POWERING DESALINATION WITH RENEWABLE ENERGIES in Morocco
Powering desalination with renewable energies in Morocco
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<td>ANRE</td>
<td>Autorité Nationale de Régulation de l’Electricité</td>
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<tr>
<td>BOT</td>
<td>Built-Operate-Transfer</td>
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<tr>
<td>BOOT</td>
<td>Build-Own-Operate-Transfer</td>
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<tr>
<td>BW</td>
<td>Brackish Water</td>
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<td>CAPEX</td>
<td>Capital Expenditure</td>
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<td>CESE</td>
<td>Conseil Economique, Social et Environnemental</td>
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<td>CSP</td>
<td>Concentrated Solar Power</td>
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<td>DH</td>
<td>Dirham</td>
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<td>FAO</td>
<td>Food and Agriculture Organization</td>
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<td>GCC</td>
<td>Gulf Cooperation Council</td>
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<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<td>IPP</td>
<td>Independent Power Producer</td>
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<td>LCOE</td>
<td>Levelized Cost Of Energy</td>
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<td>MED</td>
<td>Multi-Effect Distillation</td>
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<td>MENA</td>
<td>Middle East and North Africa</td>
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<td>MSF</td>
<td>Multi-Stages Flash</td>
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<td>OCP</td>
<td>Office Chérifien du Phosphate</td>
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<td>ONEE</td>
<td>Office National de l’Electricité</td>
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<tr>
<td>PMV</td>
<td>Plan Maroc Vert</td>
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<td>PNE</td>
<td>Plan National de l’Eau</td>
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<td>PNEEI</td>
<td>Plan National d’Economie d’Eau en Irrigation</td>
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<tr>
<td>PPA</td>
<td>Power Purchase Agreement</td>
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<td>PPP</td>
<td>Public Private Partnership</td>
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<td>PV</td>
<td>Photovoltaic</td>
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<td>RO</td>
<td>Reverse osmosis</td>
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<td>SNE</td>
<td>Stratégie Nationale de l’Eau</td>
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<td>SWRO</td>
<td>Seawater Reverse-osmosis</td>
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Morocco is one of the most water-scarce countries in the Middle East and North Africa region. Eighty percent of Morocco’s territory is arid to semi-arid. Due to a combination of a decline in precipitation, a commensurate decline in river runoff, population growth, and strong economic development, water resources are under severe pressure. Water availability in Morocco has dropped from 730 m$^3$ per person in 2005 to 645 m$^3$ per person in 2015, and it is projected to reach 510 m$^3$ per person per year by 2050. The Kingdom is carrying out an ambitious strategy involving multiple aspects of the water management value chain, including the installation of several desalination plants.

Desalination is a water treatment process that separates salts from saline water, which results in an output stream of freshwater and some leftovers. It is typically an energy-intensive process mostly powered by fossil fuel sources as of today (with around 76 million tons of CO2 emitted per year worldwide). Knowing that the technology is expected to cover 14% of the world’s water needs by 2050, this could pose a climate and environmental risk if no proper actions are taken. One of the most effective ways to cut emissions is to couple desalination plants with renewable energy sources such as wind, solar, geothermal, and others to provide the required clean energy input.

This is particularly true for Morocco. The country is in fact endowed with a tremendous wind and solar energy potential, solid leadership in the installation and management of renewable energies, and the technical capacity to explore new advancements in this field. In addition, with rising fossil fuel prices and decreasing renewable energy costs, this solution also appears cost-effective.

This report, therefore, proposes desalination powered by renewable energy as a sustainable opportunity to meet the country’s water needs while minimizing the environmental footprint of the process. In particular, the document showcases the various desalination technologies and the models applied globally, analyzing the technical performance and costs, and delves deeper into the current situation and the market potential in Morocco, including regulatory, finance, and technical capacity. Policy recommendations are based on interviews and a thorough analysis of the literature.

The report has been prepared through a collaborative effort between RES4Africa Foundation and AFRY. For a decade, the Foundation has acted as a catalyst for dialogue between the European private sector and Morocco’s decision-makers, providing support at the policy and regulatory level and fostering knowledge transfer and investments in the energy transition. AFRY, as a knowledge partner, provides expertise and insights to address and solve some of the most important issues of our times.

We wish to thank the partners from industry and policy-making who generously provided their knowledge and insights. Their precious input contributed to making this report an example of sound analysis and another step towards a sustainable future for Morocco, its citizens, and the planet.

Roberto Vigotti,
Secretary General RES4Africa Foundation

Antonio Nodari,
Head of Central & South Europe Region AFRY
In July 2022, the Moroccan Ministry of Water and Logistics declared a nationwide state of water emergency. Between 1960 and 2020 Morocco have been experiencing about a 75% decrease in water availability, with water levels reducing from 2,560 m³ to 630 m³ per person over the above 60-year period. With water resources decreasing drastically and domestic water withdrawals on the rise, the Moroccan government has recently published national water plans and strategies leveraging on the use of desalination technologies, with established ambitious medium and long-term targets for 2030 and 2050. Desalination, as planned by the 2020-2050 Water National Plan, is projected to reach 1 Bm³/year in 2050. This is expected to satisfy at least 5% of the future water demand.

To achieve these targets, the government started implementing some institutional reforms. Law 36-15 (2016) introduces a legal framework to support water desalination, preparing the country for its future large-scale investments. Moreover, private players can bid for projects through tenders and partner with public stakeholders through Public-Private Partnerships (PPPs). These fixed-term contractual structures – defined by Law 12-86 (2014) – provide private investors the opportunity to operate desalination infrastructure assets that were previously owned by the public sector. PPPs, not historically adopted for desalination, are considered a key enabler of the future value for the sector, attracting international players in the market, along with their respective networks, technologies, and experiences.

Morocco has a relatively small desalination capacity compared to Middle-Eastern countries: merely 0.5% of the entire capacity of the Middle East and North Africa (MENA) region. In addition, only a few small-scale desalination projects are coupled with renewable energy. Indeed, the government has announced in 2020 the construction of 10 medium to large-scale desalination projects (from 17,300 m³/day to 822,000 m³/day), mostly concentrated along the Atlantic coast. For the large-scale projects the Office National de l’Electricité et de l’Eau Potable (ONEE) requires the coupling with renewable energy as a mandatory project feature within the project’s pre-qualification dossier, as for the Casablanca plant. According to our analysis (see Figures A and B), renewable desalination plants will represent 5% of the total renewable energy consumed in Morocco.
However, according to the analysis carried out in the report, there are still several barriers to the development of desalination projects powered by renewables. Public governance coordination, power and water infrastructures readiness, water tariff adequacy, social awareness, and technological improvements could hinder the openness, attractiveness, and readiness of the renewable desalination market. In this framework, several key areas of improvement have been identified to unlock the adoption of renewable desalination. **A more integrated structure of the water and energy sectors would ease the institutional complexity and improve the governance of renewable desalination.** In addition, infrastructural challenges remain in terms of power systems integration, flexibility, efficiency, and in terms of water distribution from the desalination plants to the end users.
Other barriers that could impede the development of a renewable desalination market include high investment costs, the lack of an incentive scheme, and to a lesser extent the lack of an environmental impact assessment Law for desalination plants. As a net-energy importer in the most water-stressed region in the world, Morocco’s decision to turn to seawater desalination coupled with renewables is a strategic adaptation policy that reaps benefits for both the water and the energy sector. However, **stronger policy integration and cooperation between both sectors is key to maintaining a strategic synergy and balancing the country’s water demand and energy transition targets.** At the infrastructural level, Morocco is already deploying ambitious efforts to modernise its power system for the integration of high percentages of renewables. Complementing that with adequate water transportation infrastructure is crucial to enable the necessary water supply connections and keep the cost of desalinated water at an affordable level.

**Innovation will continue to play an increasingly important role in the development of seawater desalination,** and different technologies and combinations with renewables are emerging. Moroccan policymakers need to consider different options according to the locally available sources, and the potential utilisation of thermal and electrical storage technologies to overcome the intermittency issues. Given the high capital cost of renewable energy desalination, steps should be taken to attract a wide pool of investors, from the private, public, and international spheres. For that, incentive mechanisms and suitable contractual structures need to be provided to attain economic sustainability.

Because of the relatively recent introduction of desalination in Morocco to meet the freshwater demand, it is also crucial to examine and address the ensuing social and environmental impacts on the country. **Consequences on the marine environment and human health need to be incorporated into the regulatory framework of desalination.** Furthermore, it will also be important to engage with local communities and end users with suitable communication strategies.

Finally, building expertise and leadership in the renewable desalination field will play a crucial role in localising knowledge and innovation, and addressing the need for qualified staff to operate the renewable desalination plants. Supporting existing research centres and science parks, setting up educational specialisations in desalination, and fostering knowledge transfer between different educational institutions within and outside of Morocco would contribute to building the necessary bridge to support a sustainable renewable desalination sector.
10 Recommendations for the deployment of renewable desalination in Morocco

1. **Sector Structure.** Policy integration is key in tackling complex issues. The Water-Energy nexus could be seen as a way to look at policy and regulation design to maximise co-benefits and synergies from the energy and the water sectors. Stronger cooperation between the energy and water sectors should be encouraged and supported in governmental and non-governmental institutions.

2. **Infrastructure.** Morocco should continue in the process of modernisation of the power systems allowing for the integration of high percentages of renewable energies, while securing flexibility and efficiency, through digitalisation and integration of smart grid systems. At the same time, improving water transportation infrastructure is an enabling condition to connect sea-side desalination areas to the main-land arid regions and lower the cost of the water delivered.

3. **Regulation and policies.** Thanks to the establishment of ANRE, it will be possible to simplify the procedures for the domestic production of electricity and sale of surplus energy to the grid, as well as to identify and remove the bottlenecks in the licensing process. The publication of the implementation decrees for energy Law 40-19 could also help in promoting renewable energy desalination and attract investors.

4. **Incentive Scheme.** The adoption of renewable desalination technologies could rely on the existing mechanisms for renewable energy development given the great potential of the country and the low cost of the latest projects. To speed up the process of deployment, it is important to simplify the entire regulatory framework for IPP participation in the market.

5. **Contractual Structure.** PPPs and corporate PPAs could be a solution from a contractual point of view for renewable energy desalination. This could be facilitated by the implementation of the provisions of the related laws and would accelerate the time-to-market of this kind of technology.

