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The Geopolitics of Seawater Desalination

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Abstract

A rapidly-expanding market

Water desalination is gradually emerging as the leading solution to cope with increasing water stress: i.e., the imbalance between water demand and quantities available. The United Nations estimates that by 2025, two-thirds of the world's population will be affected by such challenges. The causes of water scarcity are multiple, including climate change, intensive agriculture, and population growth. This requires states to rethink their water policies, which are central to preserving their stability, resilience and sovereignty.

A real "boom" in desalination industries is at work. The majority of Gulf countries now largely depend on desalinated water for their inhabitants' consumption: in the United Arab Emirates (UAE), 42% of drinking water comes from desalination plants producing more than 7 million cubic meters (m^3) per day, in Kuwait it is 90%, in Oman 86%, and in Saudi Arabia 70%. In 2022, there were more than 21,000 seawater desalination plants in operation worldwide, almost twice as many as a decade ago, and the sector's capacity is growing at between +6% and +12% per year.

By 2030, desalination capacity in Middle Eastern countries is expected to almost double, as part of plans announced in the region to prepare these economies for their transition to "post-oil" and to foster resilience. Saudi Arabia's desalination capacity is set to increase from 5.6 million cubic meter ($m^{3)}$ per day in 2022 to 8.5 million m^3 per day in 2025, and it will have to cover more than 90% of the country's water consumption. The same holds for the UAE, Kuwait, Bahrain and Israel, where the production of desalinated water will more than double by 2030.

With the rise of available solutions to meet all such needs, these technologies are now in demand on virtually every continent, while the Middle East today represents only 50% of installed capacity worldwide. In Africa, large-scale projects have recently been announced in Algeria and Morocco, countries that until now have had sufficient resources. Other countries such as Ghana, Senegal and Kenya supply many cities with desalinated seawater. This is also the case for Cairo. In the Indo-pacific region, particularly in China and India, the needs for desalinated water are increasing, driven by growing industries and decreasing available water. In 2020 alone, the construction of more than 35 desalination plants was announced in China, as well as six in the Philippines, and six in Taiwan. In the Americas, the west coast of the United States stands out with important projects in California, and Texas is not far behind. In Latin America, new projects are emerging in Peru and Chile, driven mainly by the

needs of the mining industry, while in Mexico the demand for desalinated water notably comes from the population. Finally, island areas stand out for their strong needs for desalinated water: Cebu in the Philippines, Cape Verde, the Canary Islands and the Maldives are increasingly using desalination capabilities.

European firms still lead, but Asian or local players are taking off

There are many industrial players of varied size, although some have emerged for more than ten years as undisputed market leaders: in France, they include Engie and Veolia, whose merger with Suez opened up new prospects in the Americas, the Middle East and Europe; but there is also IDE Technologies, the Israeli champion of desalination; Korea's Doosan Heavy, China's Abengoa, and Spain's Acciona.

More recently, companies in emerging countries have distinguished themselves by obtaining large-scale contracts. This is particularly the case of Gulf players like the Emirati company Metito and the Saudi firm Advanced Water Technologies. Egypt also has industrial actors. Overall, the technology of reverse osmosis is largely mastered, while production differentiation concerns capacity, operational costs, electricity consumption and plant life.

A huge environmental challenge

Desalinating seawater is an expensive, energy-intensive process that releases significant amounts of greenhouse gases (GHGs) in most countries that have a very intensive CO_2 electricity mix. Desalination plants generally use lots of electricity, with variations depending on the technologies employed. Thermal desalination processes, used less and less, consume more than 5 kilowatt-hours (kWh) of energy per cubic meter of desalinated water produced. By contrast, the reverse osmosis desalination process, now the most widespread, can desalinate 1 m^3 of water with an average of between 2.5 and 3 kWh, the record being set by a Saudi plant at 2.27 kWh. Desalination plants in the Middle East have largely benefited from an energy mix based on fossil fuels that permit cheap desalination. Electricity consumption for water desalination increased threefold in Saudi Arabia during the period 2005-2020, reaching about 6% of the kingdom's total electricity consumption, or about 17 terawatt hours (TWh) in 2020. It is equivalent to the annual production of a large nuclear power plant. Doubling desalination capacity will therefore boost electricity demand and associated GHG emissions if the electricity mix remains largely dominated by hydrocarbons. The demand for gas and oil to produce this electricity would also increase. Several Gulf countries are beginning to mobilize renewable energy sources, such as the Al Khafji reverse osmosis plant in Saudi Arabia, which desalinates

60,000 m^3 every day, and which is powered by photovoltaic panels. Finally, there are also power stations that operate using wave and geothermal energy.

Another issue with desalination concerns the management of brines: i.e., the remaining water, heavily loaded with the salt particles that have been separated from seawater, is often released into the sea, causing increased salinity levels in coastal waters.

How to improve performance along the entire water chain is the last key issue, not just at the production level. Losses in transmission and distribution networks from factories to final consumers are extremely high, reaching levels of more than 50% in most Gulf countries.

The use of desalination seems inevitable and destined to experience a very strong expansion. It is therefore urgent for these production processes to remove their dependency on fossil fuels because the doubling of installed capacity in the Middle East by 2030 is set to lead to a significant increase in emissions, unless electricity mixes become greener, as in the UAE which has deployed nuclear power in particular.

Two solutions are thus required: on one hand, the setting up of desalination plants powered by low-carbon energy sources (fields of solar panels, concentrated solar power, wind turbines, wave energy, or even nuclear power), possibly with combined cycle power plants for back-up capacity. The aim is therefore to decarbonize electricity mixes to ensure plants provide low-carbon water supplies. On the other hand, the construction of infrastructures of this kind must not replace a policy of energy efficiency, the optimization of desalination plant fleets, the search to cut losses and waste, reducing consumption subsidies as well as the collection and treatment of wastewater. Improving water sector governance and encouraging sustainable water use policies in industry, agriculture and the residential sector, are essential.

Ahead of the 22-24 March 2023 United Nations Water Conference in New York, with the successful COP15 on biodiversity and with the UAE presidency of COP28, water governance, and the development of a sustainable industry across the globe, is becoming central to achieve several Sustainable Development Goals and avoid fueling additional environmental degradations, as this industry is set to boom in the coming decade.

