Renewable energies powering seawater desalination in Morocco

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Abstract. Several reasons including fast-paced development, global warming, unsustainable water use, and many others have prompted many areas around the world to experience water shortages. But with salt water accounting for approximately 97.5% of total water on Earth and its availability in almost every country, desalination has emerged as the go-to solution. This comes with some associated issues, namely, significant energy requirements. These are largely satisfied by fossil fuels, which are becoming increasingly scarce and contribute to greenhouse gas (GHG) emissions and, therefore, global warming. Thanks to renewables, desalination plants could be able to sustainably overcome such shortages, particularly in Morocco. This is attributable to the country's favorable meteorological conditions for solar and wind plants, and to the large amount of land available for hydroelectric plants. This paper discusses the main benefits associated with the use of renewables in seawater desalination plants. Notably, the contribution to increase the share of renewables in the energy mix and to reduce GHG emissions. Moreover, it reviews certain obstacles encountered, including costs and grid stability issues, which could be complex and costly to overcome. The paper also highlights the necessity of adopting AI, IoT, and waste management technologies to further optimize processes.

Abbreviations

RES: Renewable Energy Sources	MSF: Multi-stage flash	MED: Multiple effect distillation
MVC: Mechanical vapor compression	RO: Reverse osmosis	GHG: Greenhouse gas
TVC : Thermal vapor compression	ED: Electro-dialysis	LCOE: Levelized Cost of Energy
AI : Artificial Intelligence	IoT: Internet of Things	SWRO: Seawater Reverse Osmosis

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1 Introduction

Human life preservation and the continuity of its daily activities, i.e., agriculture, industry, and more, require freshwater. The latter is getting scarcer due to a combination of several factors: demographic growth, fast-paced development, global warming, and lack of sustainable water use [1]. However, nearly 97.5% of the earth's water is salt, and almost all countries have access to it [2]. Removing salts and minerals from it, in other words, desalinating it [3], is an interesting approach to secure the availability of freshwater. A whole range of techniques have been developed in this regard. Yet each of them requires an energy supply that can be met through the use of conventional energy sources, i.e., fossil fuels. These sources are considered to be depleted and their use leads to massive greenhouse gas (GHG) emissions. Consequently, exploiting them raises certain risks, mainly in terms of sustainability.

To secure access to freshwater without compromising sustainability, alternative energy sources must be harnessed. In this regard, Renewable Energy Sources (RES), which are replenished by nature [4], have come into play. Solar, wind, hydro, geothermal, and biomass were identified as the most prominent RES [5]. Solar energy, which is derived from the radiation of the sun, can be harnessed to provide thermal or electrical energy. This can occur through the use of several technologies, including solar thermal and solar photovoltaic systems [6]. Also, a wind turbine converts the wind's energy from kinetic to mechanical form, in order to turn an alternator and thus generate electricity [7]. Moreover, a turbine (or waterwheel) converts the energy of water in movement to mechanical energy that could be then transformed into electricity (hydropower) [8]. Besides, geothermal energy refers to the heat that exists in the interior of the earth and which can be converted into other forms of energy [9]. Furthermore, biomass is regarded as a RES which can be exploited to produce energy. It encompasses any organic substance originating either from plants, for example agricultural crops, or from animals, like animal waste [10].

This paper looks at the use of RES to drive desalination plants in a Moroccan context. By answering the research questions below, this paper can achieve its stated purpose.

- What are the most frequent seawater desalination techniques?
- What is the status of seawater desalination and renewable energy in Morocco?
- What are the benefits and challenges involved when it comes to powering seawater desalination plants with renewable energy in Morocco?

To answer the research questions above, the remainder of the paper is broken down into three sections, followed by a discussion and then a conclusion.

2 Seawater desalination methods

Desalinating seawater that has a total dissolved solids (TDS) count between 35 and 45 g/kg, enables producing freshwater which has a TDS of less than 1 g/kg [11]. The process includes the following steps:

- From the sea, raw water is extracted;
- The latter passes through a pre-treatment process, during which all particles in suspension are removed;
- When pretreated water passes through processes such as Reverse osmosis (RO), dissolved solids are removed, producing freshwater while the brine solution is discarded;
- In response to the water's end use, i.e., consumer use, industrial use, and so on, the freshwater undergoes a post-treatment process whereby its pH is adjusted [12].

