



Utilization of Sustainable Energies for Purification of Water



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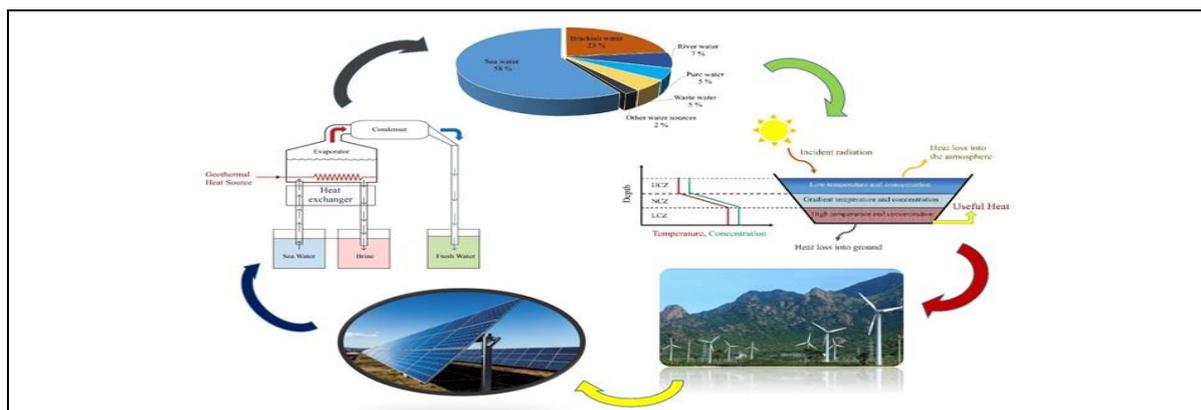
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ABSTRACT

Water and energy are the most important topics on the environment and sustainable energy development agenda. The social and economic health of the modern world depends on sustainable supply of both energy and water. Many areas worldwide suffering from fresh water shortage are becoming increasingly dependent on purification as a highly reliable and non-conventional source of fresh water. Therefore, purification market has greatly expanded in recent decades and expected to continue in the coming years. The integration of renewable energy resources in purification and water purification has become increasingly attractive. This is justified by the fact that areas of fresh water shortages have plenty of solar energy and these technologies can be used due to their low operating and maintenance costs. This review paper discusses the systems that can be used to harness renewable energy sources including, solar collectors, solar ponds, photovoltaics, wind energy and geothermal energy and finally a discussion and conclusion about some distinguished features of each process. Merging of these renewable energy sources with conventional sources has led to optimize the performance of purification plant, less maintenance requirement and reduction in overall cost. It was found that, to choose the best renewable energy source for a purification plant in a particular area, important determinative factors should be considered such as water salinity, area remoteness, plant size, technical infrastructure of the plant, capacity factor, energy consumption and capital cost of the equipment.

GRAPHICAL ABSTRACT



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Introduction

Water as one of the most plentiful resources on earth has covered three-fourths of the planet's surface. Around 97% of the earth's water is the oceans and 3% (about 36 million km³) is fresh water found in the poles (in the ice form), lakes, rivers and ground water supplying most of human beings, animal and organisms needs. Nearly, 70% from this tiny 3% of the world's total fresh water available is frozen in glaciers, permanent snow cover, ice and permafrost [1]. Thirty percent of all fresh water is underground which most of it is located in deep ground levels, hard-to-reach aquifers. Among the total fresh water amount, lakes and rivers contain just a few more than 0.25% of this amount [2]. Therefore, of the total amount only 0.014% is directly available for humans and other organisms [3]. In recent years, demanding for fresh water has significantly increased due to industrialization, life standard, and depletion of natural resources [4].

Purification of seawater is increasingly being considered around the world's a potable water supply, especially in the dry and remote areas where demand has been increasing beyond sustainable supply, where water resources are depleting, fragile or overdrawn and reliable sources become unreliable due to climate change which may be caused of global warming [5]. It is anticipated that by 2040 the global need for freshwater will be greater than the amount available [1]. Therefore, enormous attempts are now demanded to provide available new water resources to diminish the water scarcity in countries with water shortages [3]. Moreover, rapid population growth is also putting pressure on existing water resources, forcing governments to meet additional water demand to be able to provide purification process systems.