Contents

Introduction

The summer of 2022 was marked by a period of exceptional drought in Europe and in many countries around the world, as in the Horn of Africa. Water stress is strengthening and progressing geographically. A country is said to be in water stress if water availability is less than 1,700 cubic meter (m^3)/year/inhabitant. Several countries in Africa and in the Near and Middle East are already affected by these extreme events, while the Mediterranean region is being increasingly impacted.

In a context of strong growth in water demand – in industry, agriculture and by the general public – the seawater desalination industry has experienced very strong growth over the last twenty years. In addition to climate change, leading to the scarcity of fresh water sources and droughts, along with population growth, the increase in demand for desalinated water comes from the depletion of available resources, as is the case with groundwater in Saudi Arabia for example. Consequently, the gap between available water resources and demand is widening: this is the so-called *water demand gap*.

Aware of these constraints, a few countries have embarked on the deployment of seawater desalination capacities as part of a dual strategy for emergency response *and* anticipation of the future. Desalination infrastructures thus expanded from 18,000 plants in 2017, generating about 97 million m^3, to more than 21,000 in 2022, producing nearly 110 million m^3, with capacity growth in the sector running at between 6% and 12% per year. Since 2000, global capacity has increased fivefold. Between 2019 and 2020, it is estimated that desalination capacities worldwide increased by 4.7 million m^3/day, which is significant. Every day, more than 300 million people benefit from desalinated water.[1]

Desalination is largely concentrated in Middle Eastern countries, accounting for about 50% of global capacity. In the Gulf countries alone, the growth in installed capacity between 2019 and 2020 was in the order of 1.2 million m^3. The Gulf states stand out in this process with huge factories: for example, Saudi Arabia and Qatar have built plants capable of desalinating more than 200,000 m^3/day per unit, while other plants operate at capacities of less than 1,000 m^3/day. Thus, in Qatar, the Umm al-Houl plant has a capacity of 282,000 m^3/day; and the Jebel Ali plant in the United Arab Emirates (UAE) has a capacity of 2 million m^3 per day. The water desalinated by these new mega-factories is mainly used to supply expanding urban centers. In the UAE, 42% of drinking water comes from desalination, with

1. See International Desalination Association (IDA): https://idadesal.org.

levels of 90% in Kuwait and 90% in Qatar. Other markets are gradually emerging elsewhere, driven by droughts and population growth. This is the case in North Africa, the Americas as well as in certain parts of Asia.

This study aims to analyze to what extent the seawater desalination market will develop over the next decade, what strategies are adopted by industrial, state and local actors, and how this increase in needs may be reconciled with the challenges of the energy transition and the preservation of the environment.

Desalination: A Sector Growing Exponentially, Driven by Declining Water Resources

The prospects of water stress make the increase in demand for desalinated water inevitable

The prospects for water stress are proliferating around the world. Already, more than 2.2 billion people lack sufficient drinking water. By 2050, desertification alone will threaten the livelihoods of nearly 1 billion people in about 100 countries.

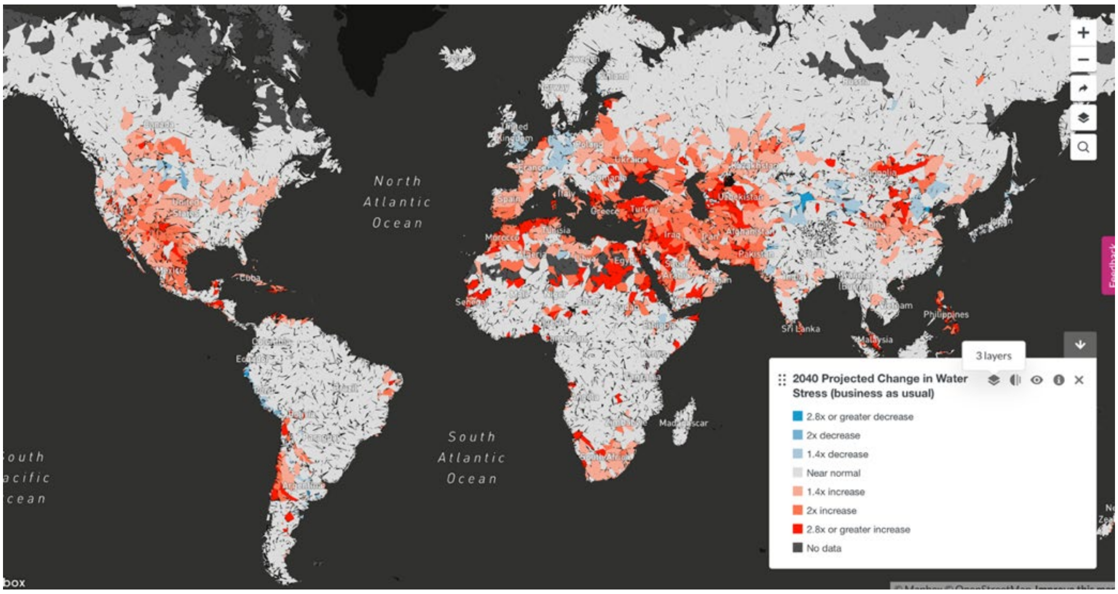
The Middle East is particularly affected by this phenomenon, and the estimated number of people exposed to water stress will double by 2050. More than 60% of the Middle East's population lives in areas exposed to high water stress, and 70% of economic activities are also located in these areas. This scarcity of resources affects not only surface water but also groundwater. Agriculture is partly responsible for the lack of water resources, as the sector consumes about 85% of the region's water.[2] More than 41 million people in the region lack well-managed access to water, and 66 million people lack basic sanitation services.[3] Some areas are particularly prone to these extreme conditions, such as the Iraqi Basra region but also some areas in Jordan, Sudan and Yemen – poor countries affected by major droughts.

