses back into the ocean. The impacts of the brine discharge are due to the high level of salinity, chemicals and total alkalinity and alteration to the temperature.

These impacts could be considerable in terms of the influence on the marine organisms such as the development of species, survival of larva and breeding and reproductive traits.

In fact, the brine discharged by desalination plants contains twice the salt concentration of seawater and does not contain oxygen, discharging it into the sea / ocean causes it to sink and spread along the sea/ocean floor, where it can have a devastating impact on benthic ecosystems, including the suffocation of fish eggs and other marine organisms that inhabit this region (EFD group, 2017). The delicate ecosystems on the ocean floor can be suffocated by the negative environmental impact of brine, resulting in a potentially disastrous environment for marine life and what is known as “kill zones” or “dead zones.”

Even if desalination production costs have decreased in the last decade, those related to the disposal of the brine have shown an only limited reduction of the relative costs. New production strategies benefit from modern and efficient freshwater-generation plants, but the management strategies are based only on the few traditional options for the disposal of wastes.

The criticism received since the proliferation of desalination plants in the last decade focused on the super-heated effluent that many thermal plants discharged back into the sea and how it could kill corals and other marine life. Desalination industry contests the saying that desalination facilities nowadays cool this bilge so that it no longer poses such a threat.

Another environmental concern centers on the use of fossil fuels to power desalination, especially in the MENA region. A study published in January 2019 (UNU-INWEH, 2019) ignited fresh controversy about “toxic chemicals” in the brine that desalination plants pour into oceans.

World’s 18,000 desalination plants discharge 142 Mm^3/d of brine − 50 % more than previously estimated; enough in a year to cover Florida under a foot (30.5 cm) of brine (UNU-INWEH, 2019). The scaling is due to the accumulation of salt particles on the desalination plant components, and desalination plants try to get rid of it using chemicals, like Polyphosphate.

This salty concentrate may contain harmful residues from anti-scaling and anti-fouling chemicals used in the plants, according to the UNU-INWEH study.

In addition, brine can also deplete oxygen in surrounding waters, suffocating marine organisms and disrupting food chains. According to UNU-INWEH (2019), 55 % of global brine is produced in just four countries: Saudi Arabia (22 %), UAE (20.2 %), Kuwait (6.6 %) and Qatar (5.8 %). This is due to the dominance of thermal desalination technologies in those countries (the trend is changing currently), which typically produce four times as much brine per cubic meter of clean water as plants where RO dominates. However, the study failed to differentiate between thermal and membrane technologies. Some facilities try to dilute brine by dispersing it over larger areas of the sea or processing it to extract valuable metals and minerals. However, such methods are technically challenging and expensive according to the same study.

The main impact could be resumed as follows:

- raising the salinity of seawater: High salinity and reduced dissolved oxygen levels can have profound impacts on benthic organisms, which can translate into ecological effects observable throughout the food chain;
- polluting the oceans with toxic chemicals used as anti-scalants and anti-foulants in the desalination process (copper and chlorine are of major concern);
- Brine management can represent up to 33 % of a plant's cost and ranks among the biggest constraints to more widespread development (UNU-INWEH, 2019).

However, a recent study carried led by Southern Cross University in Australia, has found an unexpected benefit at the Sydney Desalination Plant: the excess salty water discharge attracts lots of fish. Lead researcher, Professor Brendan Kelaher (Kelaher et al., 2019) from the University's National Marine Science Centre, reported there was an almost three-fold increase in fish (pelagic and demersal) numbers around the desalination discharge outlet. Following the cessation of discharge, such an increase returned to levels such that there was no longer a significant effect compared to the period prior to the commencement of the desalination plant's operations. Kelaher et al (2019) explained that well-designed marine intake, outtake systems and processes used to support the increasing demand for drinking water can also improve local fish abundances and species richness.

RO desalination technology is used to treat water in industrial and agricultural, among other applications. It effectively removes salts and contaminants from brackish, seawater or wastewater. RO produces a clean stream of high purity water and brine that requires disposal. Brine is a highly concentrated solution of the salts and contaminants separated from the feed water with the RO membranes. The disposal of brine, which is estimated to be twice as salty as seawater, causes significant pressure to aquatic organisms. Hence, we need proper disposal for it, which many times requires permits or other regulatory compliance actions.

In an era of inspired recycling and enviable reuse of industrial and manufacturing by-products, the water treatment industry continues to search for innovative disposal options or, better yet, viable secondary use options for high TDS (total dissolved solids) RO concentrate streams.

There are many brine disposal options available today, all of which have a different environmental and capital impact but no one satisfying the interested parties fully.

Several factors are limiting the disposal options and challenging the search for a technically, environmentally and financially feasible method. Among other factors: plant size, increasing regulations and public concerns. The discharge volumes are a particularly limiting factor for seawater desalination plants (Bleninger & Jirka, 2010). The advantages and disadvantages of typical brine management options are summed up in Table 16.