There are various conventional techniques for water purification. Photocatalysis is one of the well-known methods applied for water treatment. Sajjadnejad and Karimi Abadeh in

2019 [6], produced a TiO₂ photocatalytic film by sol gel method to degrade methylene blue for water purification. Desalinating seawater is one of the water purification types. Desalinating is an expensive process, as it requires considerable amount of energy. However, it is a growing field around the world as governments and private investors realizing to choose it, as the drinkable water needs are crucial. In general, seawater purification refers to separation and removal process of salt from seawater to make it drinkable water. This process has attracted significant attention in many countries that is due to recognition the sea as an abundant source located close to the metropolitan area.

Many areas experience a shortage of fossil fuels and an insufficient electricity supply. Development of compact and small-scale systems for water desalination process become essential in such areas [7,8]. Purification technologies have become one of the most important and applicable solutions in the Middle East and Mediterranean countries. Around two-third of the world's water production by desalination process is produced in Saudi Arabia, Kuwait, and North Africa [5]. Also, in Perth, Australia, it has been demanded to produce a third of its freshwater by removing salt from seawater [9].

All the conventional seawater purification techniques such as reverse osmosis, electro dialysis and thermal distillation consume a large quantity of energy such as oil, which may adversely affect the environment. and Therefore, the renewable energy utilization as an environmentally friendly reliable energy source, is more and more considered for seawater purification [10]. Figure 1 demonstrates a general classification of water desalination technologies is reported [3]. The dominant desalination processes are MSF and RO with 44% and 42% of worldwide capacity, respectively. The MSF partakes more than 93% of the thermal process production, while RO

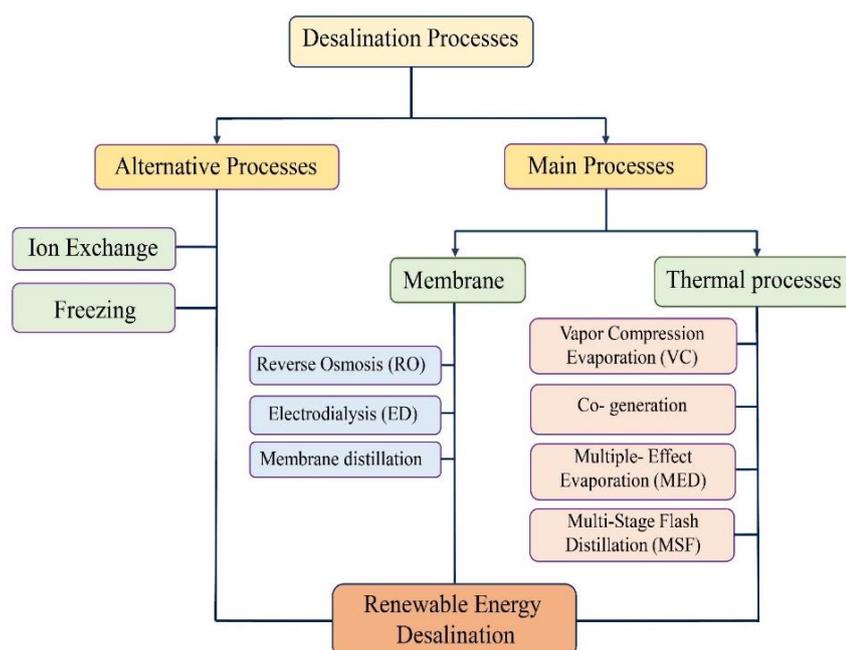
process possesses more than 88% of the membrane process production [11].

RO is among the most efficient desalination techniques, requiring about 3-10 kWh of electric energy per m³ of freshwater produced from seawater [12]. In this method, sea water is pushed to a chamber and purified by passing through a semi-permeable membrane [2]. A schematic performance of reverse osmosis process is demonstrated in Figure 2(a). Electrodialysis (ED) is another popular technique used for desalination. In this process, salinity is reduced by transferring ions from the feed water section, through anionic and cationic transfer membranes, under the influence of an electrical potential difference [2]. Figure 2(b) illustrates a schematic of electrodialysis reversal (EDR) method which is a known and important electrodialysis technique. In this method, a membrane like the one in reverse osmosis process is utilized, but in this case, an

electric charge passes through to the anode and cathode that leads to separation of anions and cations. The anions such as Cl⁻ ions are dragged to the anode by passing through the anion-transfer membrane and Na⁺ ions are drawn to the cathode, separating the Na⁺ and Cl⁻ ions, and finally pure water is produced.