Elsewhere, areas that once benefited from an abundant supply of freshwater thanks to well-stocked aquifers, gradually experience shortage of water as well. These include: the west coast of the United States, North Africa (especially Morocco, planning to build about ten additional plants in the coming years, including the continent's largest in Casablanca with a capacity of 200 million m^3/year, but also Tunisia, Algeria and Libya), southern Africa, Central Asia, and parts of South America. Water problems are not spared in island states like Australia, Cape Verde, the Philippines, the Canary Islands and Madagascar: all of these countries suffer from a scarcity of water resources. Projections by the World Resource Institute, an independent

2. *Towards a New Generation of Policies and Investments in Agricultural Water in the Arab Region: Fertile Ground for Innovation*, Food and Agriculture Organization of the United Nations (FAO), 2019, available at: www.fao.org.
3. *Running Dry: The impact of Water Scarcity on Children in the Middle East and North Africa*, United Nations Children's Fund (UNICEF), August 2021, available at: www.unicef.org.

think tank, have shown that, in a business-as-usual scenario, all these areas are likely to experience a 2.8-fold increase in water stress.

Evolution of Water Stress Situations in 2040



Source: World Resource Institute.

An issue of sovereignty and tensions

Israel as a forerunner

While the use of desalination is now widespread in several countries, Israel stands out as a pioneer.

With over 9 million residents, the country has always included water as a key parameter of its national resilience strategy. Israel has been supplied by Lake Tiberias, but it was forced to rethink its water strategy in the early 2000s, due to the unprecedented drying of the lake. Between 2005 and 2016, the Israeli government and its Water Authority oversaw the emergency construction of several desalination plants along the Mediterranean Sea. The first project emerged in 2005 with a plant being built in the south of the country, in Ashkelon, and initially providing 50 million m^3/year (its capacity has since increased to 118 million m^3).

The activity is managed by the state and its water agencies. At present, six medium-sized desalination plants operate in the country and provide all the water needs of the population and industries. Most recent developments include the expansion of the Sorek plant that supplies water to the inhabitants of Tel Aviv (an additional 200 million m^3/day), while a new plant and water pipe system has just been completed to fill desalinated water from the Mediterranean into the Sea of Galilee (a freshwater lake) so as to top it off. This will also allow a water for solar power deal with Jordan to take shape (more details in the next section). In total, by the end of 2022, the country's desalination capacity was expected to reach 800 million m3/year and provide more than 80% of domestic water consumption. A seventh plant will be built by IDE technologies, bringing total capacity to 900 million m3/year. By 2030, desalinated water is expected to reach 1.2 billion m3/year according to Israel's Ministry of Finance.[4] The construction of new plants is regularly supported by major international financial institutions. For example, the European Investment Bank (EIB) has granted Israel a loan of €150 million for the development of the Sorek II desalination plant, with a capacity of 200 million m3 per year, one of the largest in the world. The project marks an important milestone in the desalination industry, with cutting-edge technology helping reduce energy consumption and CO_2 emissions. The contract award to IDE was marked by geopolitical tensions as the U.S. was reported to have intervened to avoid Hutchinson Water International, a Hong Kong based company, winning the tender.

Desalination Capacities of Israeli Plants

Plant	Desalination capacity	Date of construction
Ashkelon	118 million m^3/year	2005
Hadera	127 million m^3/year	2009
Sorek (south of Tel Aviv)	150 million m^3/year	2013
Palmachim	90 million m^3/year	2007-2013
Ashdod	100 million m^3/year	2015
Sorek II	200 million m^3/year	Announced in 2019, will be completed soon
Plant in Galilee	>100 million m^3/year	Opened at the end of 2022

Source: Government of Israel, www.gov.il.

The risk of conflicts over water resources

Projections of a "water crisis" in regions heavily impacted by climate change are accompanied by increased geopolitical risks. Dams are under great pressure. This is the case, for example, of the Grand Ethiopian Renaissance Dam, which is crystallizing tensions between Sudan, Egypt and Ethiopia. It is also true for Turkish dams on the Euphrates and Tigris rivers that impact Syria and Iraq. Although less studied, desalination infrastructures are also at the heart of negotiations between the states of the region, as evidenced by the case of Jordan.

4. "Background – Seawater Desalination in Israel", Government of Israel, January 26, 2021, available at: www.gov.il.

Jordan is a country of just over 10 million inhabitants, including 2.9 million non-nationals, and is presently facing a deteriorating economic situation with a public debt of 88.4% of gross domestic product (GDP) and 24% unemployment. The kingdom is already heavily impacted by climate change, with precipitation expected to decrease by 30% by 2030. While the country's capital, Amman, is currently supplied by water drawn from groundwater at the Saudi border, projections show the city could suffer from a complete water shortage by 2040. The pressure on resources is amplified by the massive influx of refugees from neighboring countries, including Iraqis, Palestinians but also Syrians. For example, more than 80,000 people live together in the Zaatari camp alone, supplied by 65 water trucks per day.

This water crisis calls for the countries of the region to strengthen their cooperation. But overcoming tensions is a challenge. It was within this framework that a tripartite memorandum of understanding was concluded in 2021 between Israel and Jordan, with the support of the UAE, as an extension of the Abraham Accords. In exchange for installing solar panels in the Jordanian desert to supply Israel with electricity (600 MW), Jordan will benefit from 200 million m^3 of desalinated water annually. In addition, it is expected that Jerusalem will pay $180 million each year to be shared between the Jordanian government and the Emirati company in charge of building the solar farm. This draft agreement, welcomed in 2022 during Joe Biden's visit to the UAE, has not yet been finalized and faces political resistance from the Jordanian population, opposed to any cooperation with Israel. When the project was announced, several members walked out of Jordan's House of Representatives in protest.