Several processes have been developed to remove dissolved solids, and they can be sorted into two types, precisely, thermal and membrane-based ones. In addition to multi-stage flash (MSF) and multiple effect distillation (MED), there is another type of thermo-desalination process. This is frequently used and known as vapor compression (VC), which can be either thermal vapor compression (TVC) or mechanical vapor compression (MVC) [13]. Furthermore, as with RO, electro-dialysis (ED) also forms part of the main membrane -based technologies [13]. With the exception of MVC, every thermal desalination process demands two energy forms, namely low-temperature heat and electricity. Whereas, RO & ED processes require only electricity [14].

According to several studies, Tayeh, show that RO accounts for 70% of the worldwide desalination market, followed by MSF (18%) and MED (7%). This makes these three technologies the most sophisticated currently used [15]. Table 1, illustrates some of the advantages and constraints of these, along with their total energy consumption and corresponding costs.

Table 1. Advantages, drawbacks, and certain specifications of MSF, MED, and RO.

Desalination process	**MSF**	**MED**	**RO**
Advantages	With a high freshwater recovery rate ranging from 30% to 80%, this process ensures maximum production of freshwater; This technology can operate even when the water is highly saline; It ensures the production of freshwater with a higher quality than the one that could be obtained with the RO process.	Moderate energy requirements and capital costs compared to those associated with MSF; Thanks to an operating temperature lower than that of the MSF, the risk of corrosion and scaling is reduced; Able to process water with a high salt content; Better treated water quality than that obtained through RO.	Here, the energy consumption is lower than that of thermal technologies; Easy to Resizing; It can be integrated with several RES; Lower investment costs.
Disadvantages	It requires a high amount of energy, as compared to RO and MED; Since the feed water contains ions that cause scaling, this process struggles with fouling and scaling. Massive capital investment.	In this process, heat exchangers have to be maintained regularly; Large surface area required, as for MSF, compared to RO.	It is prone to biofouling; Highly saline water is not suitable for this type of desalination process, on account of the osmotic pressure involved; Expensive in terms of operation due to chemicals and membranes costs.
The equivalent total energy consumption (KWh/m^3)	Between 19.58 and 27.25	From 14.45 to 21.35	Between 3.7 and 8
Cost ($/m^3)	1.578–2.204	1.097–1.502	0.5–2
References	[16][17][18][19][20]	[21][17][22][20]	[22][15][17][19][20]

3 Status of seawater desalination and renewable energy in Morocco

3.1 Seawater desalination status

Climate change, reduced dam supplies, and increased water demand have led to a decline in the annual water consumption per capita in Morocco. This has fallen from 2,560 cubic meters (m^3) in the 1960s to 565 m^3 nowadays, and is expected to reach 480 m^3 by 2030. This places the country in an alarming position (27th) among the countries most prone to water scarcity *[23]*. Hence, to satisfy drinking, industrial, and irrigation water needs in Moroccan cities and urban centers, the country has undertaken to develop the desalination sector recently. Currently, with 15 plants in operation, the country can provide approximately 192 million m^3 of desalinated water per year [24]. Fig. 1 outlines the main milestones in the development of the country's desalination sector over time, along with an outlook for the future.

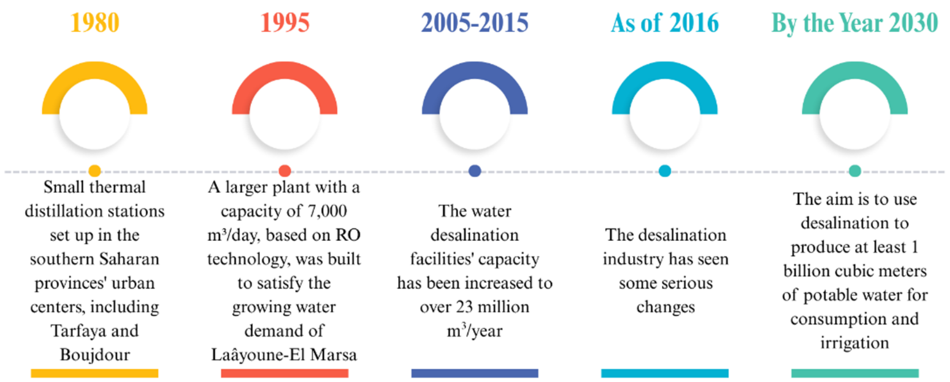

Fig. 1. A brief overview of Morocco's desalination sector (Adapted from [25]).

