Chapter

The Connection between the Impacts of Desalination and the Surrounding Environment

Adel Hussein Abouzied

Abstract

The background of water desalination is covered in this chapter, along with an analysis of the environmental issues the desalination industry faces and suggestions for how to address them, to close the gap between the growing demand for water for all purposes and the natural water resources' finite availability since the early 1970s. While a few number plants established in desert locations desalinate brackish and saline groundwater, most plants built in coastal areas desalinate seawater. Desalination of water has detrimental effects on both marine and terrestrial habitats. Desalination plants also deal with issues such as corrosion, sedimentation, membrane fouling, and scale formation, the disposal of rejected brine from coastal or inland desalination facilities and its harmful impacts on the ecosystems of the marine environment and groundwater. Focus should be placed on achieving zero-brine discharge, incorporating solar-pond technology, using renewable energy sources in desalination, and supporting research and development in the field of water desalination in order to reduce the negative effects of the desalination industry on the nation. Desalination still has difficulties in managing its waste products and minimizing its energy requirements in order to avoid negative environmental effects.

Keywords: desalination, environment, water, brine management, desalination alternatives

1. Introduction

The need for water is always rising to keep up with the demands of population growth, improving living conditions, expanding green space, rising per capita consumption, urban development, and industrial growth. According to MOEW (2010), demand management may involve increasing public awareness, water tariffs, reducing water losses, and effective water billing and bill collecting [1]. Over-pumping groundwater to meet the rising water demand has resulted in the depletion of significant aquifers and the worsening of groundwater quality [2]. The use of unconventional water sources, like treated waste-water and desalinated water, has greatly increased to close the gap between water supply and demand. However, this strategy has detrimental effects on the environment and raises the energy demand necessary

No.	Country	Total capacity (million M^3/d)	Market share (%)
1	Saudi Arabia	9.9	16.5
2	USA	8.4	14.0
3	UAE	7.5	12.5
4	Spain	5.3	8.9
5	Kuwait	2.5	4.2
6	China	2.4	4.0
7	Japan	1.6	2.6
8	Qatar	1.4	2.4
9	Algeria	1.4	2.3
10	Australia	1.2	2.0

Table 1.
Top 10 nations that use desalination, taken from Nair and Kumar.

for the expansion of water desalination, MOEW (2015). Communities have resorted to alternate water sources, such as desalination, water recycling, and water import in several places across the world where local water basins are becoming depleted [3, 4]. Desalination is the process of purifying saltwater by removing extra salt and other dissolved compounds. The World Health Organization's 500 ppm drinking water limit is reached or exceeded by this method, which lowers salt content [5, 6].

Water is a national resource that requires a national strategy for integrated water-resources management and to address the difficulties brought on by the increased water demand [7]. Desalination has solidified its place in recent years as a means of reducing the world's water shortage. Reverse osmosis is the most widely used technique in the global desalination market and is regarded as the most optimal membrane-based desalination process, producing around 50% of the desalination water. Desalination uses a lot of energy, though, and historically has relied on fossil fuel-based processes [8–10].

Since then, the desalination of brackish water and seawater has spread fast throughout the world. More than 17,000 desalination units were operational in 2013, delivering around $80x10^6$ m^3/d to 300 million people across 150 nations. By 2015, the production capacity had nearly reached $97.5x10^6$ m^3/d, and by 2050, it is anticipated that there will be $192x10^6$ m^3/d of desalinated water available [5]. The top 10 countries using desalination are listed in **Table 1**.

2. Technologies for desalination

Reverse osmosis (RO), Forward osmosis (FO), multi-effect distillation (MED), multi-stage flash distillation (MSF), Vapor-compression (VC), Ion exchange, Membrane processes, Electro-dialysis (ED), Capacitive Deionization (CDI), Nano-filtration (NF), Membrane distillation (MD), Hydration (HY), Secondary Refrigerant Freezing (SRF), Solar Still Distillation (SSD), and Solar Chimney (SC) are all processes used in water desalination plants. Many cogeneration facilities where the thermal energy needed to desalinate water are also used to generate electricity. The most common method for pumping brackish water through membranes while utilizing electrical energy is reverse osmosis (**Figure 1**) [10, 11].