Recently, these renewable energy sources have been attracted enormous attention due to their highly capability of combining with thermal distillation or membrane desalination systems in water production processes. Moreover, there are several possible combinations of solar energy and desalination technologies, which could have higher promising water production with regard to economic and technological feasibility than other techniques. Some combinations are better suited for large-size plants, whereas some others are more adequate for small-scale applications [3].

Figure 1. A general classification of water desalination technologies [3]



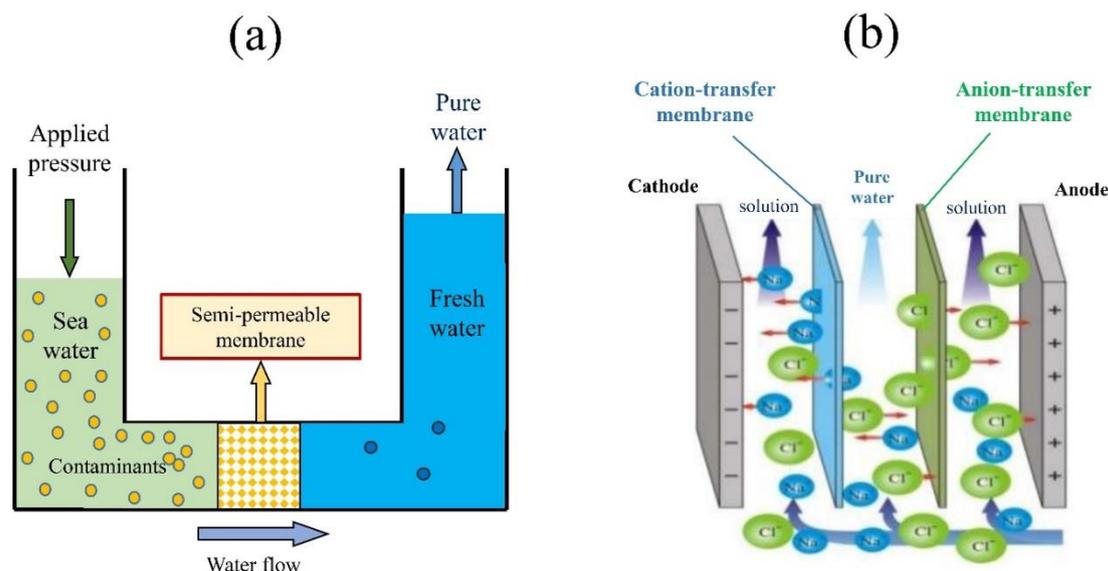


Figure 2. A schematic of (a) reverse osmosis (RO) process, (b) electro dialysis reversal (EDR) process.

Water demand and consumption

There is an inseparable relation between water and energy source production and utilization [13]. From the beginning of humankind until now, rivers, lakes and underground water reservoirs have been used for fresh water requirements in domestic life, agriculture and industry. About 70% of total water consumption is used by agriculture, 20% is used by the industry and only 10% of the water consumed worldwide is utilized for domestic needs [14]. However, expeditious industrial growth and the worldwide population explosion had resulted in a rapid increase of demand for fresh water for the household needs and for crops to in order to adequate quantities production of food. Furthermore, the rivers and lakes pollution caused by industrial wastes and the large amounts of sewage flowed out has become a great concern. In overall, water demand duplicates every 20 years, so emergency situation in water providence is certainly very alarming [2-14].

Importance of purification

The only nearly inexhaustible sources of water are the oceans. However, high salinity is their main drawback. Therefore, it would be attractive to takeover of the water-shortage problem with the purification process [15]. In overall, desalination means to remove the salt from seawater (or so-called saline water). According to World Health Organization (WHO), the water salinity permissible limit is 500 parts per million (ppm) and for special cases up to 1000 ppm, while most of the water available on Earth has salinity up to 10,000 ppm, and seawater normally has salinity in the range of 35,000-45,000 ppm containing total dissolved salts [2-14].

Surplus salinity of water side effects seriously deals with the health issues such as; taste and stomach problems and laxative effects. Thus, the purification system is to clean or purify seawater or brackish water and supply water with total dissolved solids within the permissible limit of 500 ppm or less [15].

Purification and energy

In general, energy is as important as water due to the development of good life standards as

it is the force putting in operation all human activities. Purification processes require significant quantities of energy for separation of salt compounds from seawater. The dramatic increase of desalinated water supply leads to a series of problems which the most significant of are those related to environmental pollution and energy consumption caused by the use of fossil fuels.