6. **Environmental Impact.** It is crucial to design a specific law on the environmental impact assessment of desalination plants. Given the particular concerns about brine management and its impact on the aquatic environment and tourism, the lack of a regulatory framework might undermine the adoption of desalination.

7. **Social Awareness.** A long-term and consistent communication strategy to communicate progress in the field and the success stories of renewable energy desalination installations to local communities and relevant stakeholders would increase the social acceptance of the adoption of the technology.

8. **Technical Skills.** Education at all levels is necessary, covering technological, economic, social, and institutional aspects of renewable energy coupled with desalination. Renewable energy desalination should be included as part of universities’ and technical schools’ curricula to cover the technology in more detail.

9. **Technology.** Renewable energy technologies and desalination technologies have developed along independent paths. To overcome the challenge related to the intermittency of supply, hybridization together with tailor-made control systems can guarantee continuous operation along with the utilisation of electrical storage technologies (in particular, batteries), which is considered the best solution.

10. **Investment.** Desalination investments have been slowly implemented in Morocco due to the relevant CAPEX required. It would therefore be important that the national plans take into account the economies of scale of the plants and that the DFIs are involved, pooling private, international, and public resources to finance this type of solution.
Chapter I

The Water-Energy nexus and its implications for the MENA region
Defining the Nexus

Water is the most important resource impacted by climate change. It channels its main consequences to all aspects of the economy, society, and environment - through precipitation, storm surges, floods, droughts, rising seas, and groundwater recharges. Leveraging on the potential of water and limiting its destructive aspects are crucial objectives that require coping with water-related extreme weather events - like severe droughts and floods - as well as trends that will change rainfall patterns, and increase the water demand.

About 1.6 billion people live in countries with physical water scarcity, and in just two decades this number may double, representing over 40% of the world’s projected population. However, it is not only the population that is pressuring water resources: increasing productive uses are also evident. The global population tripled in the 20th century, but the use of water increased six-fold. By 2050, water demands are expected to increase by 400% from manufacturing, and by 130% from household use1.

Looking at freshwater withdrawal from streams, lakes, aquifers, and human-made reservoirs, data suggests that demand has been growing rapidly during the last century and it still is in most parts of the world. The global freshwater withdrawal was probably around 600 km³/year in 1900 and increased to 3,880 km³/year in 2017, according to recent estimates2. The highest rate of increase was registered (around 3% per year) during the period 1950–1980, due to population growth, and groundwater development, particularly for irrigation. The rate of increase is currently approximately 1% per year, aligned with the population growth rate.3

Among the most important risks caused by water, droughts are the costliest with significant impacts on agriculture: in the USA they can cause an average of US$6–8 billion worth of losses in agriculture; in China, they resulted in an annual grain production loss of more than 27 million tons over the last two decades. Enhancing water security could stabilise food crop production and prices.

Indeed, in its annual survey of almost 900 leading decision-makers from business, academia, and the public sector, the World Economic Forum ranks water crises and failures to adapt to climate change as two of the greatest global risks.4 Addressing these problems will be critical in achieving the new and ambitious Sustainable Development Goals (SDGs) adopted by the United Nations in 2015 and, in particular, SDG Goal 6 (Universal access to clean water and sanitation). Water has cascading effects across the economy which will impact the achievement of other SDGs too, urging the need for a shift in the way water is managed, going beyond business-as-usual remedies. There is a greater need for coordination between sectors that use water as the common factor of production.5

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2 See FAO, Aquastat.
5 UN-Water (2021).
On the other hand, energy is another critical element to human well-being and together, they have paramount roles in the achievement of the SDGs. Meeting the ever-growing water and energy needs of an increasing population, rapid economic development, and expanding consumption patterns pose a real challenge to many countries, especially the ones characterised by increasing water scarcity. If left unmanaged, this water scarcity has the potential of jeopardising food security and putting a strain on socio economic stability in many regions of the world.

The strong interlinkages that exist between water and energy will further exacerbate this challenge as water is needed in the production, transportation, and use of energy. Similarly, energy is needed in the several stages of water management such as extraction, treatment, and distribution. This suggests that strong trade-offs exist between the way water and energy are managed, leading to the fact that the policy choices made in one department have clear consequences in the other one. For instance, data suggests that the same countries that rank low on access to water also tend to have very poor access to electricity.6

In the same wake, according to the IEA, the role of energy is paramount in the achievement of SDG 6 as the amount of energy used in the water sector is projected to double by 2040.7 Conversely, a growing global energy demand calls for greater consideration of water use in the energy sector. This interdependency between the systems by which water and energy are produced and distributed can be best described as the water-energy nexus.

Addressing the water-energy nexus demands surely a technological approach, driven by research and innovation. Nevertheless, policies need to promote and accompany this progress. In the global race towards decarbonization, countries that are most threatened by climate change are urged to go beyond a compartmentalised approach in drafting their energy transition strategies and rethink their governance to create more integrated policies.

The Water-Energy Nexus in the MENA region

In the MENA region, the water-energy nexus has emerged as a critical issue in the last decade and, taking into account the aspect of food security, it is considered to be the key to the region’s climate mitigation and stability. The MENA region is one of the most water-stressed regions in the world8 with one of the highest water-withdrawal-to-availability ratios.

Although water endowments differ in the region, a recurring trend is that both surface and groundwater resources are facing a non-sustainable use and overexploitation. This large definition of water scarcity

7 See https://www.iea.org/articles/introduction-to-the-water-energy-nexus.
8 World Bank (2018).
does not consider the improvements that nonconventional water supplies provide, as is the case of the Gulf Cooperation Council (GCC) countries and Israel, but it emphasises the alarming decrease in physical water availability in the region. As figure 1 shows, most countries will experience an increase in water scarcity ranging from 25% to 100% by 2050, whereas countries hit by conflict and fragility will suffer more severe consequences such as the case of Yemen and the Syrian Arab Republic.9

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Figure 1: Projected range of water scarcity in the MENA by 205010

Source: World Bank and University of Maryland calculations.

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**Water and agriculture**

Besides water availability, the other issue underpinning water scarcity is that the water cycle will become less and less predictable, making rainfall events highly variable, thus disrupting water supply and agricultural systems, especially for small-scale farmers in rainfed areas who produce a significant part of the food demand in the region. Moreover, limited water availability will also result in changing the types of crops that will be grown in the region in the future, therefore affecting local food consumption patterns as well as agricultural exports. Studies suggest that all countries in the region stand to witness losses in their agricultural production. Saudi Arabia will suffer the highest losses by 2050 (65%), followed by Yemen

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10 Ibid page 2.
(35%) and the Syrian Arab Republic (13%). In addition to rising food security concerns, export revenues from agriculture are expected to drop in most countries. As figure 2 illustrates, being the most populated country in the region, Egypt is projected to be the most affected country by the decline of agricultural exports, followed by Saudi Arabia and Israel.

Figure 2: Changes in net agricultural exports in the MENA, 2050 and 2100

On the demand side, climate change and urbanisation are enhancing the competition over water use between the agricultural sector, which remains the principal source of water withdrawals in the region (see Figure 3), and the industrial and urban sectors which are considered high-value uses of water. In MENA countries, agriculture holds an overwhelming share of water withdrawals - approximately 80% - reaching even higher levels in countries like Morocco, Saudi Arabia, Syria, and Oman. Industrial water withdrawals tend to hold a smaller share with respect to withdrawals for domestic uses which are expected to take a larger share with the projected population growth.

Another critical aspect of water scarcity is the water loss experienced in the various countries of the region at the level of transmission and distribution, not to mention agricultural losses, which pose a challenge to public utilities and call for greater efforts in water efficiency and irrigation agriculture. In several countries, governments have put in place awareness campaigns to educate institutions and the general public on the imperative of water conservation and issued strict rules for the provision of well licences.

12 Ibid page 5.
Figure 3: Water withdrawals by sector in the MENA region\textsuperscript{14}

Water withdrawals, by Sector, and by Country and Economy

MENA = Middle East and North Africa.

Water and energy

In the context of high population growth and rapid economic development, water scarcity not only affects the domestic, agricultural, and industrial water supply, but it also impacts the region’s capacity to meet its future energy needs. Indeed, shifts in precipitation patterns and droughts have clear impacts on hydropower generation as water levels are increasingly lower in dams, and water shortages jeopardise the output from thermal power plants that use freshwater cooling.\textsuperscript{15}

On the other hand, to meet growing energy demands in the region, electricity generation is expected to increase significantly by 2050 (see Figure 4). Policymakers will need to account for the impacts of water scarcity in the long-term as they design their respective energy transition strategies and water policies. Processes such as seawater desalination, wastewater treatment, and groundwater pumping will continue to take up more space in the booming energy demands. Yet energy system approaches will differ according to the level of economic development, fossil fuel reserves, and concern for water and food security.\textsuperscript{16}

\textsuperscript{14} World Bank (2018).
\textsuperscript{15} IEA (2021).
\textsuperscript{16} World Bank (2018).
These water and energy constraints have the potential to push energy systems in the direction of using non-conventional water resources and less water-intensive cooling options, thus spurring the adoption of renewable energy technologies. Renewable energy sources use little or no water and are expected to grow tenfold by 2050. This shift will be possible largely thanks to the continuous fall of the Levelized Cost of Electricity (LCOE) of PV and onshore wind technologies, which went respectively from USD 0.417/kWh to USD 0.048/kWh and from USD 0.102/kWh to USD 0.033/kWh between 2010 and 2021.

These developments go hand in hand with climate change mitigation efforts and the energy transition strategies adopted by several MENA countries in the last couple of years. Many have decided to capitalise on their abundant renewable energy sources endowments and set clear visions with ambitious RES targets for the next decades. Morocco and Egypt are arguably the most advanced countries in the clean energy transition in the region, but many others are following suit, taking advantage of this window of opportunity to build a sustainable future.

In that scenario, seawater desalination coupled with renewables is therefore one of the solutions to address simultaneously the projected water and energy demands. Due to the high costs of conventional sources and the energy intensity of the process, desalination development has been concentrated in high-income and fossil fuels-rich GCC countries (Figure 5). Although renewable-powered desalination has the potential to break the cost

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18 Ibid page 30.
19 IRENA (2022).
barrier and become a viable alternative to traditional freshwater resources for net energy importing countries. This would provide relief to the already pressured groundwater and surface water resources, help countries have a more balanced and reliable water supply, while improving energy security and independence.