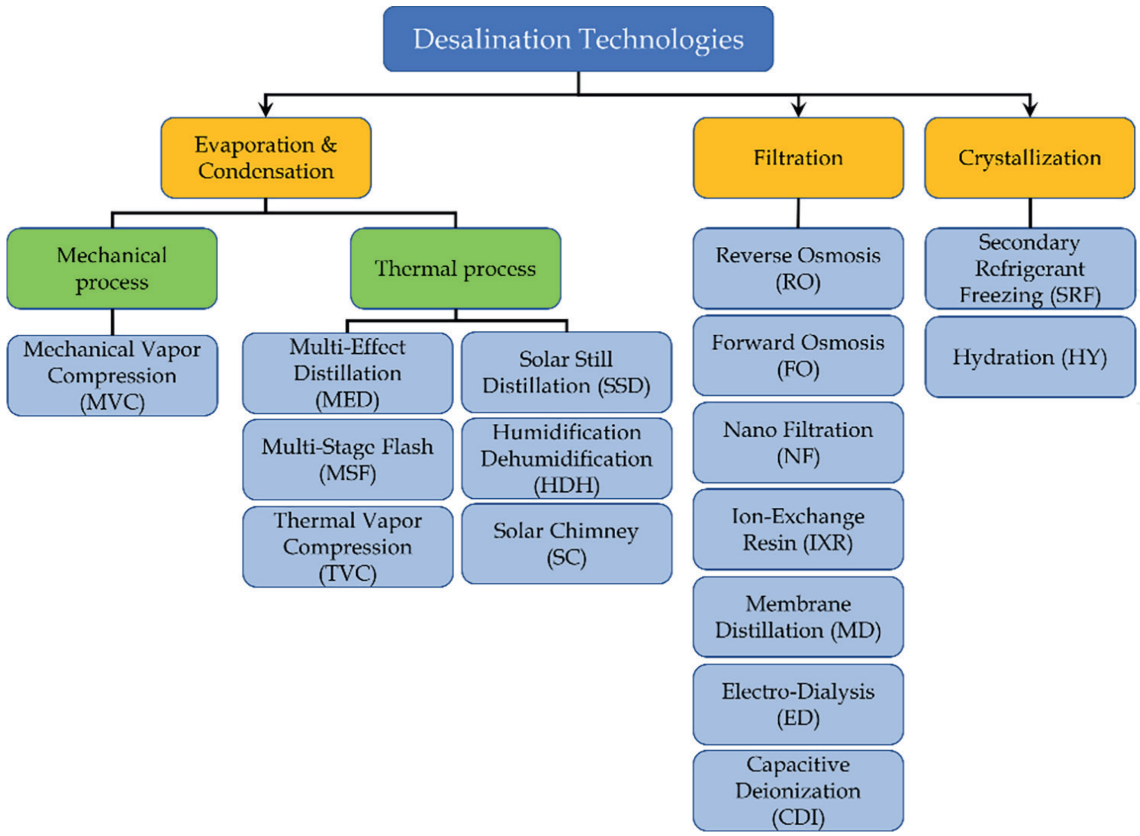

Figure 1.
Shows the grouping of desalination technologies according to their operating principles.

2.1 Environmental difficulties

The World Wide Fund (WWF) of the Global Freshwater Program criticized saltwater desalination as an expensive, energy-intensive, and method of producing drinking water that emits greenhouse gases [12]. In addition to reducing places for fishing, swimming, and enjoyment, desalination plants also release brine, which contributes to visual pollution. The produced water from the desalination plants must also undergo post-treatment, which includes treatments for organics, hypoxia, carbon dioxide (CO_2), copper (Cu), hydrogen sulfide (H_2S), hydrogen ion concentration (pH), coagulants, chlorine (Cl), and copper. Desalination plants also deal with issues like corrosion, sedimentation, membrane fouling, and scale formation. Concerns were raised by Al Asam and Rizk (2009) over the disposal of reject brine from coastal and inland desalination facilities because of their harmful effects on the ecosystems of marine environment and groundwater [13].