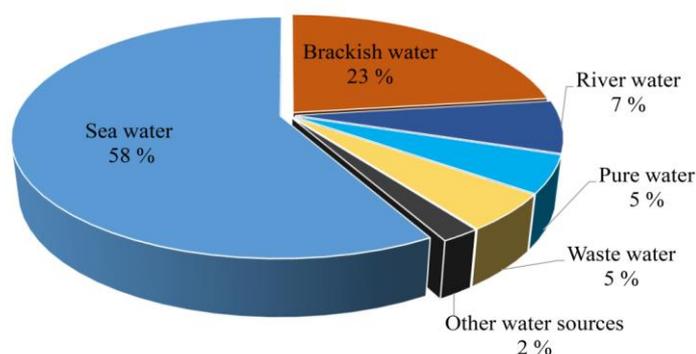
Renewable energies as a clean friendly source of energy to apply small-scale desalination units in remote areas has received enormous attention in recent years [16]. Renewable energy is considered as a reliable, variable and eco-friendly choice when depletion of fossil fuels global reservoirs threatens the long-term sustainability of the world economy [17]. The integration of renewable resources in desalination and water purification is becoming increasingly attractive. Renewable energy systems produce energy from sources, which are freely available in nature. Their main characteristic is their friendly behavior to the environment, which in other words means no harmful effluents is generated by these renewable energy sources. Fresh water production using purification technologies driven by renewable energy systems is to be considerate a viable solution to the water shortages in remote areas characterized by lack of potable water and conventional energy sources such as heat and electricity grid. Worldwide, several renewable energy purification pilot plants have been built which

the majority has been successfully operated for years. Almost, all of them are custom designed for specific locations and consume solar, wind or geothermal energy to produce fresh water. Operational data and experience from these plants can be used to attain higher reliability and cost minimization. These renewable sources are applicable in certain areas and are likely to become more widely feasible solutions in the near future [15]. By considering the climate change due to global warming in recent years and also climate protection targets and strong environmental concerns, future water desalination around the world should be powered by clean natural resources such as solar, wind, geothermal energy and other renewable resources.

Purification market

All around the world, there exists many areas suffering from fresh water shortage that are being enormously dependent on purification, as a highly reliable and non-conventional source of fresh water. Purification market has increasingly expanded in recent decades and they are expected to continue this rising trend in the coming years [15]. Seawater purification is being applied at 58% of installed capacity worldwide, followed by brackish water purification accounting for 23% of installed capacity [2-14]. Figure 3 depicts the global desalting capacity ranked according to feed water sources [14].

Figure 3. Global installed purification capacity by feed-water sources [14]



Renewable energy system powers

Solar thermal and photovoltaic (PV) systems, wind power, biomass, marine, geothermal and some other sources are the basic kinds of renewable energy used nowadays [17]. The coupling of desalination systems to renewable energy sources such as solar or wind power has become very attractive in many remote areas where the desalination water process often occurs simultaneously with the lack of conventional power sources [18].

This section presents a review of the possible systems such as solar, wind and geothermal energy power that can be exploited for renewable energy collection and alteration into usable energy, which may be used into power purification equipment for water desalination.

Solar power

Solar energy can be used to convert sea water into fresh water with simple, low cost, and economical technology and thus it is suitable for small communities, rural areas and also areas where the income level is very low [19]. Recent developments indicated that, solar-powered desalination processes are better than the alternatives including, ED, RO, and freezing, for fresh water provision in remote rural areas [20]. In this section, various solar energy systems are presented. These include solar collectors, solar ponds and photovoltaic cells (Solar cells).

Solar collectors

Solar energy collectors are a special kind of heat exchanger that transforms solar radiation to internal energy of the transport medium. Solar collector is the major component of any solar system. In fact, this device absorbs the incoming solar radiation, converts it into the heat, and transfers this

heat to a fluid which is customarily air, water, or oil flowing through the collector [21]. Then, the solar energy collected is carried from the circulating fluid either directly to the hot water or space conditioning equipment or to a thermal energy storage tank from which can be drawn for utilization at night and/or cloudy days. The schematic mechanism of a solar collector is seen in Figure 4. Basically, there are two kinds of solar collectors which are non-concentrating (stationary) and concentrating types. A non-concentrating collector has the same area for both intercepting and absorbing solar radiation, whereas a sun-tracking concentrating solar collector usually has concave reflecting surfaces to intercept and focus the sun's beam radiation to a smaller receiving area which leads to increased radiation flux. Great numbers of solar collectors are available in the market. A comprehensive list is shown in Table 1 [22]. A comprehensive review was done by Kalogirou in 2005 [23], which has been dealt with the collectors and renewable energy, various types of collectors and their corresponding systems and applications is completely discussed.