Figure 5: Water withdrawals by source in the MENA region, 2010\textsuperscript{20}

In the fast-evolving contexts of the Middle East and North Africa, bracing for a water-scarce future therefore requires more than just looking at water policy, but rather at the whole system where food, energy, and water intersect. In such conditions, water security will become increasingly challenging to meet and will demand new policy and technology instruments that integrate all the nexus elements identified in this chapter. Leveraging the potential of renewables and increasing cooperation around water, agriculture, and energy will also play a defining role.

\textsuperscript{20} World Bank (2018).
Chapter II

Addressing the Water-Energy Nexus: desalination coupled with renewable energies
Desalination: a brief introduction

Desalination is a water treatment process that separates salt from saline water, which results in an output stream of freshwater and a stream of water with a high salt concentration along with some chemical leftovers (the so-called brine). Available technologies are mainly classified into two categories: those based on a physical change in the state of the water and those relying on the concept of filtration and using membranes. Seawater is often the raw water source used to supply this process, but several applications include brackish water as well.

Historically, desalination was born in the military realm in the United Kingdom at the end of the 18th century, then it was used in commercial cargo ships where it served the purpose of providing more navigational autonomy to the ships without having to store water onboard. The ships, which were equipped with steam engines, used single flash distillation as it was the first desalination technology developed at the time.

Since then, the desalination industry has grown steadily, and the first desalination unit was completed by a company called Weir Westgarth in Glasgow which kept a monopoly until World War II. In 1907, the first desalination plant was realised in the Gulf in the city of Jeddah by a Dutch company, then it was replaced with two units produced by Weir Westgarth with a total capacity of 135 m$^3$/day. Other desalination plants were installed in the Gulf countries starting in 1953 and many followed throughout the world, using different technologies.

Currently, it is estimated that 15,906 desalination plants are in operation, in 177 countries with a total desalination capacity of about 95.35 million m$^3$/day (34.81 billion m$^3$/day), and this figure is going to increase sharply in the next years due to the installation of mega plants. Large numbers of desalination facilities are located in the MENA (4,826 plants, 47.5% of global desalination capacity), East Asia, and the Pacific (3,505 plants, 18.4% global capacity), nevertheless, all continents register the presence of desalination plants. Moreover, it is important to highlight countries such as Israel, the United Arab Emirates, Kingdom of Saudi Arabia that cover more than 50% of their demand with desalinated water, which is used both for industrial and household purposes, and also for power, irrigation, military, and other uses (see Figure 6 and 7).

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22 Ibid page 2.
Today, desalination can be realised using several technologies. In general, a desalination plant involves different processes to obtain freshwater, among which the desalination unit is the most energy-consuming component. A desalination plant normally includes:

- Intake, composed of pumps and pipes to take water from the source (sea or brackish water)
- Pre-treatment, consisting of the filtration of raw water to remove solid components and the addition of chemical substances to reduce the salt’s precipitation and the corrosion inside the desalination unit
- Desalination, where freshwater is extracted from saltwater
- Post-treatment, to correct pH by adding selected salts to meet the requirements of the final uses.

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24 Authors’ elaboration on the data presented in Curto D. et al.
25 Ibid.
Desalination technologies can be divided into two major categories: thermal technologies (MSF, MED, and AD) and membrane separation processes (RO). Among the most important technologies, it is possible to find Multi-Effect Distillation (MED), Multi-Stages Flash (MSF), Vapor Compression (Thermal Vapor Compression, TVC, and Mechanical Vapor Compression, MVC), Reverse Osmosis (RO), Electrodialysis/Electrodialysis Reversal (EDR), Capacitive Deionization (CDI), Membrane Distillation (MD), Humidification–Dehumidification (HDH). In terms of feed water, the highest majority of desalination plants are installed along the coastlines to tap into the potential of seawater which is used at a percentage of 60.8% of global installed capacity, versus only 20.6% for brackish water.26

Figure 8: The trend of installed capacity and operative desalination plants27

Figure 9: Possible combinations of RES with desalination processes28

28 Ibid.
As figure 8 shows, thermally driven technologies such as MSF and MED dominated the sector until the late 90s. Yet with the acceleration of the global freshwater demand and the inevitable climate impacts on water availability, there has been a parallel development of new desalination technologies driven by the imperative of minimising costs and making desalination more innovative. Today, desalination capacity installed worldwide is on an upward trajectory with, on one hand, a steady growth of MSF, and on the other hand an exponential growth of RO technologies.

Membrane technologies play a dominant role nowadays – 69–73% of all installed systems globally, while thermal techniques account for ca. 27%. Among membrane techniques, RO dominates the global market as it is currently the most economical process for a wide range of salinity levels (seawater and brackish water). For low salinity feeds, mature processes such as ED and EDR are considered. Other emerging processes, such as AD, and MD are under development and may have great potential in the future. An interesting process is also CDI, which can be considered a desalination technology for brackish water.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Advantages</th>
<th>Drawbacks</th>
</tr>
</thead>
</table>
| MED        | • High water quality  
• Low energy consumption | • Scaling on the pipes |
| MSF        | • Maintenance operations to remove the scaling are simpler than in MED  
• High water quality  
• High-rated capacity | • High energy demand  
• Huge investment  
• Corrosion problem  
• Slow start-up  
• The entire plant is stopped for maintenance |
| MVC/TVC    | • High water quality  
• Low energy consumption | • Low production capacity |
| RO         | • Only electrical demand  
• Low investments  
• Coupled with many renewable energy sources  
• Modular structure of plant | • Lower water quality  
• High costs for membranes and chemicals  
• Subject to biofouling |
| ED/EDR     | • High purity of Freshwater  
• Energy consumption proportional to salt concentration | • Only for brackish water (up to 2000 ppm)  
• Bacterial contaminants not removed by the system |
| CDI        | • Potentially more efficient than ED | • Only for brackish water (up to 2000 ppm) |
| MD         | • No applied pressure  
• Low operating temperature | • Fouling of the membrane  
• Pretreatments are required |
| HDH        | • Low operating temperature  
• Simple operation | • Optimization of the thermodynamic cycle and flow rates  
• Three circuits: air, water, freon |

Desalination coupled with RES

To date, seawater desalination remains a costly process. As the demand for desalinated water is set to grow, a crucial concern is the high energy consumption of desalination processes, in contrast to conventional water treatment methods. While surface freshwater treatment consumes about 0.6 kWh/m³, SWRO consumes about 3 kWh/m³, although being the least energy-consuming desalination technology in the market. Moreover, besides the heavy energy cost, desalination powered by fossil fuels also carries a negative environmental impact that results in greenhouse gas emissions, which further exacerbates climate change and thus water scarcity.30

In this context, desalination coupled with renewables provides a very promising direction for the future of water supply, as a carbon-free and less energy-intensive option. This is even more true for regions where water scarcity and high availability of renewable energy sources coincide, such as the MENA region.

Being two distinct technologies, renewables and desalination can nevertheless be combined in different ways (see Figure 9). The desalination process can be powered by energy generated on-site (electricity, heat, or mechanical) from either solar or wind power, depending on local availability. Furthermore, RES are even more compatible with desalination technologies that use electricity and, in those cases intermittency issues are usually overcome by connecting the installation to the grid to create compensation. In addition, batteries for energy storage become relevant in the case of off-grid systems and certain thermal desalination technologies such as MSF and MED.31

In general, selecting the most appropriate RES for the desalination process requires the assessment of several factors: the geographical location and the RES resources available, the water salinity level, water demand, the desalination plant size, the availability of grid electricity, and the distance from end users.

It is also important to note the differences between desalination technologies which, depending on the parameter, present advantages and disadvantages. As regards the ability to be coupled with many RES, RO tends to rank very high as it exclusively runs on electricity which simplifies the coupling. In terms of energy consumption, RO is also the least energy-consuming desalination technology in the market, followed by MED and MVC/TVC, while for ED/EDR, the energy demand is proportional to salt concentration. As for water output, MED, MSF, and MVC produce the highest water quality (see Table.1).

That being said, solar power is currently the most prevalent RES technology coupled with desalination processes worldwide and the most prominent combinations are photovoltaic installations with reverse osmosis (PV-RO).

Cost per RE technology

For the calculation of the cost of desalinated water using RES, it is necessary to factor in several aspects. First of all, an important parameter to consider is the electricity consumption or the heat per unit of desalinated water (cubic metres). In the case of SWRO, the electricity consumption is about 3–4 kWh/m³ for large-scale desalination plants and about 1–5 m³/h for smaller-capacity plants. In a cogeneration large-scale system, the cost of the MSF technology is about 2.5–4 kWh/m³ of electricity and about 7.5–12 kWh/m³ of thermal energy, while for the MED technology, it is about 1.2–2 kWh/m³ of electricity and 4–7 kWh/m³ of thermal energy.\[^{32}\]

The cost of desalinated water using renewables is still very high due to the high energy consumption of the desalination process. For instance, in the case of solar energy, the price ranges from 11.7 – 15.6 USD/m³ for PV-SWRO and 2 – 2.5 USD/m³ for a Solar CSP-MED system of a 5,000 m³/day capacity. Similarly, in the case of wind-powered desalination systems, the price fluctuates between 2 – 5.2 USD/m³ for Wind-RO and 5.2 – 7.8 USD/m³ for Wind-MVC (see Figure 10).

One of the biggest obstacles that hinder a large-scale transition from conventional fossil fuels to renewable energies for desalination is the intermittency issue. The latter can be circumvented by introducing battery storage options such as lithium-ion, lead-acid, nickel-cadmium, or sodium-sulphur. In the long term, the economic viability of renewable desalination plants is set to improve as PV costs decrease and low-cost batteries with a long lifecycle are introduced to the market.