Some plants are located in inland areas, away from the sea, and the brine they produce is put into evaporation ponds, injected deep underground or converted into a slurry that is processed into a dry salt for disposal.

Evaporation ponds for disposal of concentrate from desalination plants need to be constructed as per a specific design and maintained and operated properly so as not to create any environmental problem, especially with regard to groundwater pollution. Liners are the most important feature of an evaporation pond and one of the major components in the construction cost. They should be impermeable to avoid brine leakages and mechanically strong to withstand stress during salt cleaning (Ahmed et al. 2000). The use of clay liners

Table 16: Comparison of brine disposal options for desalination plants

Disposal method	Advantages	Disadvantages
Surface water discharge	› Can handle large volumes › Natural processes promote degradation › Water body promotes dilution › Often least expensive option › Possible dilution and blending with power plant discharge	› Limited natural assimilation capacities causing adverse impacts on marine environment if exceeded › Dilution depends on local hydrodynamic conditions › Good knowledge and monitoring of receiving waters required
Sewer disposal	› Dilution through waste stream › Uses existing infrastructure › Possible beneficial treatment	› Restricted capacity depending on sewage plant › Must meet sewer quality standards › Final disposal generally still to surface water
Deep well injection	› No marine impacts › Good option for smaller inland plants	› Only cost efficient for larger volumes › Maximum capacity hard to assess › Dependent on suitable, isolated aquifer structure › Danger of groundwater pollution
Evaporation ponds	› No marine impacts › Possible commercial salt exploitation › Low technological and managing efforts	› Strongly restricted capacity › Large areas of land necessary › Only in dry climate with high evaporation › Risk of soil and groundwater pollution › Disposal of unusable salts needed

with low permeability will substantially reduce the cost of construction, although a small number of leakages are to be expected.

Brine disposal methods are primarily dictated by geography but traditionally include direct discharge into oceans, surface water or sewers, deep well injection and brine evaporation ponds.

Desalination plants near the ocean (almost 80 % of brine is produced within 10 km of coastline) most often discharge untreated waste brine directly back into the marine environment.

Inland brine production is a particular issue in China (3.82 Mm^3/d), USA (2.42 Mm^3/d) and Spain (1.01 Mm^3/d).

Table 16 (continued): Comparison of brine disposal options for desalination plants

Disposal method	Advantages	Disadvantages
Land application	› No marine impacts › Alternative water source for irrigation of tolerant species	› Only for smaller discharge flows › Possible adverse impact of chemicals and pollutants on plants › Risk of soil and groundwater pollution › Storage and distribution system needed
Zero liquid discharge	› No liquid waste disposal › Recovery of salt and minerals	› Still not feasible on industrial scale › Solid residuals › High energy need › Expensive

In countries such as Oman, UAE and Saudi Arabia, the most common disposal methods in inland areas are evaporation ponds and land application. It is well known that worldwide MENA is the largest producer of desalinated water, producing half of the regions water capacity. Several new plants are planned in the upcoming years to meet the increasing demand.

Since the discharge, removal or treatment of brines from membrane-based seawater desalination plants are one of the most challenging issues within the desalination business, MEDRC is planning to run a brine discharge competition for researchers from different universities and research institutes of the region.

Several factors intervene when it comes to deciding on the best option such as the volume or quantity of brine, quality of brine, location, and availability of the receiving site, regulations, costs, and public acceptance. On the other hand, there is another possibility which is reusing the brine: fish culture (Barramundi, red snapper, black bream, Mullet, tilapia, and brine shrimp), algae production, agriculture (salt tolerant crops) or biosaline agriculture, solar ponds, and minerals recovery.

Innovative and non-traditional use of the brine is its involvement in several industrial processes with the dual beneficial objective to reduce its volume significantly to be discharged and mitigate the adverse effects of some contaminants such as CO_2.

That is said, there are economic opportunities to use brine in aquaculture, to irrigate salt-tolerant species, to generate electricity, and by recovering the salt and metals contained in brine – including magnesium, gypsum, sodium chloride, calcium, potassium, bromine and lithium.

With better technology, a large number of metals and salts in desalination plant effluent could be mined. These include sodium, magnesium, calcium, potassium, bromine, boron, strontium, lithium, rubidium and uranium, all used by industry, in products, and agriculture. The needed technologies are immature, however; recovery of these resources is economically uncompetitive today.

Using saline drainage water offers potential commercial, social and environmental gains. Reject brine has been used for aquaculture, with increases in fish biomass of 300 % achieved. It has also been successfully used to cultivate the dietary supplement Spirulina, and to irrigate forage shrubs and crops (although this latter use can cause progressive land salinisation.

Wider adoption of membrane technologies, particularly in the MENA region, looks like the best way to reduce chemical-laden brine, because the adopting membrane technologies for pretreatment reduce the use of chemicals. Almost all new facilities planned in the region will use RO, a trend likely to continue as budget-minded Gulf governments cut subsidies on fossil fuels. These cuts, by making thermal plants less competitive, are the main reason membrane technologies are finally taking off there.