Solar ponds

The solar pond is one of the simplest devices for direct thermal conversion of solar energy [24]. The basic concept of a solar pond emanates from giving heat to a large pond of water in such a way in order to prevent the heat losses which would occur if less dense heated water is allowed to rise to the pond surface and lose energy to the environment by convection and radiation as shown in Figure 5. This device can be accomplished if a stagnant, highly transparent insulating zone such as a glass glazing is put in the upper part of the pond to maintain the hot fluid in the lower part of the pond.

Figure 4. The schematic mechanism of a solar collector for water desalination

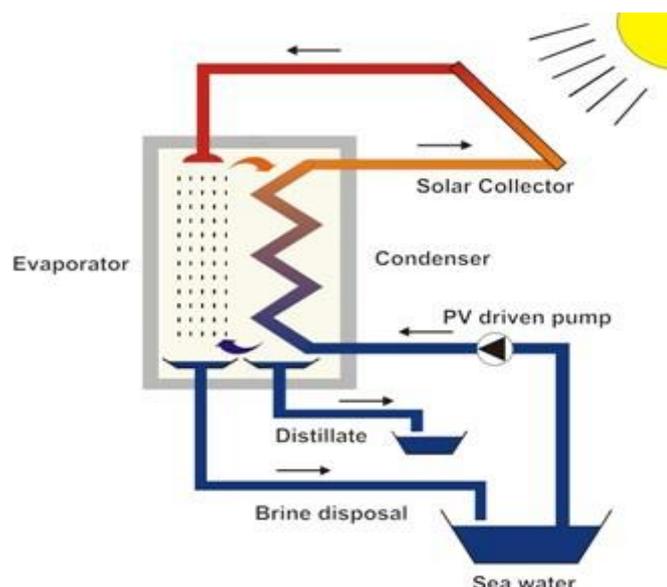


Table 1. Solar energy collectors (Concentration ratio is defined as the aperture area divided by the receiver/absorber area of the collector) [22]

Motion	Collector type	Indicative temperature range (°C)	Absorber type	Concentration ratio
Stationary	Evacuated type collector (ETC)	50- 200	Flat	1
	Flat type collector (FPC)	30- 80	Flat	1
	Compound parabolic collector (CPC)	60- 240	Tubular	1.5
	Linear Fresnel reflector (LFR)	60-250	Tubular	10- 40
Single-axis tracking	Parabolic trough collector (PTC)	60- 300	Tubular	15- 45
	Compound parabolic collector (CPC)	60- 300	Tubular	5- 15
	Cylindrical trough collector (CTC)	60-300	Tubular	10- 50
Two-axis tracking	Parabolic dish reflector (PDR)	100- 500	Point	100- 1000
	Heliostat field collector (HFC)	100- 2000	Point	100- 1500

In a nonconventional solar pond, part of the incident insolation is absorbed and converted to heat, which is stored in the lower regions of

the pond. Solar ponds are both solar energy collectors and heat stores. Salt gradient lakes,

which exhibit an increase in temperature with depth, occur naturally [2].

A cost analysis was done by Glueckstern in 1995 [25], for various desalting technology like solar pond, concentrator collector and seawater reverse osmosis process. The author indicated that the salt-gradient solar ponds to power hybrid MED/SWRO systems are currently the preferred technology for large-scale desalination.

In general, solar ponds constitute of three main zones with different temperature and salt concentrations which are defined as follows:

1. The upper convecting zone (UCZ) which contains almost constant low salinity at close to ambient temperature. Typically, the UCZ zone with a thickness of 0.3 m, is the main result of evaporation, wind-induced mixing and surface flushing. It is kept as thin as possible by using wave-suppressing surface meshes and placing wind-breaks near the pond [2].
2. The non-convecting zone (NCZ), in which both salinity and temperature increase with depth. The vertical salt gradient in the NCZ prevents convection and therefore provides the thermal insulation. The temperature gradient is formed due to the absorption of insolation at the pond base [2].
3. The lower convecting zone (LCZ) which contains almost constant, relatively high salinity (typically 20% by weight) at a high temperature. Heat is stored in the LCZ possessing the special size to supply energy continuously for the whole year. As the depth increases, the thermal capacity increases and annual fluctuations of temperature decreases. However, large depths increase the initial capital costs and require longer start-up times [2].