Most desalination processes require a lot of energy. If renewable energy sources are not employed for the production of freshwater, desalination has the potential to increase reliance on fossil fuels, raise greenhouse gas emissions, and exacerbate climate change. Surface water intakes for desalination pose a serious threat to marine life [6]. When mature fish, larvae, and other marine life are stuck in or sucked into open sea surface intake pipes, serious harm or death may result. According to the State Water Resources Control Board, the open ocean intakes utilized by California's coastal power facilities destroy 70 billion fish larvae and other marine species every year. The utilization of these open ocean intakes is being considered for desalination facilities all around California. Due to the dangerously high concentration of salts and other minerals included in brine waste, it may also represent a hazard to marine life and water quality. Because its high salinity and density, brine waste can collect in and around disposal sites, suffocating animals that live on the ocean floor and drastically changing coastal ecosystems [5, 6].

A hyper-saline slurry known as brine is created when minerals, extracted salts, and some source water combine. Compared to salt water, brine has a substantially higher salt concentration, which makes disposal difficult. The ocean is frequently used to dispose of waste brine. Brine can be discharged through diffusers or blended with other water sources to lessen salinity to minimize environmental effects during disposal. Diffusers are used to spread brine at various desalination facility discharge sites and to encourage brine mixing with ocean water. Desalination also has a number of negative environmental effects, such as excessive CO_2 emissions and waste compounds that have an impact on marine environments when they are released [6, 14].

2.2 Alternatives to desalination

Desalination is an expensive method to increase local water supply because it uses a lot of energy and has negative environmental effects. Is the average cost of ocean-water desalination a problem or a solution? Desalination plant in the Canary Islands' Lanzarote. Desalinated water is frequently 2–4 times more expensive per acre-foot than other water sources. Desalination by the ocean is ineffective. For every gallon of freshwater generated, approximately two gallons of ocean water are needed. This means that a single, massive desalination plant cannot address the issues with the local water supply. Increased regional water supplies can be achieved by water conservation, water use efficiency, storm water capture, reuse, and recycling, which are frequently more affordable than desalination. These alternatives also offer benefits that are frequently disregarded in cost–benefit analyses, such as flood control, habitat restoration, and pollution abatement [14].

2.3 Physical effects of desalination

The fundamental physical problem that water desalination presents to the environment is the temperature difference between rejected brine and feed water. The temperature of ambient saltwater is often 10 to 15 degrees Celsius lower than that of rejected brines, which is harmful to marine ecosystems. The brines released into the marine environment float on the water's surface due to their greater temperature. The water-dissolved oxygen decreases with increasing temperature, and this decline in levels of water-soluble oxygen can cause toxicity affecting marine life. The temperature variation is a minor problem as indicated by Younos (2005). This region is naturally hot, and large annual variations in temperature represent a natural phenomenon. However, persistent long-term variations in temperature of seawater can be extremely harmful and cause the death of many marine species [14].

2.4 Chemical implications of desalination

Chemicals are introduced as antiscalants during the pretreatment and chlorination procedures in the desalination business. The compounds that remain in the rejected brine are thought to be responsible for the chemical consequences of water desalination. Desalination plants in the Arabian Gulf region pump tones of metals, chemicals, and chloride into the sea each day to desalt more than 24 million m3 of seawater.

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Chemical	Symbol	Use
Sodium hypochlorite or Chlorine	NaOCl or Cl	Chlorination and prevention of biological growth in membrane facilities
Ferric chloride, or Aluminum chloride	$FeCl_3$ or $AlCl_3$	Disinfectants for flocculation and removal of suspended matter
Sulfuric acid or Hydrochloric acid	H_2SO_4 or HCl	Adjustment the pH of the seawater
Sodium hexa meta-phosphate	$(NaPO_3)_6$	Prevention of scale formation
Sodium bisulphate	$NaHSO_3$	Neutralization of chlorine in the feed water
EDTA	$C_{10}H_{16}N_2O_8$	Removal the carbonate deposits
Citric acid or Sodium polyphosphate	$C_6H_8O_7$ or $NaPO_3$	Cleaning membranes three to four times

Taken from Younos (2005).

Table 2.
Chemicals used in desalination plants' pre-treatment.

Al Barwani and Purnama (2008) claim that the UAE, Saudi Arabia, Qatar, Kuwait, Bahrain, and Iran each have over 120 desalination plants that discharge daily amounts of ammonia (NH_3), 24 tons of chlorine (Cl), 65 tons of antiscalants, 300 kilograms of copper, and 65 tons of antiscalants into the Arabian Gulf. If low-quality stainless steel is utilized in the construction of desalination facilities, brine discharge will contain high quantities of iron (Fe), chromium (Cr), nickel (Ni), and molybdenum (Mo). **Table 2** provides a list of the typical pre-treatment chemicals used in desalination plants [15].