The imperative to make seawater drinkable shows no sign of easing. At current consumption rates, the UAE's largest emirate may run out of natural groundwater supplies "within a few decades," the Abu Dhabi Environment Agency (EAD) said in a 2017 report. Rising demand for limited water resources is spurring new ideas for food production as much as for desalination. The International Center for Biosaline Agriculture (ICBA) in Dubai recycles brine to irrigate salt-tolerant plants such as salicornia, which can be eaten or used for biofuel (Dionyssia Aggeliki Lyra et al., 2016). The research institute also breeds food crops like quinoa that flourish in salty, desert soils.

IV. Legislation impact on desalination industry and practices

Critics of desalination stress that the way desalination plants release the remaining salt brine into the ocean is harmful to the marine ecosystem. Specifically, the concentrated salt brine can affect the salinity level of coastal ecosystems and, in turn, harm marine life. Therefore, it is important not only simple to regulate how the plant disposes of salt brine, but the authorities may also use the permit and concessionary process to support proposals that repurpose the brine. In other words, the authorities can allow innovation to inform their definition of best practices.

Desalination is an energy-intensive process. Therefore, authorities may have concerns about the impact of desalination plants on greenhouse gas emissions and their use of energy resources generally. As with the many examples worldwide, there are desalination projects that aim to offset energy consumption by implementing alternative energy sources. For instance, Saudi Arabia is investing in an offshore facility that desalinates water using only renewable energy.

An interesting and notable flip side of the water-energy nexus is that wastewater is becoming recognised as a potential source of energy rather than a mere waste stream. In several countries, water supply companies are working towards becoming energy neutral; they intend to generate an amount of energy from wastewater that equals the amount of energy consumed in their other operations.

The current regulations in the MENA region show two overall trends in regulating desalination plants. First, both sets of regulations promote significant government intervention in the plant's design and construction. Second, suggest supporting desalination projects that are less energy intensive and cause less harm to the environment. Governments can favour these types of projects through the permit process required to build and operate the plant. They can also support future operations by granting concessionary management contracts to supply residents with water.

If a country chooses to support desalination, its agencies should analyse how the new desalination plants impact sustainability at each step of the water treatment process. This sustainability can occur both at the economic (energy savings) and environmental (marine life protection) level.

Installation and operation of a desalination facility will have the potential for adverse impacts on air quality, water/sea environment, and ground water and possibly other aspects. These must all be considered and their acceptability and mitigation requirements would usually be matters of national and local regulation and policies. Studies to examine these effects would usually be conducted at each candidate site, and post-installation monitoring programs should be instituted (WHO, 2007). A brief partial listing of issues follows:

- Construction: Coastal zone and sea floor ecology, birds and mammals habitat; erosion, non-point source pollution;
- Energy: Fuel source and fuel transportation, cooling water discharges, air emissions from electrical power generation and fuel combustion;
- Air Quality: Energy production related;
- Marine Environment: Constituents in waste discharges, thermal effects, feed water intake process, effects of biocides in discharge water,

and toxic metals, oxygen levels, turbidity, salinity, mixing zones, commercial fishing impacts, recreation, and many others;

- Ground Water: Seepage from unlined drying lagoons causing increased salinity and possibly toxic metals deposition.

Capacity building and technology innovation

I. Capacity building efforts in the MENA region

For over the last decade, the desalination community including decision-makers, experts, industries and manufacturers have expressed in different ways the need of stronger capacity building programs in the region or at least at national levels where there are massive campaigns mainly in the GCC to localize the capacities and the technologies, and make the desalination industry run by locals. In parallel, those expressed needs also correspond to the increasing needs of the water market. One major issue in the MENA region is the lack of qualified manpower.

Most of these countries do not have training facilities or regimented programs for training the needed staff. Plant suppliers are mainly doing the training either on-site or for a short period abroad (home country of the supplier).

On the other hand, few institutions have implemented some academic programs and provided short courses and workshops in desalination; other institutions developed web-based training to the desalination community. However, these actions cannot compensate for the need for real institutional training and education as well as for research and development.

Capacity-building is urgently needed at different levels: operators, educators, academics and management. Achieving this target requires more specific training efforts in desalination technologies to encompass the principles, practice, operation and maintenance, design, human resources management as well as research and development. Such a capacity-building program is necessary not only to operate and improve existing plants but also to develop new sustainable technologies. Wastewater treatment and water reuse technologies should also be included in capacity-building programs to achieve a better integration in water resources management (Ghaffour, 2009).

The Middle East Desalination Research Center's (MEDRC) (Box 3) approach to enhance human resources and expertise in the region via training, academic education and research and development is contributing significantly to the national efforts in Oman and also in the region mainly in Palestine and Jordan.