Desalination with RE: the situation in the MENA region

In the MENA region, seawater desalination emerged as a solution to close the water gap and alleviate water scarcity a few decades ago in the Gulf countries where the acute lack of groundwater and freshwater sources made the resort to desalination a necessity. Today, the region is considered to be a leader in the desalination industry, and it alone captures about half of the world’s desalination capacity concentrated in the GCC countries. Thanks to their abundance of oil and gas and the high revenues generated, the Gulf states have been able to build larger desalination capacities concerning North African states and their Middle Eastern neighbours, also taking advantage of the prevalence of co-generation plants for power and water.\textsuperscript{34} As shown by the Global Water Intelligence data in Figure 11, membrane desalination (RO) is becoming the most used desalination technology in the MENA, followed by MSF and MED. For a long time, the desalination process was exclusively powered by non-renewable fossil fuels—typically a fuel mix of natural gas and a suite of liquid fuels, which made it an expensive and energy-intensive solution to water scarcity.\textsuperscript{35}

With the desalination capacity in the MENA projected to increase substantially by 2040, coupled with the climate protection targets and the increase of conventional energy costs, MENA countries are increasingly turning to desalination powered by renewables as a more sustainable solution to curb the future demand in water for their domestic, industrial, and agricultural sectors.

\textsuperscript{34} Konrad-Adenauer-Stiftung, (2020).
\textsuperscript{35} Shabaneh R. (2020).
\textsuperscript{36} Konrad-Adenauer-Stiftung (2020).
In the last ten years, desalination plants using solar energy have burgeoned across the region using different configurations of renewables and desalination technologies, which highly depend on the local availability of solar and wind energy, plant size, feed water salinity, and the availability of grid electricity.\textsuperscript{37} Until recently, the regional renewable desalination mosaic only comprised small, off-grid desalination plants located in remote areas, but thanks to innovation in desalination technologies and the drop in the cost of renewables, several pilot projects have grown throughout the region. In terms of solar-thermal desalination, the MENA counts about ten plants located in Tunisia, Palestine, Jordan, and the Gulf where the highest capacity was reached with the MEB technology totalling a capacity of 6,000 m$^3$/day.\textsuperscript{38}

On the large-scale end, it is worth mentioning the Al Khafji solar desalination plant in Saudi Arabia’s eastern coast. Designed as a disassociated RO and PV system where energy for RO is fed from the grid and PV will inject energy into the grid to “compensate” the energy consumed by the facility. This plant is set to produce 30,000 m$^3$/day in the first phase of the project, and a 300,000 m$^3$ facility in the second, making it the largest of its kind in the world.\textsuperscript{39}

With the growing dominance of membrane-based technology and the decline of the cost of PV, many desalination plants integrating small-scale solar PV installations with RO have been developed in the region (see Figure 12), taking advantage of the existing ample solar radiation and the easy installation of PV panels. Other innovative PV-RO desalination projects implemented at a small scale include the ADIRA plants, which were installed in 4 remote villages in Morocco with a production capacity of 5 m$^3$/day and a PV capacity of 8 kWp, covering the food and sanitation needs of the local populations. A similar system was developed in Tunisia in the village of Ksar Ghilène and Ben Guerdan with a desalination capacity of 15 m$^3$/day and 1800 m$^3$/day respectively.

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|c|c|c|}
\hline
Country & Plant & Capacity (m$^3$/day) & Contracted year & Operational year & RE power source \\
\hline
Saudi Arabia & Al Khafji & 60,000 & 2015 & 2017 & 15 MW PV \\
Australia & Kurnell–Sydney & 250,000 & 2007 & 2010 & 140 MW wind farm \\
Australia & Kiwiana–Perth & 143,700 & 2005 & 2006 & 80 MW wind farm \\
China & Dateng & 10,000 & 2013 & 2014 & 2.5 MW wind farm \\
Greece & Milos & 3360 & Unknown & 2008 & 0.6 MW wind turbine \\
\hline
\end{tabular}
\caption{Selected SWRO plants powered by RES\textsuperscript{40}}
\end{table}

More recently in the United Arab Emirates (UAE), the Dubai Electricity and Water Authority (DEWA) announced a new objective of a 100% renewables-powered desalination by 2030 through the development of solar-powered SWRO desalination plants which will allow it to save AED 13 billion and reduce carbon

\textsuperscript{37} Ibid. page 57.
\textsuperscript{38} Sayed E. et al (2021).
\textsuperscript{39} Konrad-Adenauer-Stiftung (2020).
\textsuperscript{40} Caldera U. et al (2018).
emissions by 44 million tons by 2030\textsuperscript{41}. In 2022, DEWA signed a partnership with Dutch start-up Desolenator to build a 100% solar desalination system at a target Levelized cost of water production of less than USD 0.02 per litre.\textsuperscript{42}

Wind energy also presents enormous potential for desalination, especially for countries endowed with vast wind resources such as Morocco, Egypt, and Jordan. In Morocco, several desalination projects are planned to be coupled with wind power as is the case of the Dakhla desalination plant with a capacity of 90,000 m\textsuperscript{3}/day and a 40 MW wind farm in the desert, which will be operational by 2025.\textsuperscript{43}

Besides the possibility of coupling individual renewable energy sources with desalination, the potential of hybrid systems should not be undermined. Indeed, several systems are being studied, combining either solar and geothermal energy or solar and wind energy, which could also be supplemented by a generator or an energy storage system. Such hybrid systems, although low in capacity, can be found in Tunisia (PV+Wind) and Egypt (PV+Wind+Battery) with a respective desalination capacity of 57-1151 m\textsuperscript{3}/day and 5m\textsuperscript{3}/day.\textsuperscript{44}

\textsuperscript{43}For more information see https://www.nareva.ma/en/project/dakhla-desalination-project.
\textsuperscript{44}Sayed E. et al (2021).
Chapter III

Desalination in Morocco: status and prospects
Morocco’s desalination demand drivers

In Morocco, the Water-Energy Nexus is more relevant than ever as the country is grappling with the impacts of climate change on its water security, and by extension on its energy and food security. Country-specific socio-economic, environmental, and technological drivers are expected to make the fulfilment of water needs over the coming years more challenging.

From a socioeconomic standpoint, Morocco is registering several rapid changes, which directly impact water consumption. The country’s population is expected to increase from 36.3m in 2021 to 40.87m in 2030, equivalent to a 12.6% growth. In addition, Gross Domestic Product (GDP) is expected to grow from USD 131.47bn in 2021 to USD 175.36bn in 2027 with a Compound Annual Growth Rate (CAGR) of 4.9%. The urbanisation rate increased from 58.5% in 2011 to 64% in 2021 and is expected to continue growing over the next decades.

Looking at environmental aspects, the country is essentially characterised by an arid to semi-arid climate with an average annual rainfall of less than 400 mm over more than 85% of its surface, with water resources marked by a poor temporal and geographical distribution, which makes water scarcity more burdensome in certain regions, especially in the South. Surface water supplies can vary from less than 10 bm3/year during dry years to more than 50 bm3/year during the wettest/rainy years. In addition, the average renewable freshwater resources per capita are less than 800 m3, expected to become as low as 500 m3 by 2025 due to a projected decrease of precipitation in the range of 20-30% in the medium-short term. For these reasons, Morocco is characterised by an annual water deficit of approximately 4 Bm3/year. In particular, water demand can be attributed to three main sectors:

- The agricultural and irrigation demand historically represents around 89% of the total internal demand. Indeed, the agricultural sector output is expected to grow with above-average rates of 12%, 4.8%, and 4.6% over the period 2024-2026 which will influence the water demand. The agricultural water demand is divided into the irrigation of large hydraulic (GH), small and medium hydraulic (PMH), and private irrigation (IP) perimeters. More importantly, water irrigation still presents a low degree of efficiency, and given the importance of the sector over the total demand, it has been frequently targeted for improvements within the National Plans and strategies.
- The municipal demand represents the households’ demand for drinking water. The demand accounted for a total of 1 Bm3/year in 2010 and 1.4 Bm3/year in 2020. The proportion of the population using safely managed drinking water services increased throughout the country from 67% to 80% in the period 2012-2020, with 97% access to water also from rural zones.
- The industrial and touristic demand represents the marginal portion of the total water demand, with a historical demand of 212 Mm3/year in 2010, and 241 in 2020 (see figure 13).

46 GIZ (2018).
48 See the Plan National de l’Eau (PNE, 2015).
49 United Nations Water - SDG 6 Data Portal. Available at: https://www.sdg6data.org/country-or-area/morocco.
According to the IPCC, global temperatures are expected to increase by 3.5°C. In such a scenario, drought years will become more frequent, and water availability would drop even further. This would lead to a very important decline in surface water inflows from dams, and threaten the agricultural sector - crop productivity and harvest regularity. The agricultural sector accounts for the largest share of water withdrawals in Morocco given the arid climatic conditions. This makes irrigation essential for the growth of crops, but harder to sustain during the critical, dry seasons. In 2022, Morocco experienced its worst drought in decades with rainfall going down by 64% less than the average, hitting several regions and jeopardising agricultural output and livelihoods for thousands of farmers.  

Conversely, in response to the analyzed socio-economical, environmental, and technological drivers, water demand is expected to grow from a total of 16,216 Mm³/year in 2020 to 18,494 Mm³/year in 2050, with a 14% growth rate.  

As can be seen from Figure 14, agriculture and irrigation will still absorb the largest share of the water demand in the long-term projections. Moreover, considering the important contribution of export agriculture in the Moroccan economy, notably in high-potential agricultural regions like Souss-Massa where 80% of the agricultural yield is destined for foreign markets, securing water for the crops will intensify the dilemma between food security and food competitiveness. Indeed, the strategic choice to give precedence to high-value crops raises questions about the sustainability of the domestic market and future socioeconomic impacts.

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50 Reuters 2022.
51 United Nations (October, 2021) Environmental Performance Reviews – Morocco.
The government has also estimated a growing trend of the water deficit (as a difference between internal demand and offer), that might achieve a total gap of 5 Bm³/year by 2030 if mitigation measures are not implemented.

