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Role of desalination technologies and water reuse in Water-Energy-Food nexus: an opportunity for Algeria

Nadjib Drouiche[a,*], Omar Rodriguez Villarreal[b,c,d], Sara Ouali[e,f], Seif El Islam Lebouachera[d], Richa Soni[g]

[a]*CRTSE-Division CCPM-N°2, Bd Dr. Frantz FANON, P.O. Box: 140, 16038 Alger Sept Merveilles, Algeria, email: nadjibdrouiche@yahoo.fr (N. Drouiche)*
[b]*Universidad Autónoma de Nuevo León, Facultad de Ingeniería Mecánica y Eléctrica, Pedro de Alba s/n, Ciudad Universitaria, C.P. 66451, San Nicolás de los Garza, Nuevo León, México, email: omar.rodriguez-villarreal@univ-pau.fr (O.R. Villarreal)*
[c]*Universite de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Allée du Parc Montaury, F-64600, Anglet, France*
[d]*Université de Pau et des Pays de l'Adour, E2S UPPA, CNRS, Total Energies, LFCR, Allée du Parc Montaury, 64600, Anglet, France, email: s.lebouachera@univ-pau.fr (S. El Islam Lebouachera)*
[e]*Univ Rennes 1, Ecole Nationale Supérieure de Chimie de Rennes, CNRS, ISCR (Institut des Sciences Chimiques de Rennes) – UMR 6226, F-35000, Rennes, France, email: sara.ouali@univ-rennes1.fr (S. Ouali)*
[f]*Faculté de Génie Mécanique et Génie des Procédés, Université des Sciences et de la Technologie Houari Boumediene, Algiers, Algeria*
[g]*Physics Department, Lancaster University, Lancaster LA1 4YB, UK, email: richamnit10@gmail.com (R. Soni)*

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ABSTRACT

Water resources in Algeria are scarce, often low quality, fragile, and unequally dispersed over time and space. The pressure on water resources can be associated with industrial development, a steady population growth, and demanding land irrigation measures. These conditions create a tense competition for managing water resources and sharing them between agricultural development, drinking water supply, industrial activities etc. Water treatment and reuse for agriculture is common in some countries. For example, in Spain, 71% of wastewater is used for the agricultural industry. In addition, the effect of climate change has brought national policies focused on the water-energy-food nexus (WEF) to the forefront. Within this context, desalination membrane technologies could play an increasing role for supporting segments of the Algerian economy that are heavily water dependent. In addition, by using renewable energies, such as solar energy in desalination, we would be taking advantage of Algeria's great potential, estimated at 13.9 TWh/y. By implementing water reuse and desalination strategies together in the agricultural sector, there is an opportunity to expand the access to healthy food and clean water, thereby keeping the WEF nexus effects under control. As well, effective use of energy potential for food use will be a step forward for economic growth in Algeria.

Keywords: Desalination; Climate change; Sustainable development goals (SDG's); Water scarcity mitigation

1. Introduction

Algeria has made the adaptation to climate change a cornerstone of its development in the coming decades. The country is determined to honor its commitment made under the Paris Agreement, which includes a pledge to reduce greenhouse gas release by 7%, down to 22% of its overall gaseous emissions by 2030. Moreover, a massive

* Corresponding author.

investment in renewable energy that will provide more than 20% of electricity generation capacity is central to that vision. Today, the energy policy in Algeria is primarily connected with technologies dependent on fossil fuels. The total cost for a cubic meter of freshwater is between 80 cents and $1.5 for multi-stage flash technologies (MSF), 50 cents and $1.2 for reverse osmosis (RO), and 70 cents and $1.2 for multi-effect distillation (MED), which could weaken the country's climate mitigation efforts as well as its energy security strategy (Ghaffour Nature Middle East). Thus, desalination may be profitable for producing high-value crops but it is not economically viable for irrigation due to high cost constraints [1].

In this context, water reuse strategy can be targeted for agricultural activities, which are expected to increasingly rely on hard-to-reach water sources. The reuse can serve municipalities (green spaces, street washing, firefighting, etc.), industrial groups (cooling), improve the renewal of water tables (protection against the intrusion of saltwater in the seaside) and promote the fight against agents polluting water streams (wadis, dams, groundwater, etc.). According to the National Office of Sanitation (ONA), 17 wastewater treatment plants were involved in the reuse of treated wastewater (19 million m^3) and contributed to irrigate 11,062 ha of agricultural land in 2017, that is, 40% of the volume treated by the 17 WWTPs and 10% of the total volume treated by the 144 WWTPs in operation managed by the ONA. Hence, water reuse has been instrumental to slow down groundwater depletion and environmental degradation threats. Artificial recharge of aquifers with wastewater has already been developed for about 20 y in the Mediterranean region, particularly in Israel and Australia, in areas subject to significant water stress. When evaporation is significant, the water is reinjected into the subsoil by natural filtration, via basins, or directly through wells. The interest is to store this water in the subsoil, which is thus not taken up by evaporation on the surface. Consequently, it can be reused for watering, agricultural irrigation, or even for drinking water.

This is a playful way of managing the water cycle and optimizing it. Overexploitation of aquifers will ultimately impact food security. In 2008, these basins stopped receiving water because the flows were diverted to the new Douira dam from the El Harrach wadi. The farmers demanded the resumption of groundwater recharge operations, but this did not take place until April 2011. They also discussed with the public authorities a distribution of spring water upstream of the wadi for the future, that is, the water dedicated to groundwater recharge and the amount taken for the dam supply [2].