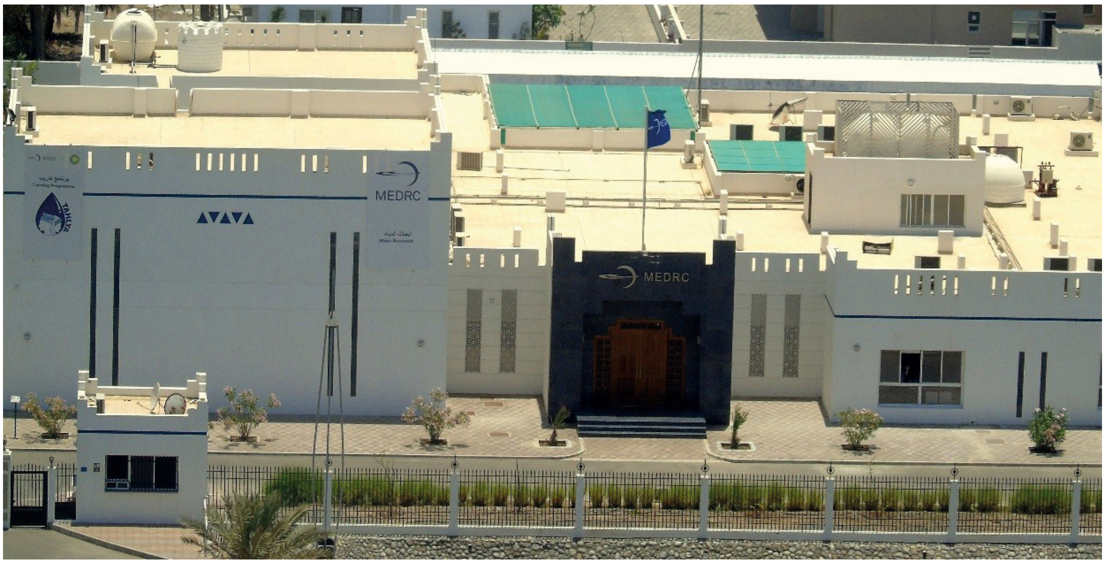
MEDRC is following several schemes to assist the region in this endeavor. These include offering short courses conducted in the region by internationally recognised experts in the field, enhancement of research capabilities by including in the research team of each MEDRC-sponsored project a researcher from the region, and by sponsoring students to undertake their postgraduate qualifications in desalination and its related fields in the region or abroad.

According to a study of Klaus Wangnick for GTZ in Germany (Wangnick, 2005), conducted in the year 2000, the total training needs of desalination personnel in the MENA region were estimated to be about 36,500 people by the year 2010. In 2019 with the growth of desalination capacities by almost four times comparing to 2010 and with the strong campaign mainly in GCC towards localisation of the human resources and the technology, the number of people needing training on desalination O&M would have increased almost by four times too in the MENA region. An essential prerequisite for a well-established desalination industry is the presence of well qualified and experienced personnel in the field. The most important recommendation in this respect is to establish training and education centers or train the staff working in the sector at academic institutions.

Box 3

MEDRC: The first and unique desalination center created in the MENA region

MEDRC is an International Organization mandated to find solutions to fresh water scarcity. Established in 1996, it conducts research, training, development cooperation and transboundary water projects. The MEDRC Headquarters is in Muscat in the Sultanate of Oman, where it operates a state-of-the-art research facility including desalination plants, laboratories, lecture halls and administrative offices. In delivering its mission, MEDRC aims to become a viable and transferable mechanism for governments seeking to address significant regional or trans-boundary environmental challenges.



MEDRC Headquarters in Muscat, Sultanate of Oman

The MEDRC research program supports the scientific quest for solutions to fresh water scarcity in the MENA region. A recognized regional center of excellence that boosts research on reverse osmosis (RO) membrane technologies, renewable energies-based desalination and environmental impacts of desalination. MEDRC aim specifically at conducting, facilitating, and promoting basic & applied research in the water desalination field. MEDRC is a regional hub for exchanging and transferring knowledge on the most innovative and efficient technologies of desalination, between and within the MENA countries.

MEDRC host a custom-built Water Training Centre at the organization's headquarters in Muscat, Oman. It is the only such facility in the region and includes training laboratories, seminar rooms, a solar array and a reverse osmosis desalination plant built especially for training and research purposes. To date more than 200 commercial training sessions covering all aspects of the water sector including waste water, solar desalination, water laboratory testing, plant design and costing, have been delivered to more than 700 students.

www.medrc.org

Desirable education programs should include all desalination technologies and their related topics, with particular emphasis on some specific ones that vary with the local needs and characteristics of a country. It should be flexible and dynamic, allowing for changes and improvement in future technologies. The program should be taught in an understandable language and meet the needs of a large population. Like all water issues and programs, awareness should start from primary and high school levels for better acceptability and effectiveness (Ghaffour, 2009).

In MEDRC, the training program provides high-quality specialized training for engineers and professional technicians who are or will be operating desalination plants or plants processing wastewater for reuse.

Technical competence is a necessity for efficient operation of desalination plants. Plants with employees who are well trained in the relevant technology and operations perform significantly better than those with lower levels of training.