As a response to these alarming climate trends, the Moroccan government has articulated several ambitious strategies pertaining to water and energy to tackle the effects of climate change that are already felt in the country and to meet the future water and energy needs for its sustainable development. In 2020, the Government launched the new agriculture strategy Génération Green 2020-2030 to continue the efforts of controlling and rationalising the use of water in the agricultural sector for more climate-resilient agriculture. These efforts started in 2008 under the Plan Maroc Vert (PMV) strategy back in 2008. The aim was to foster high-value and sustainable agriculture through the promotion of irrigation water savings, namely through the Programme National D’Economie d’Eau en Irrigation (PNEEI). Thanks to the PMV, Morocco has been able to save more than 2 billion cubic metres of water annually, develop 800,000 ha under irrigation, and contract four Public-Private Partnership projects, including two seawater desalination projects for the irrigation of Chtouka-Ait Baha (15,000 ha) and Dakhla (5,000 ha).52

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Figure 14: Morocco water demand projections [Mm³/year]

Source: United Nations

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The country is increasingly engaged in an integrated approach to its water resources to guarantee equity in water distribution throughout its territory. It is guided by the Stratégie Nationale de l’Eau (SNE) (updated in 2009), the Plan National de l’Eau (PNE) (2015-2020), and the Water Law 36-15 (2016) which give a solid regulatory base to Morocco’s water supply and use management. The policy framework includes several programs targeting different stages of the water value chain to close the gap between the current and future water demand and to better monitor water withdrawals. With a budget of 137 billion Dirham (DH), the SNE foresees a greater mobilization of water resources through the construction of small-scale and large-scale dams, but also the use of unconventional water resources.53 However, experts envisage also potential critical issues on the adequacy of the infrastructures for the water transport from the sea-side desalination areas to the main-land arid regions.

Increasing the water supply and implementing water conservation policies are essential components of adaptation to climate change. Therefore, it becomes evident that unconventional water resources such as seawater desalination will play an essential role in Morocco’s future water security.54 This greater emphasis on seawater desalination is also retained as a strategic choice for Morocco by the country’s overarching sustainable development and decarbonization scheme, namely the Low Carbon Strategy 2050 (2021). The latter delineates not only the sectorial visions and plans of action but also recognizes the nexus potentials inherent to the water and the energy sector.

On the energy side, the Kingdom is considered to be one of the most advanced countries in the energy transition in the region, owing to its ambitious Renewable energy target of 52% of RE in the installed capacity by 2030. With its abundant solar and wind resources, in 2021 Morocco has consolidated a share of 18% of electricity generation from renewable energy sources, and leveraging that potential, it has also elaborated a clear vision for the production of Green Hydrogen in an attempt to diversify its energy mix and integrate renewables in strategic sectors that are proving difficult to decarbonize.55 According to the National Green Hydrogen Roadmap (2021), responding to the potential demand for Green Hydrogen and its derivatives will require the development of the relevant infrastructure such as additional RE capacity and water desalination plants, with an estimated capacity of 4.4 Mm³/year in 2030, 21.9 Mm³/year in 2040, and 49.2 Mm³/year in 2050 according to the reference scenario.

Nevertheless, some infrastructural challenges in terms of current power systems integration, flexibility, and efficiency are still present. Moroccan power infrastructures are still undergoing a modernisation process for the integration of a smart grid system, adapting consumption to renewable production.

As desalination is set to play a strategic role in the mobilisation of water resources in the future, seawater desalination coupled with renewables is a key nexus for the low-carbon development of Morocco. Details of desalination demand drivers are summarised in Table 2.

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53 Ministry of the Energy Transition and Sustainable Development (2020).
54 Ministry of the Energy Transition and Sustainable Development, 4ème Communication Nationale du Maroc à la CCNUCC (2021).
### Table 2: Morocco’s desalination demand drivers

<table>
<thead>
<tr>
<th>Category</th>
<th>Driver</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Socio-Economic</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Population Growth | Morocco’s population is expected to grow from 36.3m in 2021 to 40.87m in 2030, equivalent to a 12.6% growth. The population is expected to further increase to 45.66m in 2050.  
                                                    |                                                                                                                                                                                                         |
| Economic Growth | GDP rose from USD 93.22bn in 2010 to USD 131.47bn in 2021 at a Compound Annual Growth Rate (CAGR) of 3.2%. GDP is expected to reach USD 175.36bn in 2027, with a CAGR of 4.9% in the period 2021-2027.  
                                                    | Between 2011 and 2021, GDP has been distributed with regular rates among agriculture, industry, and services, respectively the 12.65%, 26.81%, and 49.14% of it in 2021.  
                                                    | A relevant role within the economic and water scenario is assumed by the agricultural sector. Agriculture leads the water consumption with 89% of the total water withdrawals.  
                                                    | Agriculture grew at a 17.8% rate in the period 2020-2021 to recover from the Covid-19 crisis and is projected to grow at 12.0%, 4.8%, and 4.6% rates from 2023 to 2025 as recovery from the Ukraine war. |
| Urbanisation Growth | The urbanisation rate increased from 58.5% in 2011 to 64% in 2021. |                                                                                                                                                                                                         |
| **Environment** |                               |                                                                                                                                                                                                         |
| Climate change | Increases in annual temperatures and decreases in precipitations are making Morocco fast approaching the absolute water scarcity threshold of 500 m3 per person per year by 2030.  
                                                    | Temperatures are expected to increase by 3.5°C by mid-century.  
                                                    | Precipitations are projected to decrease by 20% to 30% in the short-to-medium term.                                                                                                                                 |
| **Technology** |                               |                                                                                                                                                                                                         |
                                                    | By 2030, the country envisages a local hydrogen market of 4 terawatt hours (TWh) and an export market of 10 TWh.  
                                                    | The plan requires the construction of 6 GW of new renewable capacity and supports the creation of more than 15 000 direct and indirect jobs.  
                                                    | The capacity required directly from renewable desalination plants would be 4.4 Mm³/year in 2030, 21.9 Mm³/year in 2040, and 49.2 Mm³/year in 2050. |

**Source:** AFRY Management Consulting

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**Targets and laws in support of renewable desalination**

The Government aims to achieve a long-term desalination production of 1,000 million cubic metres per year (Mm³/year) and it expects to generate 80% of its electricity from renewable sources by 2050. Legislative reforms allow private investors to participate in large-scale renewable desalination projects. Laws 36-15 (2016) and 13-09 (2010) give private producers the right to desalinate water and generate

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56 UNICEF (April, 2019).
renewable energy. The project structure is then ruled by Public-Private Partnerships (PPPs) with Law 12-86 (2014), which allows private players to operate in the market. To date, no formal roadmap for renewable desalination that integrates the renewables and water sectors exists. National targets and supporting regulations and policies are presented in this chapter and summarised in Figure 15.

Figure 15: Morocco public set-up on desalination

Renewable energy and desalination national targets

In terms of desalination, national targets indicate the government’s vision and efforts toward reducing the existing water deficit. The Government presents its desalination targets in the Water National Plans (“the Plans”). The most recent Plans addressing the desalination objectives are:

- The 2015 PNE, establishing the 2030 medium-term production target. It plans to achieve a total desalination production capacity of 515 Mm³/year by 2030. The consolidation of the main sub-sector programs and the implementation of the various PNE actions is expected to cost more than 220 billion DH by 2030, 7% of which is required for water desalination purposes;
- The 2020 PNE, establishing the 2050 long-term production target. The Plan sets a total desalination production capacity of 1,000 Mm³/year by 2050. The 2020 PNE would require to be supported by a total amount of DH 383 billion of financial measures for the development of the water supply, the management of the demand, the protection of the resources and ecosystems, and the water-scarcity communication campaign.
The 2020 capacity of operating desalination plants covers nearly 77 Mm$^3$/year of water demand.$^{58}$ In particular, following the FAO-Aquastat database, Morocco’s desalination capacity was about 7 Mm$^3$/year in the early 2000s, and therefore notably increased in the past years, although it is still not significant if compared with the future national targets. And the technology is expected to witness significant growth within the next 8 years (2022-2030 horizon): nine new desalination plants have been announced and are expected to reach COD by 2030.

The announced plants$^{59}$ are projected to produce an additional water capacity of 397 Mm$^3$/year, representing over a 500% growth rate between 2020 and 2030.$^{60}$ Additionally, 97% of the new capacity is disclosed to be coupled with renewable sources.$^{61}$ Following the provided projections, about 90% of the planned 2030 desalination capacity (515 Mm3/year) is expected to be covered with the combination of the newly disclosed projects and the existing operating plants to date.

As evidenced below, the largest operating plants are typically realised in two steps with an extension of the capacity over the years. For what concerns the long-term 2050 development of the market, phase 2 of the analysed projects is considered as additional capacity.$^{62,63}$ With the implementation of phase 2 of the disclosed projects to date, the country is expected to achieve about 82% of the 2050 planned capacity. Approximately 822 Mm3/year out of the 1,000 Mm3/year goal is projected to be satisfied with the ongoing projects (Figure 16).

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58 Actual capacity is given as the sum of the following operating desalination plants for seawater and brackish water: Jorf Lasfar (Phase 1 OCP), Maroc Central, Khenifra, Laâyoune, Dakhla, Boujdour, Tan-Tan, Dakhla, Zagora, Laâyoune (Phase 1 OCP), Tan-Tan, Akhfenir, Tarfaya, Tagounite, Daoura, Sidi El Ghazi, Roc Chico.

59 Projections based on the following plants’ implementation by 2030: Chtouka Agadir (Phase 1), Dakhla, Casablanca, Al Hoceima, Tarfaya, Sidi Ifni (Phase 1 OCP), Jorf Lasfar (Phase 2 OCP), Laâyoune (Phase 2 OCP), Safi. The Oriental-Nador plant is still in the study phase and is not considered for the 2030 capacity. Projections also include minor brackish investments that are represented by the following plants: Tan-Tan, Bouakraa, Aftisat, El Bouidra, Dchira, Antrift, Ain Bida. Details are found in Chapter IV.

60 Following a prudential approach, only Phase 1 capacity of Chtouka Agadir, Casablanca and Sidi Ifni plants is considered to be implemented by 2030.

61 Sidi Ifni, Al Hoceima and the Tarfaya plants are prudentially considered as traditional sourced. Moreover, the new brackish plants are also not considered to be renewable sourced, since no different information is actually available.

62 The timing consideration has been established after a prudential valuation of the precedent PPPs projects’ timeline requirements.

63 Particularly, an increase in capacity is projected for Chtouka Agadir (from 275,000 to 400,000 m3/day), Casablanca (from 548,000 to 822,000 m3/day), Sidi Ifni (from 8,640 to 17,280 m3/day) plants. For the long-term projection also Oriental plant is considered (547,945 m3/day).
On the energy side, Morocco has a huge potential to produce energy from renewables. In 2020, the country registered a consistent growth of installed capacity in renewable energy sources, mainly driven by an increase in large-scale renewable generation, which led to achieving 70% of the 2020 target of 6 GW renewable capacity. Morocco aims to produce 52%, 70%, and 80% of its total energy capacity from renewable sources by 2030, 2040, and 2050 respectively.