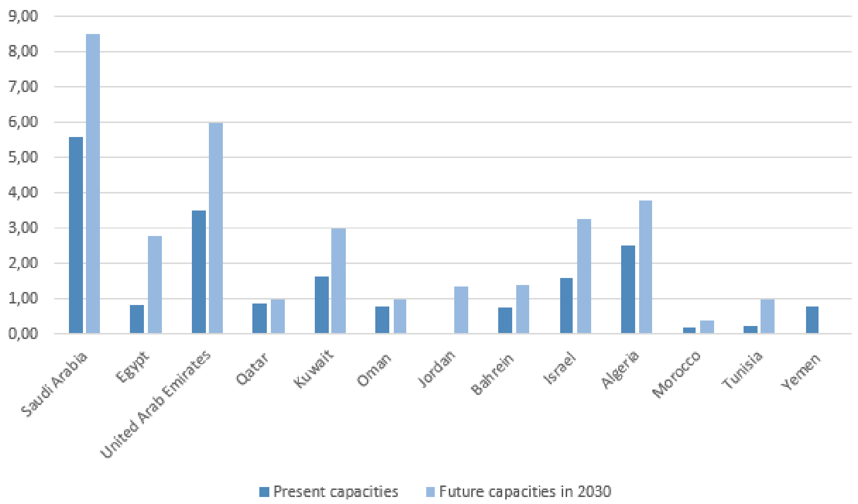
Yet things are not stalled. The construction of a desalination plant on the Gulf of Aqaba was announced by Jordan, it should produce between 250 and 300 million m^3 of drinking water per year from 2025 or 2026 – Engineering Procurement And Construction (EPC) bids were issued. Jordanian and Israeli leaders met on the sidelines of COP27 in Sharm-El-Sheikh to move the so-called "Project Prosperity" forward, with finalization expected at COP28 by year end.

Very strong growth in desalination activities in the MENA region

Faced with water stress forecasts, the Middle East and North African (MENA) states are committing to long-term action plans to increase their capacity to be resilient in the face of water stress. The development of desalination is at the heart of these five-year plans: in the vast majority of countries in the region, desalination capacity will double by 2030, or by 2050 at the latest.

- As part of the *Egypt 2030 strategy*, the Egyptian government is planning at least 14 new desalination plants as of 2022, followed by a second and third phase, aimed at reaching a desalination capacity of 6.4 million m^3/day in 2050, with about 142 plants. Egypt is currently experiencing a major water deficit estimated at 25 billion m^3, while its population is growing strongly.
- In the UAE in 2017, the Ministry of Energy and Infrastructure unveiled its *UAE Water Security Strategy 2036*, which aims to ensure sustainable access to water under normal and emergency conditions. This plan aims to reduce average water consumption per capita by 50% and cut public water demand by 21%. These are major challenges as the average daily water consumption is 550 liters, which is one of the highest rates in the world, while demand is expected to increase by 30% in total by 2030. The country's desalination capacity currently represents 14% of the world total, with 9% for Abu Dhabi alone. Abu Dhabi's production capacity is expected to increase from 1.5 million m^3/day in 2017 to over 3.3 million m^3/day in 2030. In total, the country is expected to produce more than 8.5 million m^3/day in 2030, if desalinated brackish water is also included.
- Saudi Arabia produces 22% of the world's desalinated water. The country has desalination plants that are particularly powerful and that produce more than 5.6 million m^3 of fresh water every day (2020) and meet more than 70% of the country's drinking water needs. Like most states in the region, the Kingdom of Saudi Arabia faces a twofold challenge: on one hand, its population is expected to reach 40 million in 2030, and therefore the average demand for water is set to increase by 7-8% per year; on the other hand, its water resources are decreasing, explaining the recourse to desalination. Water issues are at the heart of the *Saudi Vision 2030* plan and the country's national water strategy which aims to achieve 90% of water production from desalination by 2030, cuts in country's water consumption by 43% and re-use of 90% of water by 2040. The National Water Conservation Plan was announced in 2019. Desalination capacity is estimated to increase from 5.6 million m^3/day to 8.5 million m^3/day in 2030.
- In Qatar, desalination was introduced as early as 1950 due to very intense water stress in the country. Qatar is below the 1,000 m^3 limit available per year and per capita, in addition to having high population growth, with a population expected to increase from 2.6 million in 2018 to 4.4 million in 2030. The *Qatar National Vision 2030* plan provides for an increase in renewable energy, a reduction in emissions and the use of less energy-intensive processes.

Evolution of Seawater Desalination Capacities in the Middle East and North Africa (in millions of m³/day)



Source: Ifri estimates based on available data and plant construction forecasts.

Desalination costs have been falling over the last ten years

The increase in desalination capacity is explained by the scarcity of water resources, but it can also be explained by the increasing affordability of this technology.

The CAPEX (capital expenditure) for a desalination plant is estimated to be between US$0.65 million and US$1.2 million for every 100 m^3/day of desalinated water, which has declined significantly in recent years. Then, the energy required for desalination is considered to be about two thirds of the amount of OPEX (operating expenses) of a plant.[5]

Depending on whether the plant is thermal or uses reverse osmosis, the costs of one cubic meter of desalinated water vary greatly. Indeed, reverse osmosis technology consumes on average half as much energy, reducing OPEX. Yet this is not true for a majority of Gulf countries, due to the salinity of their water sources. As a result, thermal processes are more efficient and less damaging to membranes. In general, the larger a plant, the lower its desalination costs. Thus, the average cost of producing one cubic meter of desalinated water ranges from $0.5/$m^3$ for large plants, to more than $1.25/$m^3$ for smaller plants. Lately, desalinated water has reached very competitive production costs in the mega-plants of the Gulf (producing more than 500,000 m^3/day) where the price per cubic meter has fallen below
50 cents: it cost 0.47 $/$m^3$ at Yanbu IV, and 0.32 $/$m^3$ at Sorek II. Ten years ago, this cost was still estimated at $1 per 1,000 liters.

5. R. Semiat, "Environmental Science & Technology", *Energy Issues in Desalination Processes*, October 21, 2008, available at: https://pubs.acs.org.

A Wide Variety of Industrial Players, Led by Europe

Different types of installations meet different needs

Desalination plants are diverse. First of all, in terms of size, as the 22,000 plants listed worldwide include very small plants capable of desalinating less than 1,000 m^3 of water per day, as well as plants capable of desalinating more than 1 million m^3 per day (particularly in the Gulf countries). This is the case of the Ras al Khair installation in Saudi Arabia and Sorek in Israel.