The most often used anti-fouling is the chloride (Cl) additive, according to Höpner and Lattemann (2002). Many chlorinated and halogenated organic byproducts are created when it combines with the organic molecules in seawater. Numerous studies have revealed the carcinogenicity of these substances as well as their other negative effects on aquatic life. Only 20 μg/L of Cl can significantly limit the photosynthetic of plankton. Cl level of 50 μg/L can alter the biodiversity of marine life and significantly diminish it. Lethal Cl concentrations for various fish species range from 20 to several hundred μg/L [16].

Eutrophication issues affect the desalination plant exits where polyphosphates are used. Antiscalants have a moderate to low degree of biodegradability and unidentified adverse effects. Antiscalants have an impact on the natural processes in the marine environment that include divalent metal ions, such as magnesium ions (Mg^{2+}) and calcium ions (Ca^{2+}). Copper (Cu) compounds are poisonous and inhibit the growth and reproduction of marine species in greater quantities, according to Höpner and Lattemann (2002). Cu compounds travel through the water and gather in sediments where they are ingested by benthic marine animals and enter the food chain [16].

Backwash water with coagulants and suspended debris is untreated and released into the marine environment at discharge sites. Benthic creatures are buried in the discharge sites as a result of this process, which also intensifies coloring, reduces light penetration, and raises turbidity. If discharged to surface water without treatment, the cleaning solutions and their additives, as well as the acidic (pH 2–3) and alkaline (pH 11–12) solutions are detrimental to aquatic marine life.

2.5 Biological consequences of desalination

The early loss of species in the intake zones of desalination plants was attributed by Al Dousari (2009) to the impacts of entrainment and impingement as well as the chlorination process. High biochemical oxygen demand (BOD), which causes low dissolved oxygen (DO) in saltwater, is present in the release areas of rejected brine. Rejected brines' salinity is higher than the natural ocean salinity, which has an impact on both creatures living organisms in open water and on the bottom [17, 18]. Although certain species have evolved to the natural salinity changes, the bulk of the neighboring marine animals are at risk of death due to high salinity at the discharge area of RO plants. The habitats of mangroves and the development of corals and sea grass are significantly impacted by the decrease in saltwater quality and rise in salinity levels in the vicinity of desalination facilities [18].

The phenomenon known as "brine underflows," where layers of hyper-saline solution covered the seafloor, can result from the direct discharge of brine into seas [19]. At the point of discharge, the brine concentrate is mixed as much as is practical, although this blended product frequently still tends to sink to the ocean floor. Brine underflows gradually reduce the amount of dissolved oxygen (DO) in the ocean [20]. The habitat deterioration caused by the high salinity and low DO levels, especially for benthic (bottom-dwelling) animals, can result in fewer benthic bacteria, phytoplankton, invertebrates, and fish communities. Additionally, harmful compounds that are not usually eliminated during later steps may be included in the chemicals added for the pretreatment of feed water, such as coagulants and antiscalants [21].

It is indeed possible for the number of contaminants in the brine to be 4–10 times higher than in the source water, including nitrate, arsenic, and naturally occurring radioactive elements. As a result, the direct release of brine into marine and coastal waterways has the potential to degrade water quality and jeopardize the environment. As they need higher concentrations of pretreatment chemicals and have lower recovery efficiency, regions with extremely saline feed water can increase the environmental dangers associated with brine disposal.

Desalination plants raise other environmental and ecological issues in addition to the creation and disposal of brine. For instance, when the intake pumps of the desalination plant are operating, marine organisms like algae and plankton may become trapped and entrained [22]. Furthermore, the enormous amount of energy needed to run desalination facilities, which is often derived from fossil fuels, results in the production of major air pollutants such as greenhouse gases, which worsen climate change and the air quality. Desalination plants, for instance, are accountable for over a third of the greenhouse gas emissions in the United Arab Emirates (UAE). According to Alsharhan and Rizk (2020), the Intergovernmental Panel on Climate Change, 13 million m3 of drinkable water are produced using 130 million tons of oil per year, which contributes to widespread environmental contamination.