It is important to note that desalination and renewable targets and policies continue to be separately disclosed and this lack of integration is reflected by the absence of a coordinated strategy for the two sectors.

Renewable energy and desalination national laws

Desalination has been recently included in the national Law, with the approval of Law 36-15 in 2016. Such a Law represents a significant step for the implementation of large-scale plants, as for the first time a legal framework for desalination has been introduced in Moroccan legislation. The Law 36-15 represents a milestone for the desalination sector as it grants the right to any individual or private legal entity to desalinate the water using a concession agreement.

As far as renewables are concerned, Law 13-09, introduced in 2009, provides the Moroccan legal framework applicable to the renewable energy sector, implying the:
- opening of renewable electricity generation to competition;
- wheeling of renewable electricity via the national grid;
- possibility of exporting electricity via the national grid;
- possibility for a developer to build its own direct transmission line.

The Law facilitates the development of the renewable desalination market, as players can either directly invest in renewable energy systems or consume renewable energy as Medium-High Voltage consumers. The Law gives the possibility to sign Power Purchase Agreement (PPA) between Independent Power Producers (IPP) and end customers (High Voltage). The Medium Voltage market is not formally open yet due to the lack of secondary legislation. In addition, the long process of establishment of the electricity independent regulator Autorité Nationale de Régulation de l’Électricité (ANRE) and its very recent entry into operation is still leaving some room for improvement in terms of regulation.

According to current regulation, the right to produce and consume energy from different regions of the country is granted, facilitating the synergies between desalination and renewable plants. Thus, the risk of operating within a geographical distance between the renewable energy generation plant and the desalination plant is reduced.

When it comes to desalination project structure, Public-Private Partnerships (PPPs) have been introduced to support the growth of the desalination market in the country. Morocco’s Law 12-86 (2014) defines the PPP as a fixed-term contract, by which a public entity entrusts a private partner with the responsibility of carrying out a project’s overall design, financing, construction, maintenance, and/or operation of a structure or service necessary for the provision of public service. With the integration of PPPs in the desalination sector, private players can operate the previously public water infrastructures.

As of today, financial and tax incentives for the implementation of renewable desalination plants are not provided by the government and the country is not applying a cost-reflective tariff system for water, which reduces the self-financing capacity of the sector. This barrier is partially mitigated by the low cost of renewable energy that could be used in renewable desalination.

Finally, a specific Law on the environmental impact assessment of desalination plants is still missing. Given the particular concerns about brine management and its impact on the aquatic environment, the lack of a regulatory framework might undermine the adoption of desalination solutions.

Renewable-desalination national recommendations

Considering all national targets and laws in the field of renewable energy and desalination listed above, Ministries and their advisors have recommended the use of renewable energy for desalination plants. In 2020, the Conseil Economique, Social et Environnemental (CESE)\textsuperscript{65} advised the Government on both the

\textsuperscript{64} Chapter IV analyses the PPPs structure applied to specific Moroccan desalination projects.
\textsuperscript{65} Conseil Economique, Social et Environnemental – CESE (2020).
increase of desalination use on the national territory and its coupling with renewable sources. In particular, it suggests adopting the integration of renewable energy as the principal green source of electricity for all seawater desalination projects. The CESE also recommends using desalination to ensure, as a priority, the supply of drinking water in the region’s coastal areas, which are under water stress. Moreover, the Ministry of Energy Transition and Sustainable Development has disclosed within the Long-Term Low Carbon Strategy 2050 the commitment of Morocco to develop newer renewable desalination structures coupled with renewable energy. It also foresees a long-term energy consumption of 3,000 GWh/year by 2050 for the implementation of the new projects.

Figure 17: Timeline of relevant framework for desalination in Morocco

Source: AFRY Management Consulting

Projects and players in the Moroccan desalination sector

Morocco has a modest desalination capacity: the country counted seventeen desalination plants in 2020, with a total capacity of about 77 Mm³/year, corresponding only to 0.5% of the entire capacity of the MENA region. So far, Morocco has implemented medium-small scale projects, typically fossil-sourced with the use of Reverse Osmosis (RO) technology. The high energy costs of the process and the environmental challenges linked to desalination have been in the past among the main reasons for its low development in the country.

Ministère de la Transition Energétique et du Développement Durable (October, 2021).
Traditionally, desalination plants have been coupled with renewable technology only to support a few small-scale projects. These plants have been used to serve remote villages of the country with no access to a grid and potable water. Renewables have been adopted rarely due to their low efficiency and intermittency issues, not compatible with desalination plants requirements.

In contrast with the past situation, the large Moroccan renewable energy potential, together with innovative technological solutions, such as energy storage to mitigate intermittency, and policy reforms that push towards the implementation of RES plants, is now open to the possibility of a future deployment of large-scale desalination plants powered by renewable energy.

**Key players and operating plants to date**

Typically, desalination plants are commissioned by institutional public players. The most important are represented by the National Office for Electricity and Drinking Water (ONEE), and the state-owned Office Chérifien des Phosphates (OCP) Group, a global leader in phosphates production.

The ONEE is composed of two main branches for the management of the energy and water sectors. ONEE – water branch – is the principal state institution for the production and distribution of water, and pursues three main strategic objectives within the water sector:

- Assure, implement, and plan the provision of potable water in urban areas;
- Increase the general availability of water in rural areas;
- Improve sanitation access and service delivery.

The OCP Group - a global leader in phosphates production - is aiming to reduce its need for fresh water in manufacturing operations and to serve local citizens through its internal water program. The institution uses unconventional water sources, such as desalinated water, to achieve its target and is at the forefront of renewable coupling, since it is pursuing a long-term net-zero roadmap.

There are also several other public institutions indirectly involved in the renewable desalination market, as shown in Table 3. This institutional complexity could represent a potential obstacle to investments since the water and electricity sectors are highly fragmented with several actors and levels of governance.
Table 3: Renewable Desalination public players in Morocco

<table>
<thead>
<tr>
<th>Public Ministry / Department</th>
<th>Roles</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>The Ministry of Energy Transition and Sustainable Development</strong></td>
<td>The Ministry has primary responsibility for Morocco’s overall energy policy and oversees safeguarding the security of supply, setting rules for energy markets, and managing the low-carbon transition by promoting energy efficiency and renewable energy. Among the various departments and organisations under its supervision, those who play a central role in the development of renewable-driven desalination projects are the Department of Sustainable Development; ONEE, MASEN, and the OCP Group.</td>
</tr>
<tr>
<td><strong>The Ministry of Economy and Finance (MEF)</strong></td>
<td>The Ministry oversees the financial side of the energy sector. MEF is the financial control body of the State-owned entities involved in the sector.</td>
</tr>
<tr>
<td><strong>The Ministry of Industry, Investment, Trade and Digital Economy (MICIEN)</strong></td>
<td>Indirectly involved in the implementation of energy policy, it designs and implements industrial strategies, and works to enhance the competitiveness of the Moroccan industry.</td>
</tr>
<tr>
<td><strong>The Moroccan Agency for Sustainable Energy (MASEN)</strong></td>
<td>The Group is responsible for leading and managing the deployment of renewable energy in the country.</td>
</tr>
<tr>
<td><strong>The National Agency for Electricity and Drinking Water (ONEE)</strong></td>
<td>The state-owned utility imports electricity and is responsible for electricity distribution and water production and distribution.</td>
</tr>
<tr>
<td><strong>The National Authority for Electricity Regulation (ANRE)</strong></td>
<td>The regulator organizes the open and competitive segments of the electricity sector.</td>
</tr>
<tr>
<td><strong>The Ministry of Equipment and Water</strong></td>
<td>The Ministry manages the sector of water infrastructures through the General Directorate of Hydraulics.</td>
</tr>
<tr>
<td><strong>The Ministry of Agriculture, Fisheries, Rural Development, Water, and Forests</strong></td>
<td>The Ministry supervises the following relevant departments: the Agency for Agricultural Development; the Regional Offices for Agricultural Development; and the Provincial Agricultural Directorates.</td>
</tr>
<tr>
<td><strong>The Ministry of Interior</strong></td>
<td>The Ministry is involved in the management of the Directorate of Boards and Licensed Services.</td>
</tr>
<tr>
<td><strong>Councils and Commissions</strong></td>
<td>The National Council for the Environment and the Regional Councils for the Environment; The High Council for Water and Climate; The Interministerial Water Commission; The National Agency for Water and Forests; The Prefectoral/Provincial Water Commissions.</td>
</tr>
</tbody>
</table>

Source: AFRY Management Consulting
Since 1975, ONEE has historically carried out several projects related to the construction, operation, and maintenance of desalination plants in response to the aridity of the climate and the scarcity of conventional water resources. In 2020, ONEE and OCP operated approximately in eight major localities with drinking water from Seawater (SW) desalination or Brackish (BW) demineralization, with a total service capacity of around 200,000 m³/day. These localities were mainly Lâayoune, Boujdour, Dakhla, Khénifra, Tan-Tan, Zagora, Maroc Central, and Jorf Lasfar. Table 4 summarises the operating plants up to 2020, before the announcement of the new 2020-2050 National Water Plan. The main findings suggest that these plants are not supplied by renewable sources of energy and are developed with RO technology.