Three arguments are put forward to justify this strategy of water displacement. It makes it possible to reduce, interrupt or reverse the fall in the level of a water table, (i) protect the freshwater aquifers in coastal areas against the intrusion of the "wedge", and finally (ii) store surface water (purified effluents) for possible use. Given the level of purification envisaged, the technique of recharging the water table can only integrate complementary purification processes through the soil and defined as:

- Infiltration-percolation, which optimizes the treatment due to its limited foot print and groundwater recharge.
- Direct injection with wastewater, even if treated, is not recommended.

Storage in the ground has several benefits:

- The total of artificial reload is lower than that of superficial reservoirs of equivalent capacity since no construction is required.
- The aquifer acts as a distribution system instead of surface networks (canals or pipelines).

Underground storage avoids the disadvantages of surface reservoirs, such as evaporation losses or the appearance of tastes and odors caused by algae growth. Groundwater recharge can positively impact a reuse project by providing an invisible transition between the treated effluent and the reclaimed groundwater. Adjusting the water balance between regions through significant regional and interregional transfers makes up for deficits in some regions with accessions from other regions. The five-year program 2009–2014 led to the completion of three water transfer works from the Albian aquifer to the south, particularly towards the wilayates of Djelfa, Tiaret, Biskra Saida, Mila, Batna, and Médéa [3].

Water reuse, groundwater with and without treatment, dams, partial desalination for salt tolerant agriculture is all important points to include. In 2017, Algeria had seventy-five (75) dams with a total volume of 6.5 billion m^3. Its goal is to increase to the total number of dams in Algeria to 139 by 2030, and in doing so, reach a storage capacity of nearly 12 billion m^3 throughout the country. The strategy at the national level is to interconnect storage facilities in regional systems: thus, by integrating into a system, the dams of Kedarra, Taksebt, and Koudiat Acerdoun serve Algiers, Boumerdes, and Tizi-Ouzou; the MAO network "Mostaganem-Arzew-Oran" interconnects dams and desalination units to supply water to cities of the northwestern part of Oran. In summary, our objective in sharing that desalination by means of renewable energies can play an important role in Algeria in food cultivation, by exploiting the potential for energy generation, in water treatment for agriculture as the scarcity of freshwater resources has generated the increased use of desalination with fossil fuels and considering that Algeria has a large potential estimated at 13.9 TWh/y, it is an option that should be implemented. Algeria has a population of 42 million people, and the main problems are water scarcity due to drought, as rainfall has decreased by more than 30% in recent years.

2. Desalination vs. food production

Water desalination is used to increase freshwater resources in places where water is scarce and mainly for growing food crops and various techniques are used for this process. Distillation has been studied for many centuries by Mediterranean and Near Eastern civilizations. The first solar ponds to serve as domestic drinking water were used more than 100 y ago in Egypt [4]. The main advances in desalination were in Persian Gulf countries 50 y ago, due to their easy availability and scarcity of freshwater resources. Intensive research on such large-scale technologies began in the United States in the late 1960s [5]. In the following, an overview of various desalination technologies is presented, as the objective in this chapter is to show the energy requirements, costs, achievements, limitations and prospects of desalination.

2.1. Forward osmosis

Forward osmosis (FO) is a developing membrane process. It is based on the phenomenon of natural osmosis process which is diffusion of water via a semipermeable membrane naturally [6,7] The diffusion of water takes place from feed (dilute) to extracted (concentrated) solution. The osmotic pressure is higher than the feed solution [8].

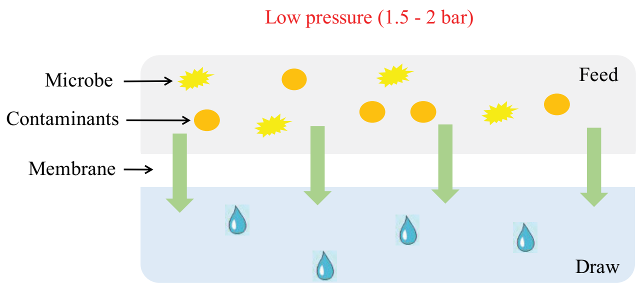

Fig. 1. Description of solution transport mechanism through a membrane in forward osmosis system.

FO technology, which is highly resistant to fouling and resistant to oxidizing agents, can be used either directly or indirectly to provide a more efficient desalination process from an energy point of view than reverse osmosis. Unintended FO desalination processes use low-salinity feed steams like wastewater sources to dilute advanced salinity seawater and produce partially desalinated water that can potentially serve for soil irrigation. Mass commercialization of FO is restrained due to some important However, some significant inhibitions like low permeate flux, concentration polarization and reverse solute flux. Some advantages and disadvantages are presented:

Advantages:

1. Reverse osmosis water filters remove many bacteria and pathogens from tap water.
2. Reverse osmosis systems take up little space. Because reverse osmosis water filters produce highly purified water, food cooked with this water will taste better.
3. Reverse osmosis water filters demineralize water, which means that they also remove healthy minerals that are naturally found in water. For this reason, they should be complemented with a remineralizing filter.

Disadvantages:

1. Reverse osmosis filtration is a slow process. Because reverse osmosis filters require pressure in order to purify water, they produce a smaller amount of drinking water than other types of purification systems.
2. Reverse osmosis equipment discharges water to the drain, as this is a fundamental part of the osmosis process. The ratio of rejected water to usable water can vary from 2 to 1 (2 L of water going down the drain to 1 L of water for consumption).

However, a major challenge for this method is to find and use a sustainable and viable energy for desalination, since a large amount of gas emissions are generated by intensive consumption, but this could be avoided through the use of renewable energies, such as solar energy, and considering that in Algeria it has great potential, the change of technology would be of great benefit.

2.1.1. Fertigation

FO has received considerable attention lately for its potential use in fertigation, a technique which exhibits the following rewards over traditional fertilization methods:

- Controlled nutrient dosing leading to enhanced nutrient uptake by plants, which in turn leads to improved root systems.
- Reduced consumption of water via improved root systems.
- Decrease in the quantity of nutrients needed due to precise dosing.
- Reduced escape of nutrients to water supplies.