The total daily capacity of desalinated seawater installed in Morocco before 2020 was 110380 m^3. This capacity was reached thanks to seven plants, managed by ONEE[i] and OCP[ii] and supplied by fossil fuel. Fig. 2 depicts the location these plants with their respective capacities [26].

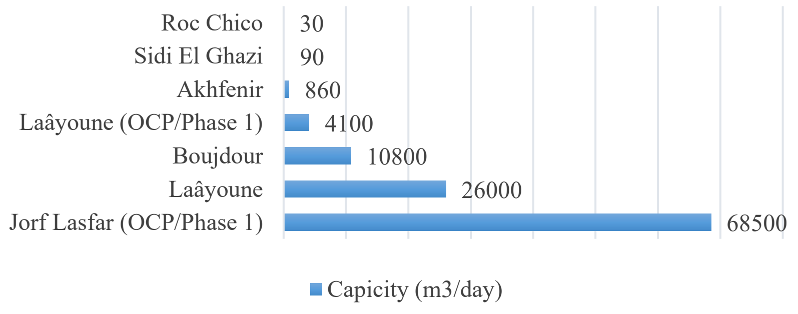

Fig. 2. Seawater desalination projects implemented before 2020 in Morocco, with their capacities (Adapted from [26]).

[i] The National Office of Electricity and Drinking Water
[ii] The Office Chérifien des Phosphates

3.2 Renewable energy status

With an installed capacity of 3727 MW, the country was one of the five leading African nations in terms of renewable capacity from 2022 [27]. To meet its growing electricity needs, the country has increased the contribution of renewable energy in its electricity production over the years, as shown in Fig. 3. This proportion will reach 52% as of 2030 [27].

The distribution of the country's renewable energy production by source, as shown in Fig. 4, provides an insight into the most predominant sources. These include solar and wind energy, which have been developed and will continue to be developed. This is attributed to the nation's plan to increase the share of renewables by 2030, launched during the COP21[i] held in 2015. The plan states that this will be achieved by increasing the share of both solar and wind energy by 20% and that of hydroelectricity by 12% [27].

The predominance of solar and wind energy in Morocco's renewable energy production is explained largely by:

• The country's considerable potential for solar energy, which stems from its annual irradiation of no less than 1,800 and up to 2,500 kWh/m² per year [28].

• The country's great potential for wind energy, which stems from its strategic location stretching between the Mediterranean Sea and the Atlantic Ocean. Wind speeds along the latter's coast can exceed 9 meters per second [29].

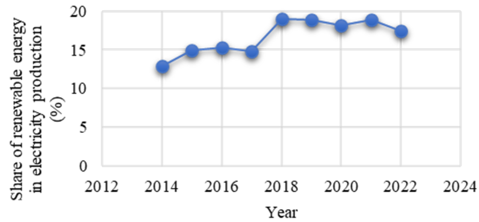

Fig. 3. The share of renewable energy in electricity production in Morocco over the years (Data extracted from [30]).