<table>
<thead>
<tr>
<th>Location</th>
<th>Capacity (m³/day)</th>
<th>Type of Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jorf Lasfar (OCP/Phase 1)</td>
<td>68,500</td>
<td>Seawater</td>
</tr>
<tr>
<td>Maroc central</td>
<td>28,500</td>
<td>Brackish</td>
</tr>
<tr>
<td>Khénifra</td>
<td>27,650</td>
<td>Brackish</td>
</tr>
<tr>
<td>Laâyoune</td>
<td>26,000</td>
<td>Seawater</td>
</tr>
<tr>
<td>Dakhla</td>
<td>17,280</td>
<td>Brackish</td>
</tr>
<tr>
<td>Boujdour</td>
<td>10,800</td>
<td>Seawater</td>
</tr>
<tr>
<td>Tan-Tan</td>
<td>8,640</td>
<td>Brackish</td>
</tr>
<tr>
<td>Dakhla</td>
<td>8,300</td>
<td>Brackish</td>
</tr>
<tr>
<td>Zagora</td>
<td>5,200</td>
<td>Brackish</td>
</tr>
<tr>
<td>Laâyoune (OCP/Phase 1)</td>
<td>4,100</td>
<td>Seawater</td>
</tr>
<tr>
<td>Tan-Tan</td>
<td>3,460</td>
<td>Brackish</td>
</tr>
<tr>
<td>Akhfenir</td>
<td>860</td>
<td>Seawater</td>
</tr>
<tr>
<td>Tarfaya</td>
<td>860</td>
<td>Brackish</td>
</tr>
<tr>
<td>Tagounite</td>
<td>430</td>
<td>Brackish</td>
</tr>
<tr>
<td>Daoura</td>
<td>240</td>
<td>Brackish</td>
</tr>
<tr>
<td>Sidi El Ghazi</td>
<td>90</td>
<td>Seawater</td>
</tr>
<tr>
<td>Roc Chico</td>
<td>30</td>
<td>Seawater</td>
</tr>
<tr>
<td>Total Seawater Capacity</td>
<td>110,380</td>
<td></td>
</tr>
<tr>
<td>Total Brackish Capacity</td>
<td>100,560</td>
<td></td>
</tr>
</tbody>
</table>

Source: AFRY Management Consulting

67 Localities with desalination plants with a capacity greater than 1,000 m³/day.
68 Agadir plant, which passed the contractual tests in 2022, is not included in Table 2, as only plants operating before the 2020 National Plan are listed.
Renewable sources have been implemented in Morocco only to supply smaller desalination projects located in rural remote areas, where no grid electricity and drinking water were available. These projects have been adopted within the ADIRA initiative (Autonomous Desalination System Concepts for Sea Water and Brackish Water in Rural Areas with Renewable Energy) with a general basic water production capacity of 1 m³/h. The plants have been powered by solar PV technology and integrated between 2003 and 2008 to support small villages of local farmers, with an estimated average population of 200 people.

Table 5: Renewable Desalination Rural Plants in Morocco (2020)

<table>
<thead>
<tr>
<th>Villages</th>
<th>Azla</th>
<th>Tazekra</th>
<th>Amellou</th>
<th>Tangarfa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Electric grid</td>
<td>Weak</td>
<td>Weak</td>
<td>Absent</td>
<td>Weak</td>
</tr>
<tr>
<td>Freshwater flow (m³/h)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0,5</td>
</tr>
<tr>
<td>PV installed (kWp)</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>2,5</td>
</tr>
<tr>
<td>PV modules</td>
<td>32</td>
<td>32</td>
<td>32</td>
<td>20</td>
</tr>
<tr>
<td>PV surface (m²)</td>
<td>33</td>
<td>33</td>
<td>33</td>
<td>19</td>
</tr>
</tbody>
</table>

Source: AFRY Management Consulting

Another example of a Moroccan renewable desalination project is located at the Al Annouar high school of Sidi Taibi, Kenitra. In 2014 a pilot of the decentralised desalination plant, coupled with photovoltaic and wind energy systems, was implemented to supply the school with its 1,200 students. The Sidi Taibi plant has been built by a European consortium of three French companies: Belectric (solar energy company), Firmus (membrane treatment company), and Comodos (wind energy company).

These smaller desalination plants are the only examples of systems coupled with renewable sources that are operating in the country. Morocco’s experience and competences with renewable desalination are still to be developed compared to other MENA countries, and are expected to increase through the expected future plants described in the section below.

Recent developments

The Kingdom of Morocco has planned to increase its volumes of generated water from desalination processes. Future projects can be divided between those commissioned by the ONEE and OCP.
The main developments are expected to be in the areas of Chtouka in Agadir, Casablanca, Dakhla\textsuperscript{69}, Al Hoceima, Safi, Tarfaya, Sidi Ifni, Oriental-Nador\textsuperscript{70} - concerning the ONEE’s plants – and in Jorf Lasfar, Laâyoune and Safi – for the OCP’s plants (Figure 17).

Future projects will be mainly medium-large scale plants and the most important cases – such as those in Casablanca, Agadir, and Dakhla – are announced within their official dossiers to be coupled with renewable energy sources. Table 6 identifies the main features of the announced plants in terms of players involved, geographical area, daily capacity, and expected investments. Some of the main projects are characterised by two main implementation phases, with the second one extending the production capacity of the plant. It is noteworthy, though, that these recent developments could be hindered by ONEE’s financial conditions, which remain vulnerable to financial headwinds and might undermine the process of reforms needed.

\textsuperscript{69}Dakhla region is included in the research.

\textsuperscript{70}Minor brackish investments that are represented by the following plants [m\textsuperscript{3}/day]: Tan-Tan (430), Boukraâ (170), Aftisat (460), El Bouidra (520), Dchira (520), Antrift (860), Ain Bida (520).
<table>
<thead>
<tr>
<th>Public Player</th>
<th>Project Location</th>
<th>Capacity [m³/day]</th>
<th>Renewable Coupling</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ONEE</td>
<td>Casablanca 79</td>
<td>• Phase 1: 548,000 • Phase 2: 822,000</td>
<td>Powered by renewable energy, as required on project’s pre-qualification dossier</td>
<td>Six final international private players consortia 71 • Estimated contract of more than 800 million euros • The construction works are expected to start by 2023</td>
</tr>
<tr>
<td></td>
<td>Chtouka Aitbaha Agadir 72</td>
<td>• Phase 1: 275,000 • Phase 2: 400,000</td>
<td>Coupling with the Noor Qurazazzate solar power plant</td>
<td>Commissioned to Aman El Baraka SA, a subsidiary of Abengoa • Operative and passed the contractual test in June 2022 • First adoption of 30-year period PPP • Estimated investment of 300 million euros</td>
</tr>
<tr>
<td></td>
<td>Dakhla 77</td>
<td>100,000</td>
<td>40 MW of installed capacity wind farm</td>
<td>Commissioned to Dakhla Water &amp; Energy Company (DAWEC), a Joint Venture owned by Engie and Al Mada • Estimated investment of 190 million euros</td>
</tr>
<tr>
<td></td>
<td>Al Hoceima</td>
<td>17,300</td>
<td>Authorities have advised the coupling with renewable energy</td>
<td>Designed and built by the Spanish company Tedagua • 14.3m USD financing through the Fondo Español para la Internacionalización de la Empresa (FIEM)</td>
</tr>
<tr>
<td></td>
<td>Sidi Ifni</td>
<td>• Phase 1: 8,640 • Phase 2: 17,280</td>
<td>Authorities have advised the coupling with renewable energy</td>
<td>Granting of 34 million USD by the KfW Development Bank in 2019</td>
</tr>
<tr>
<td></td>
<td>Tarfaya</td>
<td>1,296</td>
<td>Authorities have advised the coupling with renewable energy</td>
<td>ONEE investment of approximately 4.7 million euros</td>
</tr>
<tr>
<td></td>
<td>Oriental Nador</td>
<td>• Phase 1: 273,973 • Phase 2: 547,945</td>
<td>n.a.</td>
<td>Implementation / feasibility studies phase (about 15 months) • The consortium composed of the companies CID, Agro Concept, and Medsurvey has been commissioned for the studies • Public allocation of 124 million euros</td>
</tr>
<tr>
<td>OCP</td>
<td>Jorf Lasfar, an extension of the 68,500 m³/day plant</td>
<td>• Phase 2: 109,500</td>
<td>OCP has advised the coupling with renewable energy</td>
<td>Part of the OCP 2030 Sustainability Program</td>
</tr>
<tr>
<td></td>
<td>Laâyoune, extension of the 4,100 m³/day plant</td>
<td>• Phase 2: 20,500</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Safi</td>
<td>75,800</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: AFRY Management Consulting*

71 The international consortia chosen for the final phases of the selection are: 1) Abengoa (Spain)-Engie (France); 2) Acciona (Spain)-Afriquia Gaz (Morocco)-Green of Africa (Morocco); 3) Tedagua (Spain)-Lantania (Spain)-Acwa Power (Saudi Arabia)-Sepco III (China)-Flipar Power Holding (Morocco); 4) Nareva (Morocco)-Suez (France)-Itochu (Japan); 5) Veolia (France)-Taqa (United Arab Emirates); 6) Somagec (Morocco)-SGTM (Morocco)-IDE Technologie (Israel)-Mitsui (Japan).
72 Commissioned by ONEE and the Moroccan Ministry of Agriculture, Maritime Fisheries, Rural Development and Water and Forests.
Project structure: the use of PPPs as the main driver to attract international players

The success of the plans is linked to the presence in the market of leading international players. PPPs long-term arrangements between the Government – through its institutional players – and private companies have proven to be a successful approach, able to provide the necessary capital, networks, technology, experience, and human resources, even if providing some degree of risk for the public entity (Figure 18).

![Figure 19: PPPs strategic implications](source: AFRY Management Consulting)

The most important renewable desalination projects in Agadir, Dakhla, and Casablanca are structured through the use of Law 12-86, according to which the remuneration of the private partner in PPPs might be provided:

- entirely or partially by the public entity;
- entirely or partially by the final users;
- entirely or partially by the revenues generated by the use of the property and equipment related to the project.

Remuneration should then be guaranteed under the provision of the availability of the service and the reaching of certain performance goals by the operator.

In the MENA region, desalination projects are procured by using different types of delivery models, that vary depending on the project financing structure, location, size, risk profile, owner, and client’s experiences. Versions of the preferred models of PPPs adopted in the MENA regions are the Engineering, Procurement and Construction (EPC), Design-Build (DB), Design-Bid-Build (DBB) when the client wants to retain the ownership of the facility. In the Design-Build-Operate (DBO) method the client requires
the plant tenders for both construction and operating and maintenance (O&M) as a single package. Additionally, the Build-Operate-Transfer (BOT) involves the participation of a private project development company in the project, which owns the assets, and can be further developed into the Design-Build-Own-Operate-Transfer (DBOOT) and Build-Own-Operate-Transfer (BOOT). In all of BOT models, the assets are to be transferred to the public entity at the end of the contracted period, which spans on average 20 years. In Morocco, the BOT PPP delivery method has become the preferred one for desalination large-scale projects. The method has been adopted for both the Agadir and Casablanca projects and allows a cost-effective transfer of the risks associated with the costs of desalinated water to the private sector. This type of delivery model involves the participation of a private project development company, which owns the assets.