Fertilizer drawn forward osmosis (FDFO) can be used to supplement freshwater required to produce fertigation water for agricultural use. In a recent laboratory study, Chekli et al. [9] investigated the dilution of a commercial nutrient solution from the dewatering of a wastewater feed-stream across a FO membrane. The purpose was to grow hydroponic lettuce, which is produced when a plant is cultivated in absence of soil, that is, vegetables are mainly grown in presence of a nutrient-rich fluid. It was shown that lettuces produced by the FO Drawn Fertilizer process could develop as well as the control specimens. Moreover, even though the membrane was fouled after long operations, 75% of the initial water flux could be recovered by hydraulic flushing.

This promising technique should be considered in Algeria due to the scarcity of freshwater resources. FDFO would provide an additional source of freshwater for the farmers and thus promote the mainstreaming of a nexus approach. So far, this option has not been used in the country [10,11]. Despite a relatively expensive cost of installation the payback period can be short, making the case for conducting fully scaled studies in the country.

2.2. Nanofiltration

The most extensive use of freshwater in Algeria is devoted to land irrigation. The vast majority of this resource is obtained from groundwater, which is only available in limited supply. Each year, aquifers are gradually contaminated or emptied, thereby making water sources for soil irrigation increasingly scarce.

The aquifers along the Algerian coastline have been affected by saltwater intrusion (SI), deteriorated by wide groundwater extraction. Constant dilapidation of quality of groundwater in littoral aquifers is an important cause of concern. It has provoked significant economic losses, which has led to the deteriorated quality of freshwater aquifers. This problem is intensified due to population growth, and the fact that about 80% of the Algerian's population live in coastal regions. An excessive groundwater withdrawal, combined with a substantial reduction in recharge level ads up to this problem. Possible effects of climate change have been reported. However, potential consequences on the characteristics of potential groundwater salinization due to the autonomous process caused by seal level and changes in recharge and evapotranspiration patterns have not received as much attention. However they can be expected to include variations in groundwater level fluctuation.

Brackish water naturally prevails in Southern Algeria.

2.2.1. Brackish water

Regarding the mobilization of brackish water by demineralization, it should be noted that the only demineralization station in operation (that of Bredeah) operates with an insufficient flow rate due to lack of mobilization in the catchment area. The survey results conducted by the Department of Water Resources reveal that the South and the highlands concentrate 97% of the total potential of brackish water, thus representing a daily capacity 2.5 million m^3. The remaining 3% are in the coastal strip. The use of nanofiltration technique to facilitate drip irrigation could help farmers to keep producing crops during periods of drought, where the saline water source is all that remains available [12,13].

One advantage and disadvantage in this method are:

1. Does not require heating or cooling of feed like distillation for example which will reduce the cost of separation effectively. In addition, no mechanical stirring is required. Also, handling a high volume of feed in a continuous manner and a stable flow rate of permeate.
2. Has a limited application in the industry due to the pore size of the membrane.

2.3. Reverse osmosis

Droughts that severely hit Algeria in 2004 motivated the country's decision to invest in important seawater desalination plants. In the coming years, investments in desalination will be boosted due to the frequency, intensity, and severity of droughts, aggravated by climate change. Approving to the Algerian Minister of Energy, the conditions are underway for installing five seawater desalination plants in Boumerdes, Fouka, El-Tarf, Bejaia, and Skikda. These conditions should set down, the charge of the desalinated seawater and the deadlines for completion of these two stations with a capacity of 300,000 m^3/d each. One of the most important factors in controlling seawater/brackish water RO efficient operation is to mitigate membrane fouling, which can be accomplished thanks to a targeted pre-treatment protocol: Arras et al. [14] reported the case of a BWRO plant located in Western Algeria and exhibiting some significant pressure uptake and transmembrane pressure increase after a few months of operation. A series of membrane autopsy studies was carried out, and it was shown that some colloidal silica and fine clay particles found in the pre-filtered raw water were responsible for surface clogging. The problem was resolved by injecting some coagulants in the raw water upstream of the sand filter. In order to avoid high electrical energy consumption when operating RO plants it is important to account for compositional changes in raw water quality and adjust the pre-treatment protocols as necessary. In spite of 11 large-scale desalination plants, freshwater supply in the country is fast falling well below the UN water poverty line (less than 300 m^3/y), which is 1,000 m^3/cap/y. In the 1960s Algeria's annual per capita availability was more than 1,000 m^3 and now it has fallen down to 292 m^3. The desalination production accounted for approximately 7% of the water consumed in 2012 [15].

The energy requirements for desalination plants can be satisfied with renewable energy sources (RES). It is an attractive model as it produces little to no global warming emissions and thereby represents the easiest way to reduce carbon footprint. Wind and photovoltaic (PV) energy are the most commonly used energy sources. According to a full life-cycle emissions study of fossil fuels and renewable energies the electricity production from natural gas releases 503 g of CO_2 per kWh; coal emits 781 g/kWh. Wind, solar thermal, hydroelectric, and solar photovoltaic comparative results, were 9–10 g/kWh, 10–13 g/kWh, 13 g/kWh, and 32 g/kWh, respectively. The growing transition to renewable energy would allow Algeria to replace carbon-intensive energy sources and to significantly curb down its contribution to global warming [16,17].

And some advantages are:

1. Reverse osmosis water filters remove many bacteria and pathogens from tap water.
2. Chlorine taste and odors are also removed; your tap water will not only be safer.
3. RO systems don't use up much space and have a low energy consumption.
4. Reverse osmosis water filters are affordable and provide outstanding quality water.