There are also several desalination processes. Beginning with thermal desalination processes, these include the multi-stage flash (MSF) distillation process and the multi-effect distillation (MED) process. Then, there are different processes using membranes, like reverse osmosis and electrodialysis. Initially, the majority of plants were built on a thermal model, especially in the Gulf countries, because the MED process is barely affected by the degree level of salinity of water, which can deteriorate the membranes. Yet reverse osmosis now accounts for more than 70% of plants (i.e., a majority). Finally, desalination plants meet agricultural, industrial and consumer needs. While 70% of the world's water is used in agriculture, 20% in industry and 10% by households, the distribution varies by region. For example, in the Middle East, agriculture accounts for more than 80% of water demand and the sector is constantly increasing its water footprint due to the region's food security ambitions.[6]

French and European players are very present and integrated in local markets

European players, especially the French and the Spanish, hold leading positions in the desalination market. Their capacity to raise funds quickly, their expertise and their ability to adapt to the industrial needs of the contracting countries contribute to the influence of these companies. In France, Veolia and Engie stand out for being very dynamic in their desalination activities abroad. After the merger of Suez and Veolia, the activities of Suez Middle East were added to Veolia's business, making the group a strategic player in the region and allowing it to look at new development prospects. As for the new Suez, it is refocusing on Africa, part

6. "Food and agriculture. Land and Water Management", International Atomic Energy Agency/Food and Agriculture Organization, available at: www.iaea.org.

of Europe, Australia, China and India. Alongside Veolia, Engie maintains a leading position in the MENA region.

Spanish companies also stand out in the desalination landscape. With more than 85 plants, producing about 5 million m^3 of desalinated water every day, the Spanish company Acciona occupies a significant position in the desalination market and has been very successful with projects in Saudi Arabia, Mexico and the Philippines. Abengoa, another Spanish leader, is also continuing to entrench its position in the Gulf and Israel.

Asian and local players are growing

Asian companies are gradually joining the desalination market and competing with traditional industry leaders. In South Korea, Doosan Heavy Industries stands out for its successful international presence with more than 30 plants built and owned abroad. Recently, the Korean firm won the construction of the very large Yanbu IV plant in Saudi Arabia.

In China, the Shandong Electrical Power Construction Co (SEPCO), founded in 1985 and a subsidiary of the China Power Construction group, now has more than 85 projects in progress, in Saudi Arabia, Jordan, Nigeria, Oman, Singapore and in India, the group's largest market. HEWITT, another Chinese company, has secured several major desalination projects in China itself, and, as previously mentioned, Hutchinson Water International made it to the final stage of a major Israeli tender in 2000.

Many of the countries facing water stress have developed real local expertise in desalination. This is the case of Israel with the IDE company that has built all the factories in the country and which now runs many projects internationally, for example recently obtaining a contract in Chile. In Saudi Arabia, Advanced Water Technologies has tripled its activities, while in the UAE, Métito is booming and Masdar showcases big ambitions to develop sustainable and efficient innovations too. These local suppliers are gradually gaining prominence in the region by obtaining large-scale contracts for the construction of mega-factories.

Future Prospects in View of the Water and Environmental Crises

A water crisis is defined here as the gap between available resources and the growing demand for water. The global water deficit will increase fivefold by 2050 and it is estimated that about US$150 billion per year will be needed to address it: i.e., to ensure universal access to water and sanitation. This means that despite the adequate management of drinking water demand in the coming years, demand will still exceed supply by 40% by 2030.[7]

The Paris Agreement requires signatory countries to embark on a path to reduce greenhouse gas (GHG) emissions, and more than 130 countries have committed to achieving carbon neutrality by 2050. This clearly means that the model of desalination based on plants boosted by fossil fuels is no longer sustainable. A majority of the Gulf countries have decided to adopt a "zero carbon" strategy by 2050 or 2060, including the UAE, Saudi Arabia, Oman and Bahrain. Qatar has committed to reducing its emissions by 25% by 2030, the UAE by 23.5%, and Israel to cut its emissions by 27% by 2030 and by 85% by 2050. For its part, Saudi Arabia has committed to generate 50% of its electricity from renewable energy sources by 2030 and 50% for natural gas, thus phasing out oil from power generation.[8] These commitments mean that desalination plants will have to gradually reduce not only their GHG emissions, but their overall environmental footprint as well.

This last part outlines solutions to counter this water crisis, both in terms of demand management and water supply. Two levers must be used to prevent a water crisis: first, rationalizing the demand for desalinated water, and second, increasing the use of renewable energies.

7. "Ensuring Sustainable Water Management for All by 2030", World Economic Forum, September 16, 2022, available at: www.weforum.org.
8. "Saudia Arabia", Climate Action Tracker, available at: https://climateactiontracker.org.

The Climate and Biodiversity Challenge of Desalination

Greenhouse gas emissions

Water desalination is an industry that emits a significant amount of GHGs, as desalination processes are very energy-intensive, with energy consumption depending on the method used. Among the thermal methods (25% of plants), which are the most energy-intensive, the MSF (multi-stage flash) method consumes between 19.6 and 27.3 kWh per m^3 of desalinated water; the MED (multi-effect distillation) method uses between 14.5 and 21.4 kWh per m^3 of water; and the MVC (mechanical vapor compression) method requires between 7 and 12 kWh to produce 1 m^3 of water. Membrane methods have a lower energy consumption: reverse osmosis consumes between 2.5 and 3 kWh per m^3 of desalinated water, while electrodialysis uses between 2.7 and 5.6 kWh/m^3.

As desalination plants mainly use fossil fuels, their carbon footprint is particularly high. The current energy calculation is quite clear: desalination of 1,000 m^3 (one million liters) per day consumes approximately the equivalent of 10,000 tons of oil per year.[9] The carbon footprint of seawater desalination by reverse osmosis (RO) has been calculated at between 0.4 and 6.7 kilograms of CO_2 equivalent per cubic meter (kg CO_2eq/m^3). This means that desalination of 1,000 m^3 of seawater could potentially release up to 6.7 tons of CO_2.