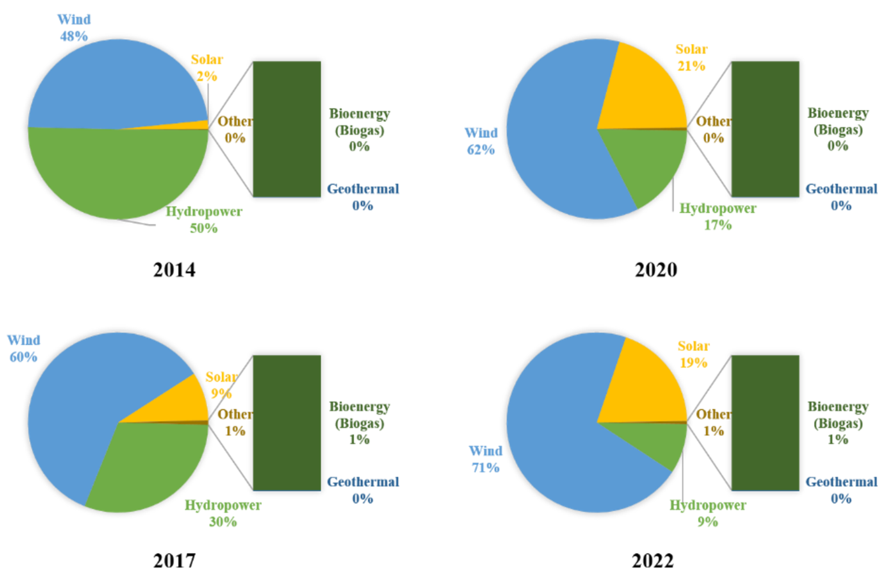

Fig. 4. Breakdown of Morocco's renewable energy production by source (Data extracted form [30]).

[i] 21st Conference of the Parties

4 Integration of sustainable energy into seawater desalination plants in Morocco

Several studies have been conducted on supplying Morocco's seawater desalination plants with energy from renewable sources. **Table 2** provides an overview of some of these studies, focusing on the benefits associated with adopting these technologies to operate these plants.

Table 2. Overview of studies conducted with a view to powering desalination plants in Morocco by renewables (focus on benefits)

Ref	Objectif	Results
[31]	Determination of the economic & environmental feasibility and the efficiency of a pilot seawater desalination unit (MVC). The unit is powered mainly by renewable energy system (63% from solar and wind), in Morocco (Laâyoune region).	By choosing the suitable effect's number and increasing the plant capacity, the cost of water produced by MVC could be lower than 0.8$/m^3. This is the average Moroccan water production cost. GHG emissions, particularly CO_2, can be significantly reduced through the use of RES.
[32]	The performance evaluation of seawater greenhouse combined with solar pone (SWGH), manly in terms of freshwater production in different sites of Morocco.	The innovative SWGH has a five to one rate of produced Freshwater as compared to the conventional one. Managing brine by reusing it.
[33]	Performance analysis of a SWRO plant, with 2.2 m^3 as daily capacity, supplied by an off-grid renewable energy system in Moulay Bousselham, Kenitra.	The region's weather conditions could be exploited to help producing water in a sustainable way. The highly energy-efficient system is an off-grid system that comprises photovoltaic panels with solar trackers, wind turbines, and lithium iron phosphate batteries.
[34]	This study aims to assess the feasibility of integrating a solar photovoltaic system into the existing SRWO desalination plant located in Al Hoceima.	Installing a photovoltaic system to secure a fraction of the plant's energy requirements could help avoid almost 1830,25 tons of CO_2 emissions annually. Analysis indicates that after 5.59 years, the system will prove its viability.
[35]	Evaluation of various strategies for a better performance in terms of the energy consumption and the durability of an existing SWRO plant (Phosboucraa in Laayoune).	To improve the efficiency of the plant, the use of pressure exchanger (PX) technology is quite interesting. This can reduce the plant's energy requirements from 8 to 2.9 kWh/m^3. And to provide this energy sustainably, a hybrid energy system can be adopted. The system relies on solar and wind energy as RES, diesel generators as a conventional one, and includes batteries for storage. This can assist in achieving a low LCOE and reducing GHG emissions as much as 80% when compared to those associated with typical diesel-powered facilities.

5 Discussion

Despite the key advantages associated with using renewables to power Morocco's desalination plants, this approach:

- has been adopted in small-scale projects implemented during 2003-2008, with a yield of one cubic meter per hour. These plants are located in isolated rural regions (Azla, Tazekra, Amellou and Tangarfa) where there are neither access to power lines nor to potable water;
- has been taken into consideration in most of the 10 large-scale seawater desalination projects scheduled for implementation between 2020 and 2050 [26].

Thanks to the technical progress made in reverse osmosis field, this technology continues to be as promising as ever. These latter include the development of membranes that are highly permeable and resistant to fouling, the inclusion of AI technologies, and more [36].