Training includes classroom instruction in the theoretical aspects of the technologies and practical training in water processing. The program is divided into various levels with each level tailored to suit staff positions from entry level (newcomers & students) through to level 3 (engineers & designers). Training can be modified as necessary to meet the needs of the operating companies of desalination plants in Oman and elsewhere in the MENA region.

Moreover, MEDRC launched in 2016 a successful vocational desalination training program called TAHLYA (desalination in Arabic), aiming at training young Omani nationals in RO desalination. The program is sponsored by BP Company with training taking place at MEDRC facilities in Muscat (Oman). TAHLYA aims to create a pool of skilled employable labor to help meet the manpower requirements of the countries expanding desalination sector. Training is delivered using a three-tiered developmental approach providing students with a strong academic and practical education and building a familiarity with real scale desalination plants and procedures.

MEDRC is giving the program an ambitious objective of helping Oman to run all its desalination plants by Omani in three years from now. Hence, this program is contributing to finding jobs for fresh graduates and unemployed engineers in Oman, and thanks to this program, the first Omani and GCC national woman is working as a supervisor in desalination operations for Veolia in Oman.

II. Technology innovation perspectives

Advances in technology and desalination systems components have resulted in a reduction of almost 80 % of the energy used to produce freshwater over the last 20 years. Nowadays, the energy needed to produce fresh water from seawater is less than the quarter of what has been used for the same purpose in the 80s.

In terms of advance in desalination technology, we are closer to the thermodynamics limits, and like in computer technology and computers, SWRO membranes are now much smaller, more productive, more selective and cheaper than the first working prototypes.

Conventional treatment technologies, such as sedimentation and filtration pretreatment), have seen modest advances since their initial use for water treatment several centuries ago; but new, more efficient desalination membranes, innovative thermal membranes or hybrid desalination technologies, and equipment improvements are released every few years.

That is said, no major technology breakthroughs are expected to dramatically lower cost of seawater desalination in the upcoming few years. However, the steady reduction of production costs, coupled with increasing costs of water treatment driven by more stringent regulatory requirements, are expected to accelerate the current trend of increased reliance on the ocean as a water source. This will further establish ocean water desalination as a reliable, drought-proof alternative for many coastal communities worldwide (Voutchkov, 2017).

Technology advances are expected to reduce the cost of desalinated water by 20 % in the next few years, and by up to 60 % in the next 20 years (Table 17), making it a viable and cost-effective competitor for potable water production.

On the other hand, improvements in membranes such as graphene membranes and other nanomaterials are likely to impact the desalination industry. However, current processes are not optimised yet to take full advantage of the higher selectivity

Table 17: Forecast of desalination costs for medium & large size projects

Parameter for Best-in-Class Desalination Plants	Year 2016	Within 5 Years	Within 20 Years
Cost of Water (USD/m³)	0.8 – 1.2	0.8 – 1.2	0.3 – 0.5.
Construction Cost (USD/1000 m³/d)	1.2 – 2.2	1.0 – 1.8	0.5 – 0.9
Electrical Energy Use (kWh/m³)	3.5 – 4.0	2.8 – 3.2	2.1 – 2.4
Membrane Productivity (m³/membrane)	28 – 47	35 – 55	95 – 120