According to Areiqat and Mohamed (2005), the corals are extremely vulnerable to a rise in the Arabian Gulf's already-high seawater temperature. Other species that rely on these biotas, such as fish, are also impacted by the low water quality. The atmosphere contains both unionized (NH_3) and ionized (NH_3) ammonia. The ratio of ionized to unionized NH_3 depends on the hydrogen ion concentration (pH), and unionized NH_3 is extremely hazardous to aquatic life [23].

3. Alleviation measures

Because the applied desalination techniques, prevalent climatic conditions, types of feed water, and environmental effects of desalination plants are the same in all of the Gulf Cooperation Council (GCC) countries, there is a need for an exchange of information and expertise to solve desalination problems [24, 25]. Research on desalination has to focus on zero-brine discharge techniques such as brine processing, solar pond utilization, and the use of renewable energy sources.

4. Zero-brine discharge

The biggest environmental issue with the desalination business is rejected brine. Plants desalinating brackish groundwater have brine salinities higher than 10,000 mg/L and larger than 40,000 mg/L, respectively. According to Abdul-Wahab and Al-Weshahi (2009), brines containing at least 70,000 mg/L of total dissolved solids (TDS) are produced at 50% recovery. Chemicals for pre-, post-, and cleaning operations are also present in the brine.

The desalination method, the caliber of the feed water, the chemical additives employed during the process, and the percentage recovery all affect the physical and chemical characteristics of the rejected brine, according to Hashim and Hajjaj (2005) and Al Dousari (2009), stated that The brine produced by various desalination plants as well as the raw water and feed water is chemically analyzed. Due to the basic character of seawater, raw seawater has higher pH values, whereas feed water has the lowest pH values as a result of the addition of sulfuric acid (H_2SO_4) or hydrochloric acid (HCl) to modify the pH during pretreatment. The chemicals added during post-treatment and the mixing of the desalted water with the groundwater of various grades are to blame for the vast range of pH values of generated water [17, 26].

The fluoride ion (F) is removed from the generated water throughout the desalination process, but the rejected brine contains more F than the raw and feeds water. F might be added again to the generated water during post treatment or the blending process. TDS levels in raw water, feed water, and produced water are all high and similar, whereas produced water's TDS level is often less than 200 mg/L [27–29].

In some of the generated water, chloride (Cl^-) and sodium (Na^+) are the predominant ions, but other distillates seem to be ion-depleted water. Sulfate ($SO_4{}^{2-}$) and Ca^{2+} ions are the least prevalent, followed by bicarbonate (HCO^{3-}) and magnesium (Mg^{2+}) ions in the generated water. In all reject brines, Cl^+ and Na^+ are the two most prevalent ions. The brine contains small levels of Ca^{2+}, Mg^{2+}, and $SO_4{}^{2-}$ as well.

Depending on the desalination process, feed water, and effectiveness of the desalination plants, the disposal of rejected brines from desalination plants along the Arabian Gulf coasts in Qatar, the United Arab Emirates, Bahrain, and Saudi Arabia result in the release of a variety of salts into seawater [17, 25, 30–32].

Al Asam and Rizk (2009) made the following suggestion: "Achieving zero brine discharge through brine recycling for manufacturing of various salts and chemical businesses near these plants can alleviate the negative environmental impacts of water desalination. A method for producing desalinated water and managing brine was proposed by the Dubai Electricity and Water Authority (FEWA) using a multi-phase desalination process with salinity gradient solar ponds. With this technology, the amount of created brine is zero, less energy is consumed, and solar ponds are utilized [13].

Australian studies stated that the value of brines released into the sea is believed to be six times greater than the value of the produced drinkable water [33]. Potassium chloride (KCl), magnesium chloride ($MgCl_2$), sodium chloride (NaCl), Epsom salt ($MgSO_4.7H_2O$), lithium (Li), and bromine (Br) salts are among the important salts present in the brine that has been returned to the ocean. The hypersaline brine that remains after desalination can be processed to produce salts with a marketable quality [33].

Recycled brine can be formed into chemical products like sodium hypochlorite, which is used as bleach, sodium cyanide, which is used in the gold industry, caustic soda, which is used in the aluminum industry, polyvinyl chloride, which is used in photovoltaic cells, and hydrochloric acid, which is a common acid used in all industries.