From this, it can be estimated that the country's expected seawater desalination capacity for 2050 will be provided exclusively by reverse osmosis. This amounts to 2 149 501 m^3 per day [26]. Consequently, the total annual energy consumption required for these plants will be in the range of 2902.9 to 6276.5 GWh, or even less. Meeting this enormous consumption by connecting these SWRO plants to the national grid, where electricity will still be produced as it is today [34], will bring serious concerns. These are mainly related to the environmental impact, as this could generate annual CO_{2e} emissions of between 2,270 and 4,908 gigagrams. The integration of RES will substantially reduce this impact. The reason behind is the fact that emissions factor of each renewable energy source is very low compared to that of conventional sources.

However, integrating these sources into such a delicate process, where the output is considered vital to sustaining human life, requires overcoming many barriers. Most of these are technical and financial in nature. Examples include high investment and operation costs, long pay-back periods, cost of energy, connecting such sources to the power grid, and more. The economic and financial issues are going to be overcome, thanks to: i) the recent competitiveness of solar and wind energy costs compared to that of fossil fuels; and ii) governments' subsidies for renewable energy projects [37]. Yet, due to the intermittent nature of RES, their integration into the grid compromises its stability, which prevents frequency and voltage from remaining stable. In this regard, efforts must therefore be made focusing on infrastructure upgrading [38].

The integration of digital technologies, notably AI and IoT, into future SWRO desalination plants will be a key milestone. They should be considered so as to: i) forecast energy demand; ii) manage electricity production; iii) anticipate maintenance requirements; iv) guarantee the quality of the water produced and so on. This approach will optimize processes and therefore reduce costs.

The published research papers regarding the integration of renewables into some existing plants have focused on the utilization of solar and wind resources. Yet hydropower would be an interesting path to explore, given that the Kingdom has vast areas of land available. The system will involve pumping pre-treated water to a certain altitude. There, the salts will be removed by RO, and then the freshwater will be redirected to a lower altitude by means of turbines. This is where the post-treatment will take place. The energy required to operate the system will be provided by a combined system of grid-connected solar and wind power, as well as energy recovered from the turbines. A feasibility study of this solution will be carried out as part of future work.

Even if seawater desalination is a key solution to ensure the availability of freshwater. A major problem involves during its functioning, as each plant produces both freshwater and a highly saline brine (waste). Getting rid of the latter is a serious concern, as it affects the marine environment. Dealing with this challenge requires treating this brine so that extra amounts of freshwater can be harvested or even resources like salts can be recovered.

Panagopoulos et al, suggest numerous ways forward, including environmental monitoring plans, zero liquid discharge, resource recovery, etc [39].

6 Conclusion

Finding ways to mitigate the worsening worldwide water scarcity has become a major research priority for scientists and other stakeholders. In this regard, seawater desalination has emerged. Several desalination processes exist, including those traded on the market, among which RO occupies the lion's share, preceded by MSF and MED respectively, and many others. These processes consume a considerable amount of energy. Nowadays, this latter comes mainly from fossil fuels, which poses serious sustainability issues.

Morocco, ranked 27th among the countries most prone to water scarcity, had seven seawater desalination plants with a daily capacity of 110380 m^3 in 2020. This capacity will have risen to 2149501 m^3 by 2050. This study was conducted to examine the potential contribution of integrating renewable energy into seawater desalination processes, particularly RO, in Morocco. This latter spotlights the presence of several factors that could enable Morocco to sustainably power its desalination plants and thus ensure its freshwater supply. These factors are mainly as follows: i) the length of the country's coastline; ii) the country's significant potential in terms of renewable energy; iii) the country's climate strategy.

Several studies have examined the role of renewables in Morocco's seawater desalination sector. Most emphasize that these sources could significantly boost the sector's cost-effectiveness and reduce its GHG emissions. The renewable energies mentioned in these studies are mainly solar and wind energy. However, attention should also be given to other sources, such as hydroelectricity. Integrating the latter into grid-connected solar and wind-powered SWRO plants, will allow these latter to produce freshwater while covering all-or-part of their energy requirements. This requires feasibility studies to be carried out.

This study also reveals the problem raised by the massive use of renewables, i.e., grid stability issues. This could be solved by upgrading the grid, which requires effort. Moreover, it notes that the use of AI and IoT, combined with brine management techniques, is expected to play a key role in upgrading Seawater Desalination plants' performances.

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