Electricity consumption in the water desalination sector increased threefold in Saudi Arabia during the period 2005-2020, reaching about 6% of the kingdom's total electricity consumption, or about 17 TWh in 2020. It is the equivalent of the annual production of a large nuclear power plant.[10] Such high consumption can be explained in particular by the fact that more than 60% of plants use thermal distillation and require large quantities of fossil fuels.[11] In total, Israel's water supply consumes nearly 10% of its national electricity production (mainly from natural gas), with desalination accounting for about 4-5% of the country's energy demand. Although this figure is lower than for air conditioners in the country, it is high enough to raise questions about the sustainability of the desalination boom in Israel.[12]

9. A. Tal, "Addressing Desalination's Carbon Footprint: The Israeli experience", *Water*, Vol. 10, No. 2, February 2018, available at: https://doi.org/10.3390/w10020197.
10. Calculations based on statistics from the Central Bank of Saudi Arabia, data collected in August 2022, available at: https://datasource.kapsarc.org. Note that this statistical category also includes education and health.
11. A. Tal, "Addressing Desalination's Carbon Footprint: The Israeli experience" , *op. cit*.
12. *Ibid*.

For the Middle East, the International Energy Agency has calculated that 5% of total energy consumption comes from desalination plants, with some disparities between countries regarding their energy mix.[13]

Renewable energy sources are not often used in desalination worldwide, with a study conducted in 2017 estimating that they provided only 1% of the energy needed for desalination.[14] Thus, while energy consumption varies according to the energy mix, the type of plant and its size, it can nevertheless be estimated that at least 120 million tons of CO_2/year are generated by desalination sectors each year. Crude oil also contributes four times more to GHG emissions than other fossil fuels used for desalination.[15] Reverse osmosis techniques are considered to be the least deleterious for the climate since they emit between 2.1 and 3.6 kg of CO_2 per m^3 of desalinated water, while thermal technologies create between 8 and 20 kg of CO_2 per m^3 of desalinated water.

Brine discharge

After the desalination process, the water is separated into two parts: the permeate (desalinated water) and the concentrate. The latter contains a very high level of salt, as well as the chemicals used in the pre-treatment and maintenance of the facilities. It is unsuitable for any agricultural, industrial or consumer use, and so this concentrate is discharged into the sea, most of the time. Every liter of desalinated drinking water produces 1.5 liters of liquid polluted with chlorine and copper (UNEP), and more than 80% of the wastewater generated by desalination ends up in seas, rivers, lakes and wetlands. The impact of this discharge on its environment depends on its hydrological characteristics and marine flows. Indeed, the release of brine does not have the same impact on the coral reefs of the Maldives, say, as it does on the oceans.

According to a 2019 UN report, seawater desalination produces more than 150 million m^3 of brine per day, which is highly polluting. In addition, 80% of these discharges occur within 10 km of coasts and fall to the seabed. These figures mask great geographical disparities, since, in reality, more than 55% of brines are produced by Saudi Arabia, the UAE, Kuwait and Qatar.[16] This is explained in particular by the fact that the majority of the plants in

13. M. Walton, "Desalinated Water Affects the Energy Equation in the Middle East", International Energy Agency (IEA), January 21, 2019, available at: www.iea.org.

14. M. W. Shahzad *et al.*, 2017, "Energy-Water-Environment Nexus underpinning future desalination Sustainability", *Desalination*, Vol. 413, pp. 52-64, July 2017, available at: http://dx.doi.org/10.1016/j.desal.2017.03.009.

15. K. Al-Shayji and E. Aleisa, "Characterizing the Fossil Fuel Impacts in Water Desalination Plants in Kuwait: A Life Cycle Assessment approach", *Energy*, Vol. 158, pp. 681-692, September 2018, available at: https://doi.org/10.1016/j.energy.2018.06.077.

16. M. Qadir *et al.*, "Economics of Salt-Induced Land Degradation and Restoration", *Natural Resources Forum*, Vol. 38, No. 4, 2014, pp. 282-295, October 28, 2014, available at: https://doi.org/10.1111/1477-8947.12054.

these countries operate with thermal energy, so that 75% of the salt water incorporated is then discharged in the form of brine, compared to 50% for desalination by reverse osmosis.

Finally, a World Bank study, analyzing the environmental consequences of desalination, estimates that if nothing is done to make desalination more sustainable, then by 2050 the annual rate of discharged brines could reach 240 km^3 (compared to 40 km^3 today), accompanied by a volume of GHG emissions of 400 million tons of carbon dioxide worldwide (by way of comparison, this was roughly equivalent to the volume of French CO_2 emissions in 2021).[17]

Technological improvements and the decarbonization of energy supply

Progress has been made in desalination technologies. Reverse osmosis, the most widely used process, now consumes less energy, and thus releases less CO_2 than thermal processes. This is the result of several decades of improvement in the energy efficiency of the technologies used. Since 1970, the energy consumption of reverse osmosis plants has been reduced by a factor of ten. The challenge of protecting membranes from salt continues, as does the search to improve the costs and energy efficiency of the process. The majority of market leaders have active research and development (R&D) departments in this field.

Yet, despite these tangible improvements, reverse osmosis desalination is still energy-intensive, which explains the gradual development of coupling it to low-carbon energy sources, mainly renewable energies, whose deployment costs have fallen sharply in recent years, or even to nuclear power.

Solar energy is considered to have the greatest potential as a long-term renewable energy source for sustainable desalination. There are two main types of solar-powered desalination: concentrated solar energy (CSP) and photovoltaic (PV) power. CSP generates direct heat and is generally used to evaporate water in thermal desalination. PV uses solar panels to produce electricity, which powers pumps for reverse osmosis. For example, the Al Khafji plant in Saudi Arabia produces 60,000 m^3 of desalinated water every day by reverse osmosis using photovoltaic panels.

A study published in the *International Journal of Economics and Management Sciences* highlights the potential of solar desalination by showing that a photovoltaic-powered reverse osmosis plant can produce water at a cost of $1.213/$m^3$, while for the moment, the cost of producing desalinated water with energy from a fuel-fired power plant oscillates

17. "The Role of Desalination in an Increasingly Water-Scarce World", World Bank Group, March 2019, available at: https://documents1.worldbank.org.

substantially between $1.118 and $1.555. The cost production record of 1.75 cents/kWh for the Sakaka project in Saudi Arabia demonstrates that renewable energy can largely compete financially with fossil fuels.