And disadvantages are:

1. Because of their excellent filtration capabilities, RO water filters demineralize water, which means that they will also get rid of healthy minerals naturally found in water, this is why RO water filters should be used together with a remineraliser filter.
2. RO water filter systems can become clogged, which is why it is a good idea to use it with a sediment pre-filter that will filter out particles that may otherwise clog or damage the RO membrane.
3. RO filtration is also considered a slow process as opposed to other types of water filtration technologies.

2.4. Greenhouse desalination

A greenhouse of sea water or brackish water is a desalination plant that is designed to humidify the greenhouse inner regions by leveraging solar energy and seawater and can produce water that is withdrawn from the air moisture. The collected water can be utilized for uses, irrigation as well as human consumption. The process consists of the evaporation of saline water heated in a humidifier where it meets the air. Humid air is driven to a dehumidifier, where its humidity content produces freshwater on condensation. Many factors affect the performance of a seawater/brackish water greenhouse, such as the height of the evaporator, the transparency of the roof on production of water and consumption of energy. Seawater/brackish water greenhouse units equipped with humidification and dehumidification (HD) desalination capability are often preferred for agricultural applications because of their low cost and ease of operation. This process offers rewards such as certain flexibility in water storage capacity, lower installation costs, simplicity of use, lower operating costs, and reliance on renewable energy resources. Since the solar energy is used, the system saves energy in a very efficient way, while requiring low installation and operating costs due to its rudimentary mechanical design. The environmental conditions are essential to ensure that the system is fully operational. In the Algerian desert and the coastal region affected by high salinity, this system is ideal to produce safe drinking water and agricultural water, and it is very convenient when the demand is decentralized [18].

Finally, some advantages and disadvantages are:

1. Such a method of desalination is backed up by scientific data and is highly understood. The technology used is also reliable that it allows for high-quality water, which means that using such method should allow for great results and could help eliminate water shortage crisis that the world might face in the future.
2. Building desalination plants is not always feasible for a country or a community, with construction costs that are high enough to prevent the development of the technology, as many people just cannot afford the initial price tag—and there are not enough returns to justify the investments made. It can be a very costly process.
3. For the average desalination plant these days, it takes 2 kWh of energy to produce 1 m^3 of freshwater.

2.5. Membrane distillation

The membrane distillation (MD) is a promising process to produce water for agricultural use and for the possible recapture of nutrients from saline and wastewater. Desalination and reuse of wastewater offer alternative technological ways to prevent the complete exhaustion and pollution of natural water resources. In coastal and inland regions, desalination can help mitigate water stress, for example: by producing freshwater from seawater, groundwater, treated wastewater and drainage water. In seawater desalination, membrane operations and integration of membrane operation with other processes in combination are already effective approaches to resolve the demand of freshwater at lesser costs and minimal environmental influence. The principles of an MD are not as a separate unit, for example membrane operations which are pressure-driven, but rather as the use of a hydrophobic microporous membrane which acts as a barrier between two phases. The non-volatile components are rejected by the membrane, so only in a gas phase is it possible to separate the volatile components. In MD, by a temperature difference, the driving force is induced between the feed side and the permeate and compared with desalination systems, it has several advantages, such as:

In MD, the induction of driving force is commonly done by difference in temperature of the feed and permeate. MD has several benefits over traditional desalination systems, such as:

1. High recovery factors due to lesser effect of feed concentration on quality of permeate.
2. Renewable energy sources can be used
3. Less operating pressure in comparison to other processes which are pressure-driven.

In Namibia, produced water is used as drinking water, mainly for industrial uses, but for irrigation in Gran Canaria, it is used without any post-treatment. Another example is a MD plant made of solar panels in Saudi Arabia that operates a membrane distillation unit based on the Memsys vacuum membrane distillation module.

Excluding the solar panels, the footprint of the plant is only 6.0 m × 2.4 m × 2.6 m, some single day tests exhibited that the plant can yield 15.39 L/h of freshwater without external energy sources, when feed temperature and flow rates are 72°C and 69 L/h, correspondingly. When irrigation water is required, this instance shows the potential of MD as a centralized/decentralized system. Despite the great potential of MD, furthermore development is required for its commercialization. The MD development phase is small if related to the water production capabilities that RO may currently have. Therefore, it is highly likely that MD combined with RO will assist to improve recovery of water and thus lessen brine discharge [19].

2.6. Electrodialysis

Electrodialysis (ED) is the passage of ions on application of an electric field across ion exchange membrane. For seawater and brackish water desalination, ED is commonly used. At present, ED is the second most widely used membrane desalination technology, that is, 3.6% of the total installed desalination capacity is treated, much less than RO with 60%.

In ED ions are separated under the influence of a gradient potential through ion exchange membranes. In the multi compartment cell, dissolved salts are transported by a direct current electric field through ion-selective membranes. Although it is suitable for wastewater because it eliminates and concentrates nutrients like nitrogen, potassium and phosphorus. It is also suitable for the remediation of brackish water for the removal of salts [20].

ED is used in plants with capacities from ~100 m^3/d to more than 20,000 m^3/d, with brackish water salinity of 1,000 to 5,000 mg/L as total dissolved solids. For example, a DE technology for desalination present in Morocco and saline groundwater is treated by electrodialysis to obtain water forirrigation having varying salinity levels (0.9, 2, 4, 6, 6, 10 dS/m). The combination of renewable energy sources with EDM can generate a more reasonable use of EDM at a lower cost for irrigation. Photovoltaic (PV) and electrodeposition applications have been studied, as reported by Ghaffour et al. [21]. In addition, IEX membranes with higher permselectivity are desired to make the ED event more attractive.

Advantages:

ED system separates without phase change, which results in relatively low energy consumption.

1. When brackish water is desalted by ED system, the product water needs only limited pre-treatment. Typically only chlorination for disinfection is required.
2. Osmotic pressure is not a factor in ED system, so the pressure can be used for concentrating salt solutions to 20% or higher.