The project in Chtouka Aitbaha, near Agadir, represents the first desalination project that the ONEE has developed under a Public-Private Partnership (PPP), established with the private Spanish player Abengoa. As evidenced in Figure 20, the full implementation of the project has taken the company about 10 years, from 2012’s call for tenders to 2022’s successful passing of contractual tests. Despite the long term to finalise the overall project, technical works have been completed in a range of 4 years from the financial closing, as required by the desalination legal framework provided by Law 36-15 (2018-2022). As a matter of fact, the country still relies on its 2015 old framework to regulate PPPs, while a new Law has been approved in 2020, but it has yet to be implemented, increasing investors’ uncertainty.

![Figure 20: Agadir project’s timeline](source: AFRY Management Consulting)

The Agadir plant is expected also to provide proof of the Moroccan population’s social awareness, a topic deemed crucial by international studies which have observed that public health issues might be correlated to the long-term utilisation of desalinated water. However, as shown by desalination experiences in other water-stressed countries, the perception of desalinated water is fundamentally impacted by the price of water, which remains a major concern for end consumers in low to middle-income countries.
Chapter IV

Estimating energy needs for renewable desalination and how to accelerate its adoption
Renewable desalination: energy generation projections in Morocco

As seen in the previous chapter, Morocco’s desalination capacity is expected to ambitiously grow within the next 30 years, in line with the growth targets set by the national Plans. Desalination growth is driven by Morocco’s water demand, which is projected to grow by 14% from 2020 to 2050. Long-term desalination projects are expected to satisfy approximately 90% and 80% of the planned capacity in 2030 and 2050 respectively. Particular relevance is assumed by the implementation of renewable energy as the main source of electricity for future large-scale projects.

In order to estimate the renewable generation required by the future desalination plants in Morocco, first of all it is important to take stock of the water demand projections (2020-2050), renewable desalination capacity projections (2020-2050), renewable energy generation projections (2020-2035) analysed in Chapter 3. Considering that the average electricity usage needed by the Reserve Osmosis technology - the most frequently used one in Morocco - is 3.0 kWh/m³ for the 2030 scenario, the renewable generation needed from the identified desalination plants in 2030 is approximately 1,050 GWh/year.\(^{73,74}\)

Moreover, technological improvements are considered for the 2030-2050 consumption projection, which are expected to lead to an average consumption of 2.2 kWh/m³. In particular, 2050 energy needs are projected to be approximately 1,900 GWh per year.

Renewable desalination plants are therefore expected to capture approximately 5% of total renewable energy generated by the country in 2030.

\(^{73}\) The value is considered as the average of the range 2.8 – 3.2 kWh/m³ reported by the World Bank\(^{30}\) for the Reverse Osmosis desalination technology in 2022; the range 2.1 – 2.4 kWh/m³ is used for 2050, considering technology improvements.

Unlocking the full potential of renewable energy for desalination

Morocco will reap major benefits from coupling desalination with RE sources. Doing so will ensure a sustainable water supply, energy security for the water sector, and environmental sustainability. However, actions could be taken to unlock investments and benefit from these technologies and overcome several challenges. To better understand how these barriers influence the renewable desalination sector, they have been grouped according to a regulatory framework which focuses on three dimensions fundamental to create an enabling environment for the scale-up of investments in renewable desalination. The dimensions are:

- **Openness** – sector and market governance. This Dimension provides an overall view of the degree of openness of electricity markets to private sector investors across the value chain. It covers, among others, energy policies, laws, and regulations meant to define the operating landscape, market-entry provisions, infrastructure development plans, sector governance structures, and related considerations.
- **Attractiveness** – sector economics. This Dimension provides an overall synthesis of the attractiveness of the electricity market to private sector investors. It assesses policies, laws, and regulations that ensure the economic viability of electricity infrastructure investments, in particular, project CAPEX and tariffs.
- **Readiness** – sector maturity. This Dimension provides an assessment of operational rules for the efficient integration and effective management of new infrastructure for investors along the value chain. In particular it looks at project financing, infrastructure, social awareness and technical expertise.

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75 GlobalData (March, 2022).
76 Based on the World Bank assessment of 34 Seawater RO plants constructed between 2001 and 2017, with a total capacity that ranged from 5,000 to 624,000 m³/day.
After a thorough analysis, Morocco's main challenges on renewable desalination have been identified as follows:

Figure 22: Morocco’s main challenges on renewable desalination

1. **Sector Structure**
   - Institutional complexity between water and electricity sectors

2. **Infrastructure**
   - Challenges in term of current power systems integration, flexibility and efficiency

3. **Regulation and Policies**
   - Lack of clear public regulation

4. **Incentive Scheme**
   - Absence of financial and tax incentives to desalination

5. **Contractual Structure**
   - Lack of mass implementation of PPPs in desalination sector

6. **Environmental Impact**
   - Absence of ad-hoc law for the government of the environmental impact of desalination activity

7. **Social Awareness**
   - Absence of in-depth studies on the social perception on the desalinated water

8. **Technical Skills**
   - Lack of development of technical know-how if compared to other Mena countries

9. **Technology**
   - Challenges on the coupling of desalination with renewable technologies

10. **Investment**
    - Relevant CAPEX requirements

Source: AFRY Management Consulting

As shown below in figure 23, the ten identified challenges impact all the three dimensions constituting an enabling environment for renewable desalination investments:

Figure 23: Morocco renewable desalination challenges: impact matrix

Source: AFRY Management Consulting
Actions to unlock investments and benefit from the renewable desalination technologies are as follows:

1. **Sector Structure.** Policy integration is key in tackling complex issues, such as climate change. The Water-Energy nexus could be seen also as a way to look at policy and regulation design to maximise co-benefits and synergies from the energy and the water sectors. Stronger cooperation between both sectors, which are still fragmented with several public actors and levels of governance, should be encouraged and supported in governmental and non-governmental institutions. Special emphasis should be given to establishing and maintaining communication channels between the decision makers of the two sectors. In particular, encouraging a new strategic synergy and planning between the two water and electricity branches of ONEE could facilitate the promotion of renewable energy desalination and the disclosure of common targets and policies.

2. **Infrastructure.** Morocco should continue in the process of modernisation of the power systems allowing for the integration of high percentages of renewable energies, while securing flexibility and efficiency, through digitalisation and integration of smart grid systems. At the same time, improving water transportation infrastructure is an enabling condition to connect sea-side desalination areas to the main-land arid regions and lower the cost of the water delivered.

3. **Regulation and policies.** All stakeholders that are interested in promoting independent production of water from desalination plants should work together to foster more straightforward legal processes. Thanks to the establishment of ANRE, it will be possible to simplify the procedures for the domestic production of electricity and sale of surplus energy to the grid, as well as to identify and remove the bottlenecks in the licensing process. The publication of the implementation decrees for energy Law 40-19 could also help in promoting renewable energy desalination and attract investors.

4. **Incentive Scheme.** As of today, financial and tax incentives for the implementation of renewable desalination plants are not provided by the government. However, the adoption of renewable desalination technologies could rely on the existing mechanisms for renewable energy development given the great potential of the country and the low cost of the latest projects. However, to speed up the process of deployment, it is important to simplify the entire regulatory framework for IPP participation in the market.

5. **Contractual Structure.** PPPs and corporate PPAs could be a solution from a contractual point of view for renewable energy desalination. This could be facilitated by the implementation of the provisions of the related laws and would accelerate the time-to-market of this kind of technologies.

6. **Environmental Impact.** One of the most relevant aspects of a comprehensive framework for renewable energy desalination is the management of the environmental impacts of the infrastructure. It is therefore crucial to design a specific law on the environmental impact assessment of desalination plants. Given the particular concerns about brine management and its impact on the aquatic environment and tourism, the lack of a regulatory framework might undermine the adoption of desalination solutions.
7. **Social Awareness.** Despite the perception of desalinated water is fundamentally impacted only by the price of water, which remains a major concern for end consumers, a long-term and consistent communication strategy to communicate progress in the field and the success stories of renewable energy desalination installations to local communities and relevant stakeholders would increase the social acceptance of the adoption of the technology.

8. **Technical Skills.** Compared to MENA countries, in Morocco the desalination sector is relatively new, which might potentially impact the development of its renewable desalination projects. Education and training on all levels are therefore necessary, covering technological, economic, social, and institutional aspects of renewable energy coupled with desalination. Renewable energy desalination should be included as part of universities and technical schools’ curricula to cover the technology in more detail. Cooperation between the universities on national and international levels should be promoted to facilitate the exchange of teaching materials, lecturers and researchers. Organising seminars, debates, and other activities specifically directed toward technicians, engineers, and decision makers, will help promote this technology, its benefits, and its applicability.

9. **Technology.** Renewable energy technologies and desalination technologies have developed along independent paths. To overcome the challenge related to the intermittency of supply from renewable energies, multiple technological solutions are possible. One approach is to provide additional sources of energy for the desalination plant so that the supply of energy is more constant. For example, this could be achieved by combining a wind turbine with PV panels. Hybridization with the electricity grid, together with tailor-made control systems can guarantee continuous operation. However, the utilisation of thermal and electrical storage technologies (in particular, batteries) is considered to be the best solution to reduce the intermittent nature of the energy supply.

10. **Investment.** Desalination investments have been slowly implemented in Morocco due to the relevant CAPEX required. Particularly, Seawater RO, the most adopted technology for desalination in Morocco, allows economies of scale only for production capacities lower than 100,000 m$^3$/day (with an average cost of 0.85 USD/m$^3$ in 2019), which are not evidenced in greater plants (average cost of 1.1 USD/m$^3$ in 2019). It would therefore be important that the national plans take into account the economies of scale of the plants and that the DFIs are involved, pooling private, international, and public resources to finance this type of solution.

By taking these actions, Morocco could meet the freshwater and energy demands, build the capacities and expertise in the renewable desalination field and play a leader role towards a sustainable energy transition in the region.

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77 The regulatory framework has already been used by RES4Africa Foundation and AFRY Management Consulting in previous reports as: Fostering small-scale deployment in Morocco (available at: https://static1.squarespace.com/static/609a53264723031eccc12e99/t/6272353096b6454376c4ad99/1651651925281/SMALL_PV_SURVEY.pdf) and Unleash decentralised development in Tunisia (available at: https://static1.squarespace.com/static/609a53264723031eccc12e99/t/60e-d53957ab2906137d4f450/1626166179519/Unleash+Decentralised+Development+in+Tunisia.pdf)
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