Many techniques have been considered in order to prevent the natural convection in a solar pond. The most conventional method used is salt stratification. As can be seen in Figure 5, the salinity increases with depth in

the NCZ until it is reached to the LCZ. Here, the solar radiation heats the high salinity water, but due to its high relative density, this hot salty water cannot rise into the lower salinity layers, thus the heat is stored and suppressed from being transferred by convection. Chemically stable salts, as well as any natural brine can be used to establish a salt-stratified solar pond. A selected salt must be safe to handle, non-toxic, low-cost and easily available, its solubility should be temperature dependent and should not reduce significantly the insolation transmission characteristics of water [26]. The salts most commonly used are NaCl and MgCl₂ [21]. Size and the salt used in solar ponds are important parameters need to be considered [27]. At the base of the pond, the calculated of salt amount is mixed with fresh water until the pond becomes half full. In order to maintain salinity gradient, brine is injected into the LCZ and fresh water is supplied through the UCZ. Jaefarzadeh [28] studied various methods of salt injection in the LCZ. The 'dynamic stability' and 'equilibrium boundary criterion' discussed and confirmed experimentally for the lower and upper gradient interfaces. A salt gradient solar pond coupled with evaporation pond was studied by Agha *et al.* [29,30]. They established that salt reconcentration due to evaporation had occurred to be an effective method of providing salt to the main solar ponds. Similar model was presented by Ouni *et al.* [31] and Alagao [32]. They established that the solar pond efficiency was 10–30%, if the storage zone temperature is kept in the range of 40 to 80 °C.

Such ponds can be a reliable heat source in a broad scale of industrial and agricultural applications such as, space heating, process heating, desalination and electricity production. Solar ponds have several advantages over other solar technologies such as low cost per unit area of collector, inherent storage capacity and easily construction over large areas [21].

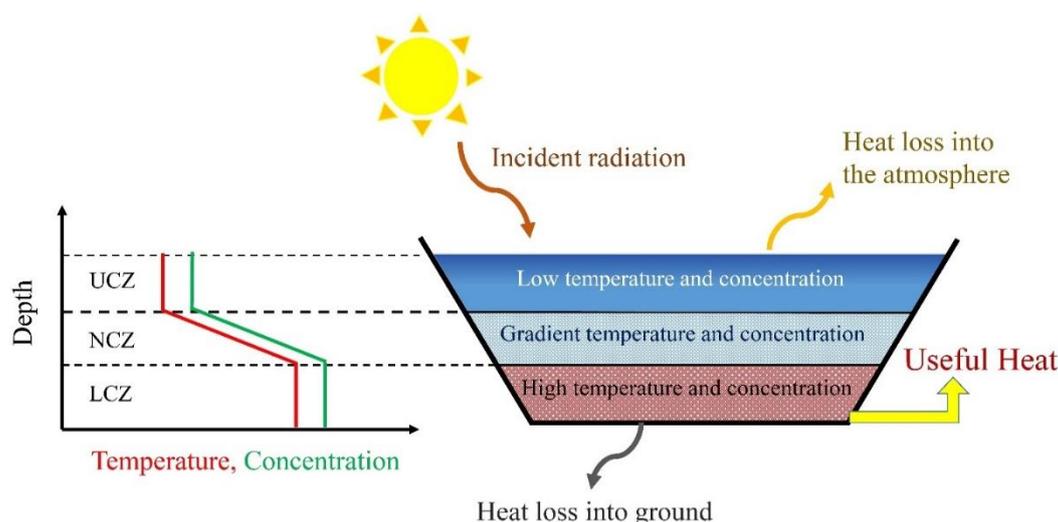


Figure 5. Schematic vertical section through a salt-gradient solar pond

Photovoltaic cells

The photovoltaic (PV) process converts sunlight energy, the most abundant energy source on the planet, directly into electricity. In fact, photovoltaic cells can absorb sunlight or artificial light, but a solar cell is a type of photovoltaic cells which only absorbs sunlight. Basically, a PV cell generates electricity without producing emissions of greenhouse or any other gases, and its operation is almost silent [2]. A PV cell consists of two or more thin layers of semiconducting material which silicon is commonly the main element. When the silicon is exposed to light, electrical charges are created and this can be conducted away by metal contacts as direct current (DC). The electrical output from a single cell is small, therefore multiple cells are connected together and encapsulated (usually glass covered) to form a module (also called a 'panel'). The PV panel is the principle building block of a PV system and any number of panels can be connected together to supply the desired electrical output. This modular structure is a considerable advantage of the PV system, where further panels can be added to an existing system as required [2].