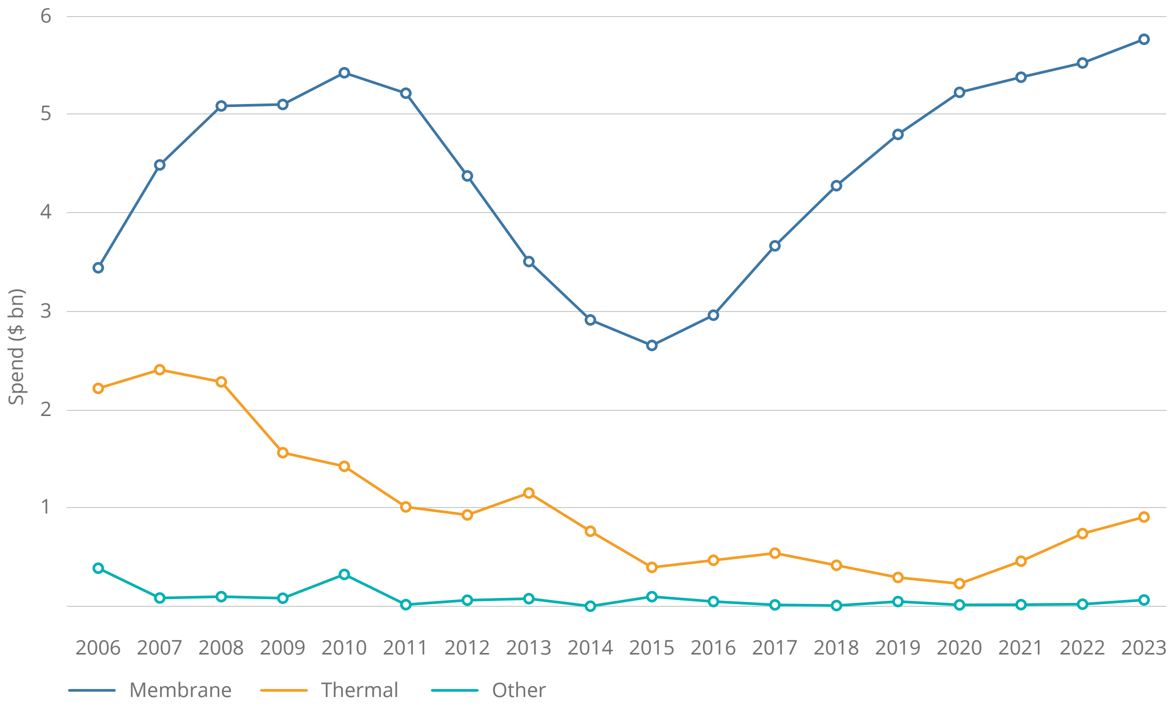
Source: IWA 2016

and permeability of graphene. New desalination processes are, therefore, needed to unlock the full benefits of graphene for instance. This process may take more than a couple of years.

That is said, membrane technologies will be definitely dominating the market even more in the upcoming years (Figure 31).

We see clearly how membrane technologies took the edge on thermal ones and the trend won't change in the few upcoming years.

Figure 31: Capex by desalination type from 2006 to 2023



Source: GWI 2018

III. Recommendations to policy-makers and investors of this sector

The global capacity of desalination plants, including renewable desalination, is expected to continue growing at an annual rate of more than 9 % (Voutchkov, 2016). The market is set to grow in both developed and emerging countries such as the United States, China, Saudi Arabia and the UAE, and even in MENA countries traditionally poor in fossil fuels such as Morocco, Tunisia and Egypt.

A transition to solar energy offers the prospect of increasing supplies of desalinated water while significantly reducing CO_2 emissions (El Kharraz, J., 2017). Deploying CSP for seawater desalination is one modern approach. PV can also be used for BW treatment and for powering water pumping stations. However, the success of solar desalination technologies at large scale commercially depends on the economic cost of converting SE into electricity. Current solar technology does not lend itself to large-scale desalination projects, but is useful at smaller scales, especially in remote areas with no grid electricity. In such areas, decentralised solar desalination plants offer independence and protection from price rises from utility or water companies, but the benefits of solar go far beyond desalination. Once installed, clean energy can also be used for soil fumigation and for drying animal feed for winter use. Thus deploying renewable solutions for increasing water supply also creates opportunities in intersecting areas.

To fight global climate change, the MENA region should reduce energy use in current water supply systems, and prohibit building new energy-intensive water projects, and if we are to keep building new desalination plants, we will need necessarily to build more solar and wind farms to generate electricity needed to operate the plants.

Integrated molten salt energy storage technology provides twice the generation compared to the same size PV project. It allows solar to operate as baseload generation and dispatch when energy is needed most at a fraction of the cost of battery and other storage technologies. It enables CSP plants to operate like a conventional fossil fuel or nuclear power plant, reliably generating electricity when it's needed most - but without the harmful emissions and any fuel cost.

Less than 1 % of MENA's land mass would be required to provide solar power for the needs of the entire region. To achieve this, the political framework must adapt: dismantle subsidies for fossil fuels, encourage joint investments and cross border grid expansion with MENA countries.

There is an essential gap between the amount of R&D focusing on the technological dimension of desalination and the research on other dimensions, mainly in what concerns financing; health impacts; social issues (and among this affordability by different kind of users), and (geo)political concerns. These questions revolve around a large number of unsustainable factors associated with desalination, which is even considered as a form of "maladaptation" to climate change. Some of the issues (energy costs, emissions, marine pollution) have received considerable attention, but others (differences in social and sectoral access, obstacles to effective water conservation policies, the potential for improving certain geopolitical and environmental situations; health effects, and others) remain more elusive and constitute fertile grounds for future investigations. Moreover, a great deal of these investigations would fall broadly within the field of socioenvironmental studies. In this sense, advancing social science research can help in bridging the gap between the technology/engineering literature and socio-environmental scholarship and thereby enhance opportunities for widening and enriching policy discourses.

Advancing our knowledge of the socioenvironmental processes associated with desalination needs research efforts in several fronts which could be framed along with the following points:

- Comprehensive data base / atlas on desalination plants and of their characteristics at MENA scale;
- Perception of desalted water for drinking by users: health hazard concerns;
- Desalination in areas of water-related geopolitical conflicts;
- Affordability of desalted water for small farmers and low-income urban dwellers;
- Desalination and the conflicts between agriculture, mining and urban uses;
- The contribution of desalination for easing the pressures on freshwater ecosystems and hence help to fulfill the national and regional strategies / policies;
- Desalination and water reuse: competing or complementing?
- Desalination as a strategy to recover polluted surface and groundwater resources;
- The financing of desalination plants and cost-sharing mechanisms among communities of users;
- The ownership of desalinated seawater;
- The potential of desalination to address climate variability (i. e. desalination as a supplementary source to be activated during dry periods) and the financial and distributive costs of on and off production of desalinated water;
- Potentialities and problems of small-scale desalination.