At this stage, most large-scale desalination projects powered by renewable energy are powered by wind power. Wind desalination is particularly well suited to coastal and island communities due to the proximity of the energy source, water and user populations. Wind power is used on the islands of Gran Canaria and Fuerteventura in Spain, which have particularly suitable weather conditions. In Australia, the Perth plant is powered by electricity from the 80 MW Emu Downs Wind Farm. Each year, this wind farm supplies 270 gigawatt hours (GWh) to the grid, which more than offsets the desalination plant's needs of 180 GWh per year. Wave energy is more difficult to exploit. An innovative project in Australia was launched in 2014 to produce fresh water and electricity from the ocean. Cape Verde is also about to see the birth of a wave desalination project. Desalination plants can also be coupled with nuclear generators and the ongoing installation of three nuclear power plants on the Emirati grid opens up the possibility of coupling with desalination plants. Solar and wind coupling therefore has very promising potential.

However, only 1% of desalination plants currently use renewable energy.[18] The Global Clean Water Alliance, founded by the International Desalination Association, has set a target that at least 20% of new desalination plants should be powered by renewable energy between 2020 and 2025. In Australia, all new desalination plants must operate on renewable energy.

Yet, obstacles remain. First, there is the question of intermittency: i.e., the mismatch between energy supply and demand due to the dependence of production on weather conditions. This is especially a problem for solar (PV) and wind power desalination.

Energy storage is becoming a requirement for the uninterrupted and reliable operation of desalination plants, but batteries are still considered an expensive option that is not necessarily a suitable solution. Several solutions can be envisaged to overcome this intermittency issue: solar and wind coupling where possible, complemented by a connection to the grid (with more green electricity); and thermal storage, as found in concentrated solar power plants that can store heat so they can continue to operate a few hours even without sunlight. "At present, most thermal storage systems are between 8 and 16% efficient. In 10 or 20 years, technical improvements are expected to increase efficiency by 15-25%," according to the World Bank (2019). Building water storage capacity is a further alternative. It is also possible to build water towers in order to store the surplus produced during the day and to return it at night.

18. M. W. Shahzad *et al.*, 2017, "Energy-Water-Environment Nexus Underpinning Future Desalination Sustainability", *op. cit.*, pp. 52-64.

The urgent need to rationalize desalinated water demand

Reducing network losses

There is an urgent need to reduce losses of freshwater distribution networks. Total water loss is calculated by subtracting the amount of water charged or consumed from the amount produced. The Middle East is characterized by particularly high network losses, estimated at between 30 and 50% in urban areas. This means that out every 1,000m^3 of desalinated water produced, only 500m^3 to 700m^3 actually reaches consumers. In Saudi Arabia, in 2018, 474 million m^3 were lost, or about 40% of total production. North African countries also experience this problem.

The economic challenge of such losses is compounded by environmental problems in a region where resources are already scarce. Malta provides an interesting example for understanding the constraints on reducing network losses. Indeed, the island installed desalination plants in the 1990s, but very quickly faced high rates of leaks even as the demand for desalinated water was increasing. The Water Services Corporation (WSC) launched a policy of reducing losses on the grid, coupled with the reduction in energy consumption of the desalination plants. The program was able to reduce losses from 4,000m^3/hour in 1995 to about 45 m^3/hour today. In so doing, it prevented the establishment of two new desalination plants that had been commissioned. Qatar also has a good record, as its water loss rate of 30% in 2011 has been greatly reduced since then. Similarly, Israel stands out with near-zero leakage rates, thanks to its highly-intensive monitoring of networks. New technologies for detecting and repairing leaks are being developed, notably by companies in Italy, where the problem is also significant.[19]

Therefore, before committing to the construction of new plants, it is imperative to put in place effective policies to analyze losses and leaks in distribution networks. This goes hand-in-hand with the clear and transparent governance of resources, which is not the case in a majority of countries, particularly in the Middle East, where overlapping administrative levels undermine the effectiveness of public policies. Finally, subsidies need to be reduced, while water collection and retreatment strategies should be developed.

19. O. Bonnel, "En Italie, la vétusté des canalisations responsable d'un gaspillage d'eau permanent", *Le Monde*, August 14, 2022, available at: www.lemonde.fr.

Transforming agriculture

To rationalize water demand, it is also necessary to transform the agricultural models of countries that consume desalinated water. Indeed, apart from network losses, it is common to see the agricultural sector consuming massive amounts of water without necessarily putting in place policies to preserve the resource. In the Middle East or Africa, agriculture accounts for a very large share of the overall amount of water consumed, even though local populations often lack it. In Middle Eastern countries, more than 85% of fresh water is used by agriculture.[20] For example, in Saudi Arabia, agricultural policies and irrigation methods used since the 1980s are considered to have been linked to the loss of two-thirds of the country's groundwater supply.

In a context of water scarcity and rising demand, the agricultural sector needs to rationalize its consumption. Israel is an example of success. In 1965, an Israeli company invented drip irrigation, a technology that has since continued to develop and is now deployed in 75% of Israeli agricultural plantations, compared to 5% on average worldwide. In addition to controlling the volume of irrigated water, farmers use recycled wastewater to water crops. As a result, the recycling rate of Israeli agriculture is 87%, compared to 20% on average elsewhere in the region. The development of economic relations between Israel and the UAE is thus driven in particular by Israel's agrotech sector, that offers solutions to the UAE, which for their part intend to develop their agricultural sector to achieve greater food security. Several solutions may be considered:

- First, increasing wastewater recycling capacities.
- Improving irrigation by drawing on Israel's example of "smart irrigation" which allows for precise control of the quantities of water used for crops, thanks to new technologies. A project in Al-Hasa, Saudi Arabia, has cut water consumption by 44%, while plant growth has risen by 21%.
- In addition to more efficient and targeted irrigation, agriculture's water needs can be reduced by changing traditional uses. Vertical farming is an example of future low water consumption agriculture. Al Quoz's farm in Dubai, producing 18 varieties of micro-shoots, is a good example.

Another issue is also the degree of salinity of the water. A number of studies have shown that desalinated water, despite its suitability for consumption, sometimes has adverse effects on crop quality. Reverse osmosis desalination is considered the best solution for this.