Disadvantages:

1. Organic matter, colloids and SiO_2 are not removed by ED system.
2. Feedwater pre-treatment is necessary to prevent ED stacks fouling.

2.7. Membrane bioreactor

For the decontamination and reuse of municipal wastewater, a membrane bioreactor (MBR) may be the most suitable technology. It offers opportunities to produce water for agricultural purposes at levels satisfactory for farmers and the environment and is an advanced membrane, combining features of both membrane filtration and the biological treatment. MBR has no biological sedimentation units, lower sludge production, fastest plant activation, and higher concentration of suspended solids as compared to conventional treatment. The effluent from MBR units is of high quality and is recommended for producing irrigation water to save freshwater resources, but it is a costly process compared to traditional processes. The future of wastewater treatment is MBRs for unobstructed irrigation, and this can be obtained once the cost of MBR technology becomes more affordable for African countries.

2.8. Capacitive deionization

The term "capacitive deionization" was later introduced as a concept in 1960 by Blair and Murphy using porous electrodes [22] and was coined by Farmer et al. in 1995 [23]. The capacitive deionization (CDI) is considered a promising technology in desalination owing to its potential for selective ion removal and collection technique and to the huge and still growing library of capacitive materials that can be utilized and enhanced in properties [24].

Fig. 2 shows a standard CDI cell consisting of two parallel electrodes made of porous material, that is, anode and cathode. Electrodes conduct the electronic charge, allowing ion access with a storage capacity and a non-conductive "spacer" channel through which water flows. On application of current on the electrodes, ions migrate to the electrode of opposite polarity, thereby reducing the salt concentration. After the desalination, to release the ions which are captured during the process, several methods like short circuiting of electrodes, reversing electrode polarity/ reversing current direction can be used [24].

2.9. Solar desalination system

The application of a solar-powered Low pressure RO desalination system to treat brackish water would result in high-quality desalinated water, thus providing a high-quality water stream for irrigation in Algeria's arid regions. In Algeria, there are municipal brackish groundwater desalination facilities, with capacities ranging from 9,000 to 40,000 m^3/d. Twelve brackish water desalination plants are in operation in the Northwest Sahara Aquifer System (NWSAS), with an average electricity consumption ranging from 0.5 to 2.5 kWh/m^3 (Fig. 3). In existing desalination facilities, the integration of solar energy could generate a high-value product from low-value resources.

Touggourt a production station of 34,560 m^3/d.
Tindouf: production 9,000 m^3/d.
We have two projects in progress.
OUED SOUF: 30,000 m^3/d this project is in the process of civil engineering.
IN AMENAS: 5,000 m^3/d extendable to 10,000 m^3/d.

- Tindouf, BWRO, Algeria, Tindouf, Algeria 2016 10,500.0 RO.
- Touggourt Brackish Water Reverse Osmosis Project, Touggourt, Algeria 2015 34,000.0 RO.
- In Algeria, in Brédéah, about 20 km from Oran, Suez built a 40,000 m^3/d desalination plant in the early 2000s.
- New plants contracted 2015–2016 A listing of new desalination plants contracted between mid-2015 and mid-2016, drawn from the IDA Inventory and GWI DesalData.
  Algeria Algeria 360 RO Brackish Temak
  Algeria Algeria 1,200 RO River/Low conc. ProMinent
  Algeria Algeria 1,680 RO River/Low conc. ProMinent

It should be recognized that the integration of solutions combining solar energy systems with desalination should encompass a detailed assessment of capacity building.

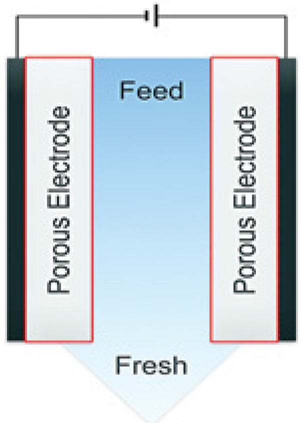

Fig. 2. CDI cell configurations used [24].