Summary

Desalination has become the most appropriate solution to produce fresh water to serve the continuously growing population in the world and to contribute to ensuring water security. In countries such as GCC, desalination has given then security of supply. In fact, several GCC cities are relying almost 100 % on desalinated water. That's said, desalination is not enough to secure water supply in cases of risks such as acute harmful algal blooms, or terrorist attacks that may stop the production of desalination plants. Doha, for example, is estimated to have just three days' water supply; it's currently building a strategic reservoir that will raise this to a week (Elgendy 2015).

The most used desalination technology is Reverse Osmosis, which have reached more than 90 % in some of the MENA countries, according to the latest information given in Desal Data.

For desalination to become an alternative to alleviate water scarcity and a climate change adaptation option in the MENA region, all water stakeholders need to be consulted extensively. This must be carried out through a participatory approach and engagement process that could be mandated by the national water strategy or equivalent (master plan). Operators, fishermen associations, farmers, municipalities, and consumers; all need to be consulted. This happened in some countries in the form of a national debate but needs further enforcement and concretisation.

Innovation in the coming years will have a significant impact on whether large-scale solar desalination projects are feasible. Governments can tackle water shortages and adapt to climate change around the globe with various strategies. However, encouraging water treatment methods with potential for innovation, like desalination, is a way of increasing governments' options when faced with droughts.

Realising the importance of desalination costing, MEDRC organised several international workshops on desalination costing in 2004, 2017 and 2018 to formulate generally accepted procedures for costing with the hope that, in the end, a standard procedure would possibly emerge that would be globally approved. However, due to the vastness of the endeavor those workshops only allowed the limited review of desalination technologies, existing cost models, desalination project boundary conditions, planning issues and case studies. MEDRC has further plans for standardising procedures for desalinated water costing and for producing a costing software package that could be made available to the desalination community.

There is an urgent need to make desalination technologies more affordable and extend them to low-income and lower-middle income countries. At the same time, though, we have to address potentially severe downsides of desalination − the harm of brine and chemical pollution to the marine environment and human health. The good news is that efforts have been made in recent years and, and we see a positive and promising outlook, with continuing technology refinement to decrease costs and increase the sustainability, using advanced pretreatments that minimize the use of chemicals, and brine discharge methods that help dilution and improving economic affordability, we see a positive and promising outlook. Especially important is to decrease energy consumption, which has an impact on the operation costs and also the environmental impact through carbon dioxide emissions.

However, another severe downside is the carbon emission associated with the high energy consumption of desalination, and how this must decrease.

Even the largest oil producing countries in the Gulf are aware of the importance of having sustainable desalination plants that will operate for the upcoming years regardless of the oil price fluctuations. Desalination consists of energy-intensive processes which explain the urgent need to reduce energy consumption (Srinivas, 2007). The RO technique is the first step towards that principle. However, more innovative techniques and processes using renewable energy should emerge as soon as possible to reduce the impact of the desalination plants, avoid huge operation costs shortly and finally meet the growing demand for fresh water in the region (Thafer, 2015). Examples of the emerging technologies would be MD, the carbon nanotube membranes, aquaporin membranes and FO processes. However, scaling up these technologies remain a big issue.

GCC countries should work on the water sector governance through applied research, information systems, better data sharing and technological innovation to find effective ways to reduce the costs as well as protecting the environment and the scarce water resources.

Policy makers need to consider the different choices for desalination based on locally available renewable energy resources. For instance, solar energy, in particular, heat from CSP for thermal desalination and electricity from solar PV and CSP for RO, is a key solution in the MENA region.

Solar desalination is a good example of the water-energy-food nexus implementation if combined with food production through greenhouses practices and other similar projects. As the demand for food, water and energy are expected to rise by 30 – 40 % by 2030, solar desalination is called to contribute significantly to SDGs 2 (food security), 6 (water) and 7 (energy). For instance, energy generation contribution in Saudi Arabia will increase 4.4 – 5.5 % by 2032 in terms of Solar PV and by 11.7 – 17.2 in terms of Solar CSP.

Furthermore, most energy strategies within the Arab world have set goals of increasing the share of RE in the energy make-up; for example, Tunisia, is aiming for 30 % share of renewable energies in the electricity mix by 2030 whereas Morocco hopes to reach 12 % by 2020, Egypt an ambitious 20 % by 2020. It is worth to mention also that one of the targets in the Arab Region is: “By 2020, develop alternative and practical solutions for using non-conventional water resources with a focus on the use of renewable energy in water desalination and water treatment for meeting the increasing water demand in the Arab Region”.