Better use of water used by agricultural and irrigation systems could cut about 20% of the gap between water supply and demand. The remaining 80% will be filled by "renewable" desalination systems (World Bank).

20 World Bank, 2015.

Controlling the discharge of brines

In March 2019, the United Nations Environment Assembly adopted a resolution on the protection of the marine environment from land-based activities. The protection and restoration of ecosystems against the impact of water, air and other pollution is a key principle of the United Nations Decade for Ecosystem Restoration (2021-2030) and the United Nations Decade of Ocean Science for Sustainable Development (2021-2030).

However, more and more researchers are highlighting the potential of brines which have a high lithium content. They would, for example, significantly increase the profitability of aquaculture for spirulina production or mineral extraction. Veolia stands out for its innovative efforts in this area. In Oman, at its Sur site (located three hours from the capital), the company has implemented a number of policies to protect biodiversity and adapt to the local environment, including: research on brine reuse, water filtration measures to protect marine species and the creation of an artificial reef.

Desalination as a last resort for states in crisis

Flexible solutions to be installed, particularly in remote areas and island states

A number of regions, especially in developing and island areas, lie far from energy networks. They therefore require the installation of modular and decentralized desalination solutions. In these regions, the cost of expanding national electricity grids in the short term to supply desalination projects with conventional electricity is higher than establishing renewable energy sources locally. The same is true for older desalination plants that are less energy efficient than new reverse osmosis plants. Small-scale desalination systems (also called modular desalination systems), rapidly deployable, do not require any network connections and therefore have an important role to play in alleviating water scarcity, all while having a minimal impact on global warming. For the moment, these small-scale systems are still 1.5 to 3 times more expensive (*Low Carbon Desalination Report*, 2016), though the decrease in the cost of photovoltaic panels in recent years has significantly improved their competitiveness.

For example, in Saudi Arabia, Suez (now Veolia) has installed modular units in containers.

Some projects stand out for their innovative character. This is the case of the French start-up Mascara Renewable Water with its OSMOSUN® process that enables desalination by batteries, thanks to solar energy. This solution combines reverse osmosis desalination with decarbonized energy. The company develops units that are 100% autonomous and desalinate between 1 and 10,000m^3 per day of seawater or brackish water. To overcome the problem of intermittency, these units can be connected to alternative sources of electricity. They have been installed in Bora Bora, Cape Verde and Madagascar, and are particularly adapted to the needs of island territories, which at one point even went so far as to envisage the supply of fresh water by boat.

This technology has brought water to more than 400 families who previously faced strong water insecurity in the Komodo National Park in Indonesia, for example, because the island only has brackish water and no exploitable freshwater source. A solar generator was installed (providing 5 kWp) to supply energy to the OSMOSUN® unit, allowing "green" water to be produced, and sold at a lower price than the local alternative of buying water on land.

The Maldives archipelago is not exempt from these problems either. Already, 39 islands have desalinated water supply systems and more than 80 islands have ordered desalination systems in addition. Eventually, the entire archipelago should be equipped with desalination facilities. The majority of operational tourist resorts already have their own infrastructures.

The financing challenges

The establishment of desalination plants in areas of strong water stress can be subsidized and supported by various actors: development banks, non-governmental organizations, as well as operators from third countries. It is crucial that the financing of development programs be conditional on the sustainability of the projects in question, an approach adopted by the French Development Agency (AFD), which has decided to bring 100% of these programs into line with the Paris Agreements. Getting all the major international financial institutions to comply with the Paris Agreement is one of the keys to strengthening the sustainability of desalination.

Conclusion

The desalination industry has been on the rise for two decades. Needs have never stopped increasing, driven by population growth, climate change and the scarcity of available resources. These needs are now reinforced by the challenges of sovereignty as well as social and economic resilience.

An important desalination industry has been developing over the past ten years, boosted first by European actors, then supplemented by Asian players, followed by new “local” companies that take a growing market share in their countries of origin. In parallel with these behemoths, capable of carrying out very large desalination projects, there are thus smaller companies capable of developing modular solutions that can be adapted to different needs. But desalination poses two problems:

- the release of brines into the seas and oceans;
- the high electricity consumption of desalination plants and therefore the potentially very high emission of GHGs related to the use of fossil fuels to produce electricity.

These issues are well-known to the actors and users of these technologies, who are gradually beginning to examine the use of desalinated water and desalination technologies.

Acting on water demand is essential and should be a priority: it is urgent to put an end to water losses in networks, which are often poorly measured and poorly managed. They are hidden and sometimes certain countries even prefer to announce the construction of new plants rather than take care of such losses. Facilitating the sharing of good practices, be they institutional, regulatory or technical, through drawing on existing expertise, is key. The question of water consumption also needs be addressed by targeted policies: towards consumers to encourage the reduction of unnecessary consumption; towards agricultural actors to encourage ambitious policies of water reuse and resource efficiency; as well as towards manufacturers who must make determined and up-to-date commitments to reduce the water footprint of their value chain.

Then, if the conventional water supplies are no longer sufficient, unconventional (i.e., desalinated) water supplies must be made as sustainable as possible. Reverse osmosis methods should be preferred but this is not enough. Desalination plants cannot continue to rely on fossil fuels as it is currently the case in most of MENA countries. The massive development of renewable energy sources, and/or nuclear, should thus be a priority, removing coal too, and finally, addressing fugitive methane emissions where there is gas fired power generation.

It is essential that access to desalinated water does not become a new cause of worsening climate change and the destruction of biodiversity. There is a key sequence of international governance meetings to advance a sustainable agenda on water desalination issues; COP27, under Egyptian presidency, followed by the United Nations Water Conference in March 2023, and in December, COP28 in the UAE: these opportunities to act both on the demand and supply side, as well as on the expansion, integration and decarbonization of electricity systems, should not be missed. IRENA’s widely recognized expertise, and the UAE's central role and position in this industry, could be game changers in this respect. So could be the growing role and interest in these technologies in North African countries such as Morocco, which hosted the World Water Council’s International Summit on Water Security in 2019 and can set a precedent for building sustainable, competitive water desalination systems, both on the demand, transport and supply sides.

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