Lithium (Li), potassium (K), and bromine (Br) salts are valuable components of the brine. Li is primarily employed in the production of lithium batteries, while Br is crucial for the production of petroleum-based goods, pharmaceuticals, and a variety of fumigants. When used appropriately, brine can be a valuable resource. It can be utilized in the production of magnesium metal, Epsom salt for horticulture, lightweight flame retardant boards and panels, refractory bricks for industrial furnaces, and wastewater treatment. Brine recycling is useful in the synthesis of compounds including sodium carbonate (Na_2CO_3), sodium bicarbonate ($NaHCO_3$), magnesium chloride ($MgCl_2$), and ammonium chloride (NH_4Cl) [33].

The manufacturing of salt from the brine of saltwater desalination using reverse osmosis technology, according to Ahmed et al. (2000) and Ravizky and Nadav (2007), maybe a lucrative industry for the GCC countries. They cited several factors, including cheap desert land, very little precipitation, powerful solar radiation, quick and simple access to ports, and rather excellent accessibility to Asian countries, which are major salt consumers. Seawater's natural evaporative concentration causes dissolved salts to crystallize and precipitate throughout time in various stages. First to precipitate are calcium carbonate ($CaCO_3$) and calcium sulfate ($CaSO_4$), then sodium chloride (NaCl), magnesium (Mg), and finally potassium (K) salts. Combining reverse osmosis (RO) and Multi-Effect Solar (MES) desalination systems can increase recovery rates from 40 to 90%. The MES desalination plants preserve the brine in a closed cycle and do not release any chemicals or brine into the ocean. The brine discharged from current desalination facilities may potentially be used by the MES plants to produce drinking water [34–36].

5. Technology for solar ponds

Al Asam and Rizk (2009) stated that, "Flat solar radiation land and water are widely available, making solar ponds as a source of renewable energy desirable. Solar ponds require year-round solar exposure, significant quantities of brine, a sufficient supply of "fresher" water, inexpensive flat terrain with low permeability, and steady electricity demand to be effective electricity generators. The degree of brine purity, the thickness of the layers within the solar pond, the upkeep of the vertical salt gradient, the area of the pond, and the depth of the groundwater all have an impact on the thermal efficiency of these systems. Normally, when water is heated, it rises to the surface, but solar ponds prevent this from happening because a lot of salt is dissolved in the hot bottom layer of the pond, making the water too dense to rise. The lower layer of the solar pond is hot (70–100°C) and has a very high salinity, whereas the upper layer is cool and has a low salt content [13, 37].

Water in the gradient zone cannot rise because the upper water is lighter and has a lower salinity, noted Safi and Korchani (1999). The water underneath has a higher salinity and is heavier, thus the water on top cannot travel downward. To allow sunlight to be trapped in the warm bottom layer, which may then be used to generate heat energy, the gradient zone can function as a transparent insulator. Solar ponds with a salinity gradient capture and store solar energy during the day and release it for desalination at night. In the pond's lowest level, solar energy is received and transformed into thermal energy. The thermal energy can subsequently be applied to the production of electricity, desalination, and space heating [37].

Because the solar pond serves as both a collection and storage mechanism, it has an advantage over other solar energy collection techniques. As a result, the pond can continue to produce electricity even when the sun is not out. The solar-pond technique needs a vast, inexpensive land area, a lot of solar energy, and a company that can use hot water effectively to offset the cost to be practical. The salinity-gradient solar-pond method for saltwater desalination along the beaches appears to be highly feasible given these circumstances.

Direct - desalination, where thermal desalination takes place in the same device, and indirect solar desalination, where the plant is divided into the solar collector and the desalination system, are the two types of solar water desalination systems [11].

The solar pond collector has the following advantages [38–40]:

- Solar ponds can have a simple design, a very large heat-collection area and low cost.
- The heat storage is massive and enables energy extraction day and night.
- The major production potential is during peak electrical-power demand in the middle of the summer.
- Generation of the heat required for domestic, industrial and agricultural applications, such as desalination, heating and generation of electricity.
- The technology and scientific principles are well understood and well documented in scientific papers.
- Production of the energy needed for the production of salts for commercial uses and reduction of the emission of greenhouse gases.