Therefore, investing in renewable energies makes sense from a water perspective. If Arab countries meet their set target shares of renewable energies in the overall energy mix, significant savings would be made in water withdrawals, consumption and their associated energy spending. The renewable energies-based freshwater generation should be seen as a valuable economic investment that reduces external, social, and environmental costs. In addition, if we use simple solar-driven small systems, it is simpler and less costly than conventional ones.

Conclusions & recommendations

Seawater desalination is vital for MENA countries and their reliance on this source is expected to grow fast. This growth will only be possible by continuing to improve the sustainability of related technologies.

Desalination can reasonably be considered a worthwhile adaptation strategy only if we ensure proper construction, minimize environmental impacts and generate electricity from non-fossil fuel sources.

The MENA region needs to localise knowledge. Currently, there are not enough qualified staff to operate modern desalination technologies, including solar desalination plants. This is why it is important to invest in training, knowledge transfer and capacity building.

By designing incentives for local businesses, governments can attract domestic investments in manufacturing critical components and cultivating local innovations to attain economic sustainability. However, government enterprises should not continue to build and operate desalination plants as before; steps should be taken to attract local investors using set targets for locally produced products and labor force and to manage these assets minimising the life-cycle cost of water and environmental impact. Like private enterprises, government enterprises should value energy at world market prices and provide incentives for in-house R&D departments to promote innovations in technology and operation.

Therefore it is recommended to create a regional observatory with the aim is to increase the cooperation and knowledge exchange between MENA countries in desalination technologies to adopt the best and most sustainable desalination technologies towards meeting their increasing water demand.

The specific objectives could be to:

- Promote localization of desalination, mainly renewable & sustainable desalination;
- Organise an annual stakeholder's forum that can prioritize and facilitate the exchange of knowledge and capacity building activities;
- Provide independent science advice to governments of the MENA on the best choices of technologies and financial set-up of their desalination projects;
- Assist key decision makers in planning desalination projects;
- Assess desalination potential including the economic, environmental and social cost;
- Provide expertise and assistance when needed and promote best practices;
- Boost innovation and knowledge transfer between MENA countries;
- Provide advisory support and contribute to national & regional desalination policies;
- Help the countries of the region to secure water supply.

It will play a proactive role in helping MENA desalination decision makers, governments and experts stay at the forefront, build expertise and show leadership in Desalination field. We also recommend to:

- Develop a comprehensive regulatory framework related to desalination and provide incentives to reduce the carbon footprint as well as the environmental impact;
- Support the existing technology centres and science parks in the MENA region;
- Expand and support technical and vocational training programs in desalination (Inc. e-learning);
- Set up extensive educational specialisations & social partnerships in desalination & water treatment;

- Increase regional R&D cooperation to ensure that the MENA region becomes an innovation hub in desalination technology.

Despite being energy intensive technology, the IPCC lists desalination as an “adaptation option” which is particularly important the MENA region and mainly in countries with high GDP and where water security can justify investments in desalination technologies. In fact, GCC countries for instance may have the financial capabilities needed for adaptation measures, the rest of the region is more vulnerable to risks.

The innovation of desalination lies not only in the technology component but in its potential use as a bridge between nations. As climate change and population growth continue to place stress on Earth’s finite water resources, we hope to make great strides in desalination and other water technologies to meet the world’s and particularly MENA’s growing demand for water.

Regional Program Energy Security and Climate Change in the Middle East and North Africa (KAS - REMENA) of the Konrad-Adenauer-Stiftung (KAS)

The Konrad-Adenauer-Stiftung (KAS) is a political foundation, closely associated with the Christian Democratic Union of Germany (CDU).

Besides the eight country-based programs which the Konrad-Adenauer-Stiftung runs in the Middle East and North Africa, the Foundation's Regional Program Energy Security and Climate Change Middle East and North Africa (KAS - REMENA), based in Rabat since 2017, implements cross-national projects with reference to the MENA region. Its objective is to strengthen sustainable development and to support the stability of the region in terms of climate change and its consequences. This implies as well the promotion of cooperation and partnership with the European Union.

The following core areas fall within the program's scope:

- Facilitating dialogue and cross-national exchange particularly with regards to concepts and measures concerning resource security, especially energy;
- Promoting political framework conditions for a reliable and sustainable water supply with a special focus on the "Water-Energy-Food" Nexus;
- Supporting development and implementation of strategies to prevent and to adapt to the political, economic, social and ecological consequences of climate change, including the linkage of climate change, security and migration;
- Promoting development of a sustainable economy with focus areas on circular economy and sustainable finance.

Our instruments for implementing our goals are cross-country and cross-regional dialogue programs such as workshops, conferences, academies or information and study visits together with international, European and local experts. The activities are designed to enhance the exchange of information and experiences. Furthermore, policy papers and research illustrate concepts for partnership-based cooperation and raise awareness among decision-makers for integrated, cross-regional solutions concerning sustainable resource availability as well as climate change effects on society, economy and security.

KAS - REMENA: https://www.kas.de/en/web/remena/home

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