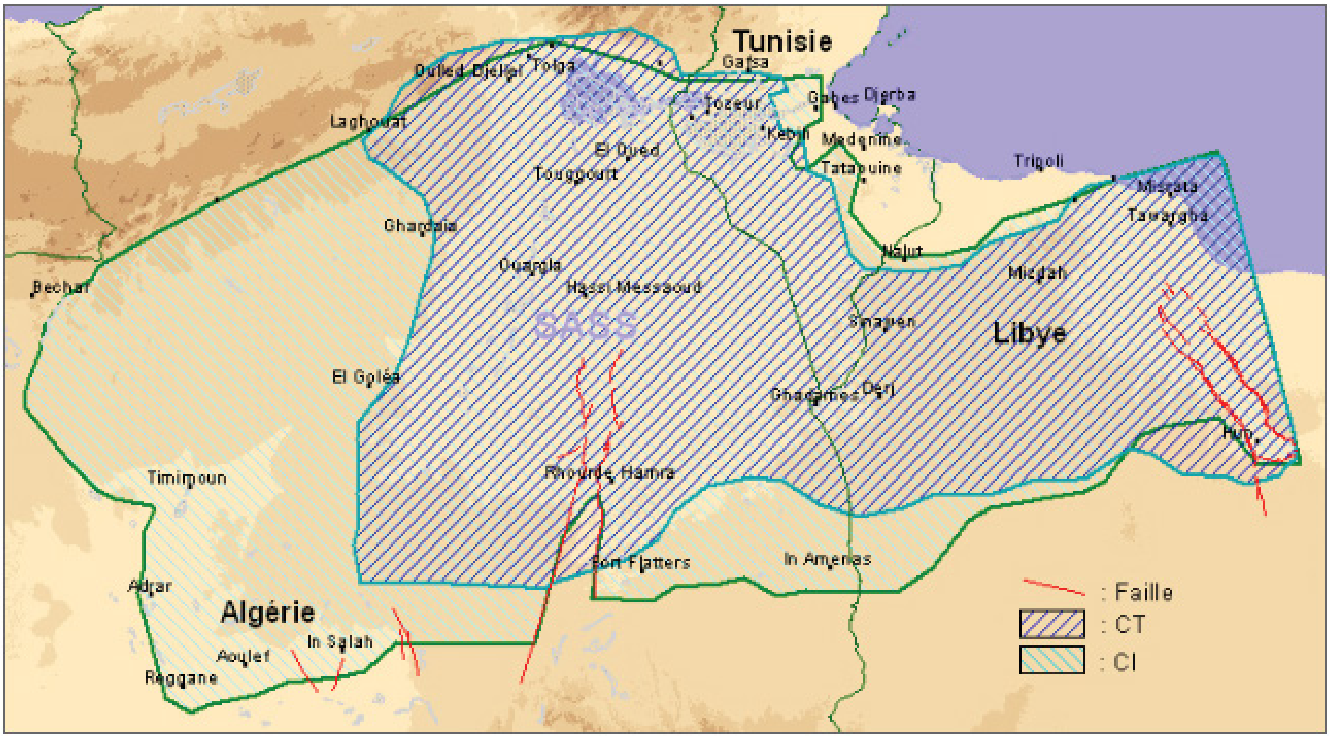

Fig. 3. Location of municipal desalination plants for brackish groundwater in Algeria [25].

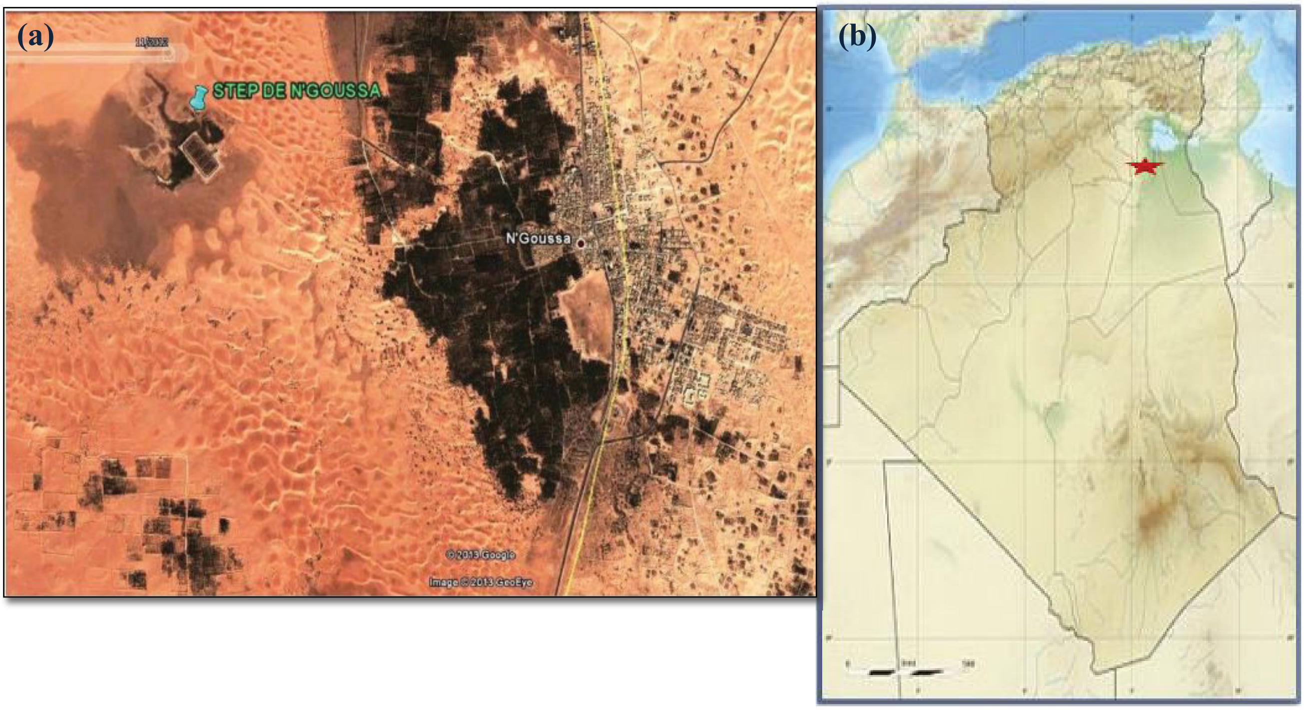

Fig. 4. (a) Location of the wastewater treatment plant of N'Goussa by planted filters of reeds and (b) locator country map frame [28].

Mahmoudi et al. established that it was critical to improve the conversion from solar energy into electrical or thermal energy so that economically viable scale-up strategies could be implemented. As solar equipment reaches mass production status (photovoltaic cells, solar collector, solar thermal plants), the case for adopting renewable-energy-driven desalination will become stronger, especially in remote areas with a high solar irradiance [26]. Ghaffour et al. [21] also noted that the development of software packages for coupling desalination and energy systems could address some limitations of solar desalination. They also cited several studies from the Middle East Desalination Research Center (MEDRC) focused on the MENA region and highlighting the need for capacity building as well as some operational challenges.

In summary, global demand for water continues to increase and freshwater sources are scarce due to the high demand for natural resources and the effects of climate change, especially in semi-arid areas. Desalination can be used to meet the world's growing demand for freshwater supplies, but it is a costly and energy-intensive process, usually from fossil fuel sources that are vulnerable to world market prices. Most desalination plants are located in regions with high availability and low energy costs. For example, 1% of total desalinated water comes from renewable energy sources, which are becoming more common and more affordable, making them a good option.