6. Renewable energy usage

Solar-powered desalination facilities in the GCC nations were the subject of several studies, including Hanafi (1991), Trieb (2007), and DLR (2007). However, except for pilot plants in a few nations, which are primarily for research purposes, there are no significant attempts to build large-scale solar desalination plants [40–42]. The first solar desalination plant in Umm Al Nar, Abu Dhabi, was created to determine if sun desalination was practical in dry regions [43, 44]. The plant uses groundwater that is saltier than seawater, has a daily capacity of 15,000 gallons (GPD), and is powered by photovoltaic panels. On Sir Bani Yas Island in the Abu Dhabi Emirate, the German company SYNLIFT Systems began operating a wind-powered saltwater desalination facility in 2003 [45]. By taking into account the type of energy that is primarily needed to run the operation, another helpful classification can be realized.

This factor is crucial for the supply of the desalination process from specific renewable energy sources (**Figure 2**) [46, 47]. Four types of energy are specifically taken into account here:

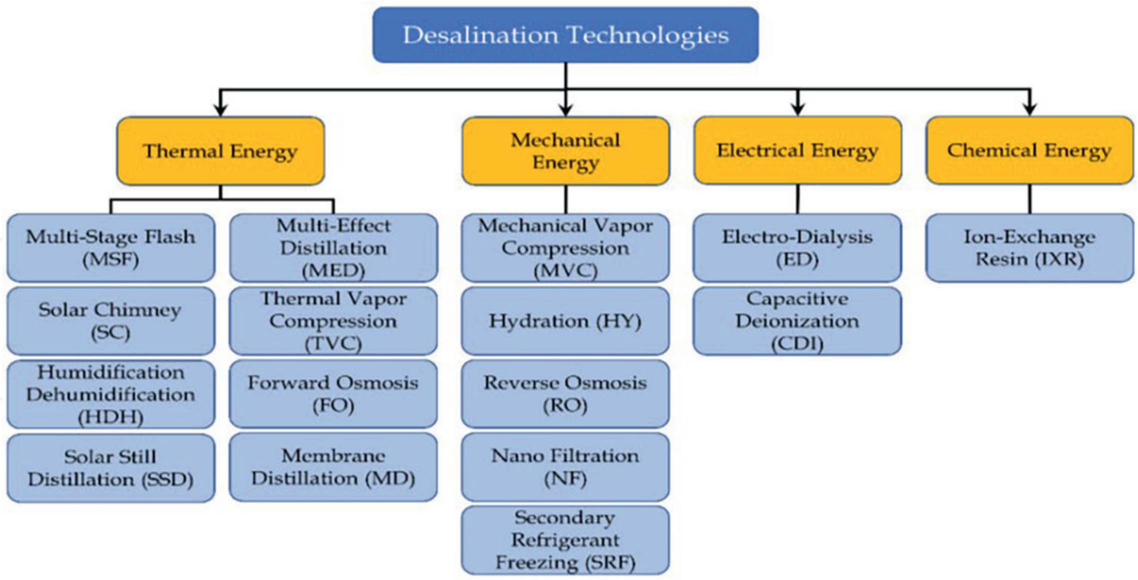

Figure 2.
Shows desalination methods are categorized according to their primary energy input.

- Thermal energy.
- Mechanical energy.
- Electrical energy.
- Chemical energy.

Therefore, it is useful to make a distinction between energy sources that can be used to produce thermal energy and electricity to provide the desalination process with renewable energy [43]. According to the typical energy output that may be produced, renewable energy sources can be categorized in the following ways to achieve this goal (**Figure 3**) [48]:

- Thermal and electrical energy producers, such as solar, geothermal, and biomass.
- Electricity producers, such as wind, hydro, tidal, and wave. The local energy resource's characteristics are typically taken into consideration while choosing the energy output.

It is crucial to solve the issue of brine generation in desalination plants. Even while the brine is frequently sufficiently diluted before being dumped back into the ocean, it is still feasible that even a small variation from the typical salinity levels will have an impact on marine life and environments. It was originally believed that the ocean was too big for anthropogenic activity to have a substantial impact, however problems like ocean acidification show that this is far from the case and even minor cumulative inputs of toxins can have large-scale effects. The creation and operation of large-scale projects like desalination plants, which can have so many negative effects, requires prudence [11, 49–51].