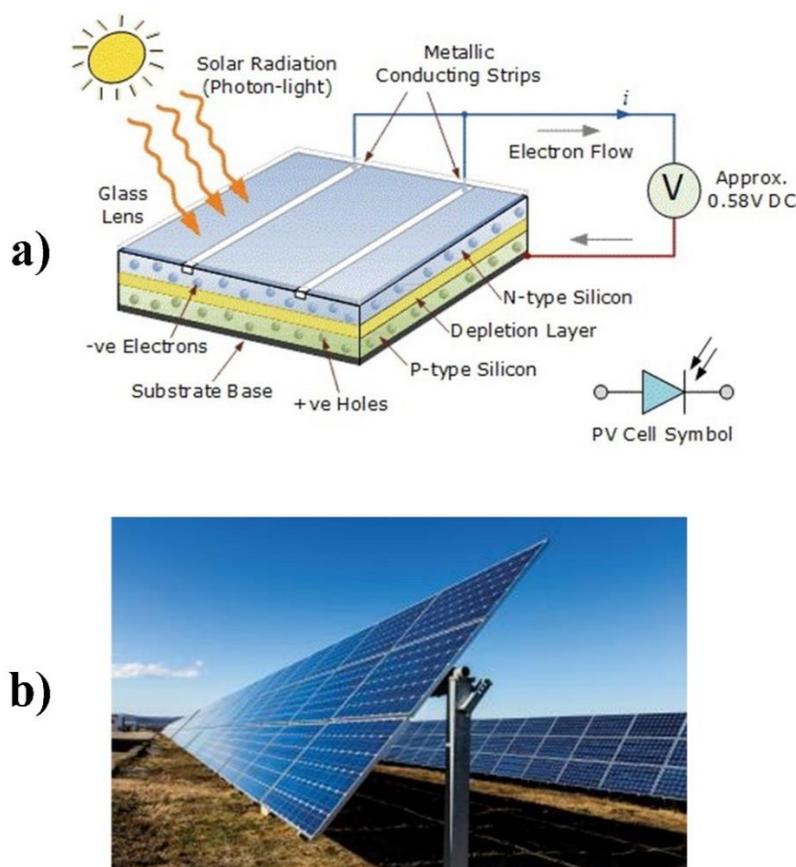
Figure 6a and b show a PV schematic structure and a large-scale PV application, respectively. As can be seen in Figure 6a, due to

absorbing light (sunlight or artificial light) by an *n*-type/ *p*-type junction (doped *n* & *p* silicon layers) which leads to diffusion of electrons in *n*-type and electron hole in *p*-type into the physical barrier between them (depletion layer) and the lower concentration regions and finally a current flow and electricity is generated.

Amorphous silicon absorbs light more effectively than crystalline silicon which indicates that the cells can be thinner. For this reason, amorphous silicon is also known as a 'thin film' PV technology. Amorphous silicon can be deposited on a broad range of substrates, both rigid and flexible [2].

Keper *et al.*, in 1985 [18], worked on optimizing matching of solar photovoltaic power with reverse osmosis desalination. In reverse osmosis (RO) two solutions are separated due to their pressure difference with different concentrations across a semi-permeable membrane [33]. Their results showed that PV systems provide high reliability and optimizing conditions. Also, energy recovery reverse osmosis (RO) desalination systems are entirely compatible with other renewable energy sources, including wind turbines and solar thermal engines.