3. Water reuse vs. irrigation

The development and equipment of new irrigation perimeters would increase from 200,000 ha currently to 400,000 ha in the medium term. Under the five-year plan 2010–2014, it is planned to increase the capacity of irrigated area of 25,000 ha/y on average. Similarly, the irrigated area in small and medium hydraulics (PMH, less than 500 ha) takes been strongly industrialized over the past 10 y (180%) and now totals almost one million hectares (350,000 ha in 2000, 90,000 ha in 2011) [27].

In some parts of the world, water treatment and reuse for agriculture is commonplace. For example, in Spain, 71% of wastewater and 22% of desalinated capacity is used for the agricultural industry. In Algeria, there is extreme pressure on irrigated agriculture due to the rapid rate of soil and water salinization caused by desertification, which leads to a reduction of arable land with good productive potential. In the western part of the country, this phenomenon is more noticeable. The main irrigation systems are in the west of the country. Of a total area of 140,000 ha, 30% of the land is made up of very saline soils.

The treatment plant of N'Goussa (Fig. 4) was installed in the context of a mega-project targeting the fight against rising waters of Ouargla. It processes city wastewater of the daïra of N'Goussa, using planted filters of reeds. It is one of the most extensive devices of biological treatment of wastewater by macrophytes. The plants used are "*Phragmites australis*", more common lycalled "reeds".

Characteristics:

Nature of the treatedwater: Domestic
Start date of the works: 2008
Companies of realization:

- Civil engineering: SNTP
- Equipment: EUSEBIOS
- Photovoltaic installations: UDES

Date of commissioning: 2010
Treatment process: Reed filters
Treatment capacity: 10,914 EQH
Nominal flow: 1,515 m^3/d

3.1. A 100% ecological station

- Deficient sludge production (~1 cm of sludge on the surface of the bed, per year).
- A treatment plant that operates in a rustic way, and requires little energy. This energy is produced by solar photovoltaic for:
- Exterior lighting and electrification of the operating building.
- It fits perfectly into the policy of sustainable development.
- Innovative, the treatment of wastewater by planted reed filters is a process designed to optimize the natural water purification cycle.
- Ecological integrates perfectly into the landscape, require in only 1.5 to 2 m^2 of floor space per equivalent in habitant.
- No visual, sound, or olfactory nuisance for the residents. There are also no issues of storage and treatment of sludge.
- In terms of economics, maintenance is reduced compared to "conventional wastewater treatment plants", and the system installations can easily accommodate clean energy sources.

4. Leveraging the Spanish model in Algeria

Spain and other Mediterranean countries have modernized their irrigation systems, as irrigated agriculture is

Table 1
Energy balance of the plant

	Outdoor lighting	Operating building
Panel surfaces	6 × 1 m^2 (lamp posts)	18 × 1, 2 m^2 (Roofing)
Installed power in WC	6 × 120 Wc	2,800 Wc
Capacity of the batteries in Ah	6 × 110 Ah	1,100 Ah
Power of the receivers in W	6 × 33 W (ecolamps)	1,400 W (lighting and PdC)
Total installed power in Wc	3,520 Wc	
Power of the receivers in W	1,598 W	

one of the most energy-intensive sectors. As an energy component, in Algeria, more efficient modes of water use have been promoted, such as desalinated water, which can be a solution for arid areas where water is very scarce. The costliest stages in the Spanish model are water extraction and treatment, accounting for 64% of total electricity demand. For example, between 2009 and 2022, irrigated agriculture underwent a rapid transformation, which generated a drop in water-related electricity demand of up to 40%.

Desalination is considered an alternative clean water supply in water-stressed countries. According to the International Desalination Association GWI/IDA, the largest producers of desalinated water in the world are Spain and Algeria, 5,000,000 m^3/d (https://smartwatermagazine.com/news/smart-water-magazine/spanish-desalination-know-how-a-worldwide-benchmark) of water for Spain, and more than Algeria 2.1 Mm^3/d of water for Algeria. In Europe, the construction of tertiary treatment plants has become of great interest. For example, according to the Water Environment Federation in 2009, for Spain, the additional energy requirement to produce recycled water is estimated at 0.13 kWh/m^3.

4.1. Optimized allocation of water and energy resources for agricultural activities

freshwater resources that are currently available in Algeria can no longer sustain the demand from its citizens nationwide, in part due to growing demographics and because of a rising middle class. In order to tackle these challenges it is recommended to implement comprehensive policies prioritizing water importation/basin transfer, increased recycling/reuse operations, and saline water desalination. Each recommendation should be weighed in terms of its ability to satisfy the national water needs and to cover its financial and environmental costs (San Diego Country 2016) [29].

Desalination plants have been selected as a viable option to satisfy clean water needs in many regions across the globe such as the Middle East, Australia, Spain, Singapore, and Southern California.

Spain is a large consumer of agricultural water, as it uses approximately 58% of the total water withdrawals (Hardy, 2010). The saline concentration present in any water source – such as clean water, brackish water, or seawater streams – dictates the choice for the best technological fit and defines the energy consumption in compliance with targeted quality standards. Learning from this experience, Algeria is therefore uniquely positioned to learn from the Spanish model. The term "water-energy nexus" has become known for the bidirectional consequences of process efficiency, resource quantity, system leakage, good or bad resource efficiency, and choice of technologies. The energy consumption associated with desalination widely varies per market area. In Algeria for instance, the energetic distribution is such that the energy area uses 0.06 kWh/m^3, and the consumption level are 0.21 kWh/m^3 for urban centers,0.34 kWh/m^3 for agricultural works, and 0.56 kWh/m^3 for wastewater action devoted to recycling operations – these figures represent each sector in its entirety [30].