Finally, desalination technology offers enormous potential for supplying water to a burgeoning global population. The need for freshwater will be met, water security will be improved, groundwater mining will be reduced, and issues with

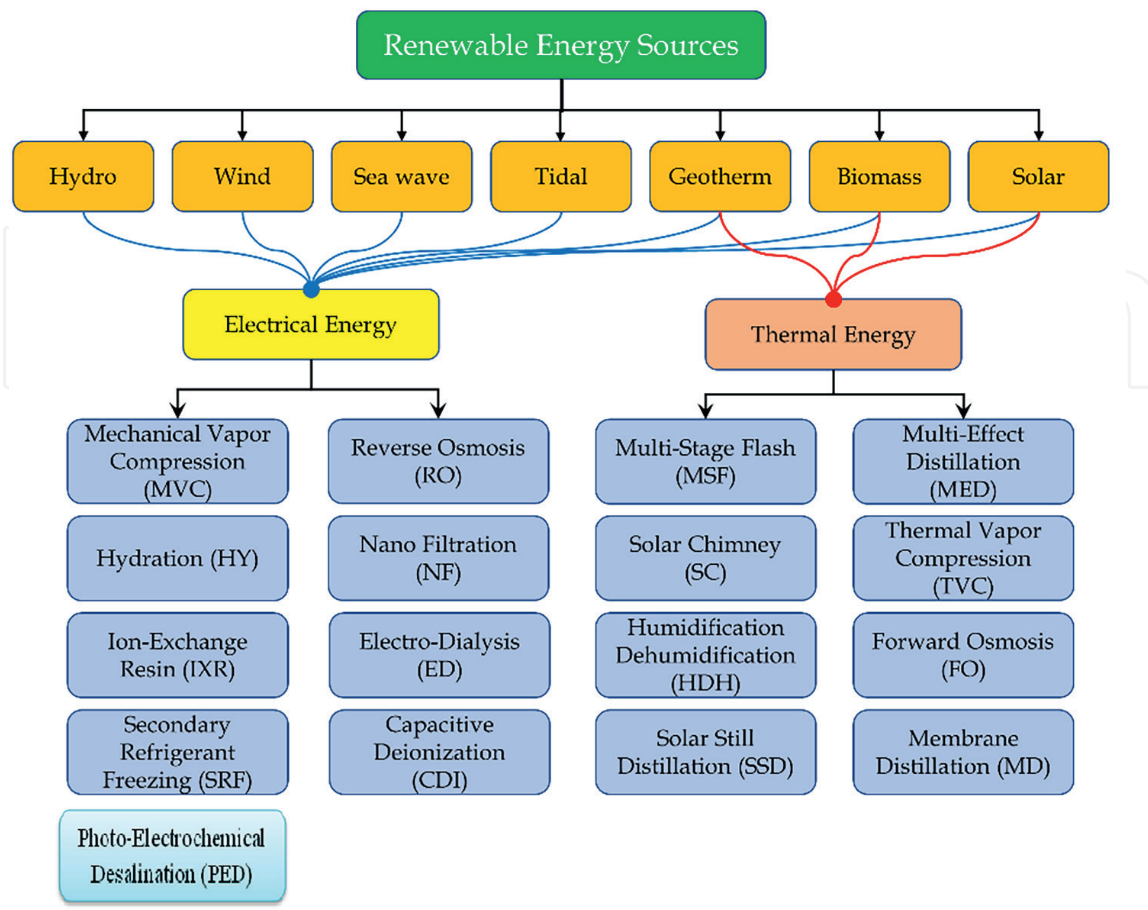

Figure 3.
Shows desalination technologies and renewable energy sources that might be combined.

public health brought on by consuming tainted surface water will be lessened. Even so, it might help ease friction over water allocation rights between and within nations. The technology must therefore be developed further, but we must also work to reduce the specific environmental and health effects it has. Desalination will become a more affordable and sustainable option for supplying water to the growing global population as a result of improved brine discharge control and desalination plant efficiency.

Author details

Adel Hussein Abouzied
Central Laboratories, The Holding Company for Water and Waste-Water Treatment, Giza, Egypt

*Address all correspondence to: adelabouzied@gmail.com

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