Furthermore, desalination technologies could simultaneously tackle the water and energy challenges, as proposed by Anderson et al. by investigating an emerging technology called capacitive deionization. In this process, the energy released by electrostatically-induced desalination is stored in a capacitor while a feedwater stream is directly pumped through a parallel-plate unit [31]. The process can be replicated until enough energy is released to produce freshwater. Unlike membrane-based desalination, capacitive deionization is not designed to block the uncharged pollutants and may therefore need to be coupled with a complementary process.

Energy and water desalination at present, the water supply is subject to severe fluctuations. Storms, flooding, and other catastrophic weather events bring excess amounts of water while droughts and desertification phenomena induce complex shortages and extreme human hardship. These contrasting environmental breakdowns extend across the globe and randomly affect developed countries and the developing world. Water levels have decreased dramatically in dams, lakes, and many sites. Nowadays, the aquifers and the Great Plains in general are being looted and depleted due to unsustainable irrigation practices, sadly without any considerations for the needs of future generations [10]. In fact, water shortage affects nearly half a billion people around the world, and it's worth stressing that water consumption greatly varies from country to country (compare for example in this regard the USA and Malaysia, Germany or Algeria) [32].

The growth and combination of non-conventional water sources has generated the need to identify new water resources, for example, reuse and desalination. Desalination is the most recent transformation of the old hydraulic model, and according to Swyngedouw [33] it has expanded.

The energy cost may vary, depending on the desalination technique used [34]. The two main sources of water resources dedicated to desalination are: seawater or saline, brackish groundwater influenced by seawater from coastal aquifers, that is, water streams that are in direct connection with the sea or aquifers that are in contact with the sea [34]. Desalination has emerged as the answer to address all the difficulties associated with water shortage, drought, environmental impact, social conflicts, and interprovincial political disputes in Spain [29]. Spain is sighted as an international reference in the field of desalination, as it has several desalination plants built already, it has the technological knowledge of establishing the plants also a knowhow of the construction and operation of desalination plants [35].

High energy costs and environmental concerns play a critical role in the development of desalination plants. In Spain, the water imbalances existing in the country explain this local desalination development [35]. Also, the first desalination plant built was based on thermal systems and technological advancement made it likely to diminish the costs associated with the RO process [36], with the increasing adoption of membrane desalination plants. Desalination has the advantage of being fed from the sea, which is an inexhaustible source and is not subject to climatic variations.

Due to highly uneven water resources, Spain has steadily invested in desalination platforms [37]. Thus building plants in the Mediterranean area, such as in Catalonia, Valencia, Murcia, and Andalusia), and in two archipelagos such as the Canary Islands and the Balearic Islands. Also, in cities such as Ceuta and Melilla located in North Africa. Hence, over the last decade, that country has increased its water desalination capacity over three times, expanding from 300,000 m^3/d in 1990, to 1 million m^3/d in 2000, and nearly 3 million m^3/d today [38].

The evolutionary growth of desalination in Spain resulted from the Action Program for Water Management and Use (A.G.U.A.) established in 2005, after amending the National Hydrological Plan. Through the building of desalination plants, this program anticipated a sequences of actions pointed at increasing the accessibility of water resources and refining their management, through the wastewater reuse with tertiary systems, transformation of traditional irrigation systems, improvements in big infrastructures and pipelines [39].

Energy consumption is being reduced with new technological contributions in desalination, for example: Energy recovery by means of high-pressure systems having an engine, a hydraulic turbine and centrifugal pump that drives the rotation of the engine [40]. One of the most significant originations contributing to the continual development of desalination is energy recovery systems, which in reverse osmosis plants can cover 25%–30% of the energy required to produce drinking water.

5. Limitations and future challenges

Water desalination is a solution to the growing scarcity and shortage of freshwater sources; however, financial and energy costs limit its use. Worldwide, nearly 700 million people do not have access to safe drinking water, and it is estimated that by 2025, there will be 1.8 billion people. Therefore, the possibility of desalination as a possible solution to water quantity and quality problems is growing. There are about 18,000 desalination plants in the world, but they are only able to meet the needs of between 1% and 3% of the world's water needs.

However, there are limiting factors for its development as desalination brings its challenges: high production and transportation costs, energy efficiency, and environmental impact. For example, Desalination also has costs for the environment in terms of greenhouse gas emissions from a large amount of energy used, and the disposal of saltwater, which, in addition to being extremely salty, is mixed with chemicals that are used for its treatment and are also toxic. The main challenge is to make desalination processes more affordable and sustainable, which has a positive impact and improves people's quality of life. Currently, desalination is largely limited to wealthier countries, especially those with abundant fossil fuel reserves and access to water.

6. Conclusions

Desalination can help mitigate water scarcity and effectively address the water-energy-food nexus in Algeria, which will enhance the production of high-value crops. Furthermore, a comprehensive desalination plant will fall within the scope of the Paris 2015 agreement, which includes a commitment to reduce greenhouse gas emissions down to 22%, representing a drop of 7% against the existing levels.

With the development of new technologies and the transition of desalination to run on sustainable renewable energies, Algeria could meet its water, food, energy needs and develop a green economy and achieve the sustainable development goals (SDGs), as it must be considered that freshwater sources in Algeria are scarce and it is necessary to contemplate new techniques to provide new sources of freshwater, such as frontal osmosis.

In recent years, Mediterranean countries such as Spain have successfully promoted the modernization of their agricultural irrigation system and more efficient ways of using water on farms. The leverage of salt water as an energy component is a good example, thereby offering a solution in arid regions where water is scarce. Replicating the Spanish desalination model in Algeria could be a viable option since both countries share comparable environmental ecosystems.

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