Figure 6. (a) a PV schematic structure, (b) a PV application



In 1995, Alawaji *et al.* [34], worked on PV-water pumping and desalination plant for remote areas in Saudi Arabia. The various parts of equipment in the PV systems and their primary operation and performance were discussed. Mohsen and Jaber in 2001 [35], proposed the development potential of RO desalination system driven by PV power assisted by a simulation model in order to predict the PV specific power delivered for a given value of the global insolation. Richards and Schafer in 2003 [36], reported the design and successful field testing of photovoltaic (PV)-powered desalination system using RO (Reverse Osmosis)/NF (Nano-filtration) membrane for remote areas in Australia. Karimi *et al.*, in 2015 [37], made a technical practicality comparison between off-grid PV-EDR (Photovoltaic Electrodialysis Reversal) and PV-RO desalination systems by means of their energy consumption. Their result indicated that for low-salinity water with

solar power, EDR was far more efficient than solar-powered RO, with a total net present price difference of 48–159%, if the blending is not an option for RO. For higher-salinity water, solar-powered RO was more efficient than solar-powered EDR, with a lower total net present cost. PV equipment has no moving parts, thus it needs minimal maintenance and has a long life-time [2]. This advantage, abundant existence of sun light and its highly ability of coupling with other conventional desalination methods in special with RO method makes it preferable choice than any other renewable solar energy sources such as solar ponds and solar collectors in many areas worldwide.

There are many factors affecting on the selection of the most appropriate solar desalination technology including feed water salinity, plant size, technical infrastructure, remoteness, availability of grid electricity and the type of solar technology available [3].

Wind energy

Effects of pretreatments

Wind powered desalination is one of the most promising alternatives of renewable energy desalination processes [2]. Wind is generated by atmospheric pressure differences, driven by solar power. Of the total 173,000 TW of solar power reaching the earth, about 1200 TW (0.7%) is used to propel the atmospheric pressure system. A kinetic energy reservoir of 750 EJ with a turnover time of 7.4 days is produced by this power [38]. This converting process mainly occurs in the upper layers of the atmosphere, at around 12 km height (where the 'jet streams' happen). By assumption the fact that if only about 1% of the kinetic power is available in the lowest atmosphere layer, the world wind potential is of the order of 10 TW. Therefore, it can be concluded that, just based on a theoretical basis, and disregarding the supply and demand contradiction, the wind could supply an amount of electrical energy equal to the present world electricity demand. As a consequence of the on-linear relationship between wind speed and the energy power of the wind, one should be careful in using average wind speed data (m/s) to derive wind power data (W/m^2). Local geographical circumstances may lead to mesoscale wind structures which possess a much higher energy amount than the calculated amount

from the most conventional used wind speed frequency distribution (Rayleigh). Permitting the increase of wind speed with height means that the energy available at for example 25 m differs from around 1.2 MW h/m²/yr to around 5 MW h/m²/yr in the windiest regions. Higher energy levels are possible if hilly sites are used, or if local topography funnels the current wind through valleys. Today, the wind energy utilization uses a wide range of machine sizes and types giving a range of variant economic performances. These are the small machines up to about 300 kW and the large capacity ones which are in the MW range [2].

Thus, among the renewable energies, wind energy has been completely utilized for power generation and wind turbines are commercially accessible on a broad scale of nominal power. The mechanical or electrical power generated by a wind turbine can be utilized in order to run the desalination plants [17].

A photograph of a wind park is shown in Figure 7. The technology of the wind turbine generators currently in use is only 25 years old, and investment in it has so far been rather modest, compared to other energy sources [2].

Wind power and desalination can be coupled in various ways and has led to act a significant role on performance of desalination process and many research works are reported.

Figure 7. A photograph of a wind park



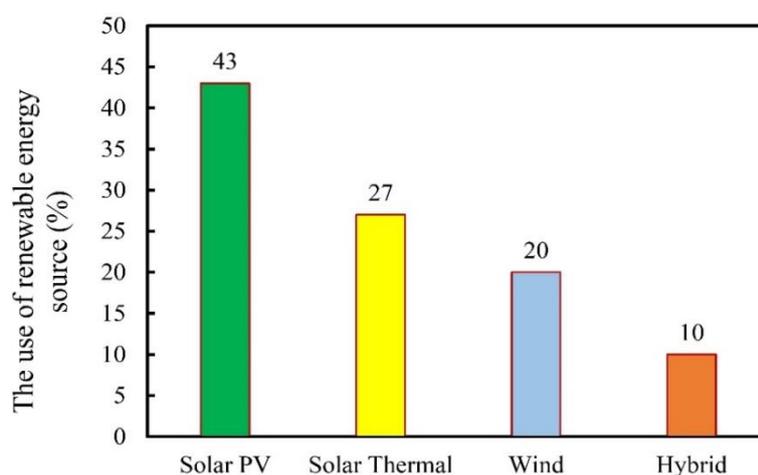
Due to converting the energy of wind power to electricity, this energy can be employed to run desalination processes such as ED, RO, MVS and green house [2, 39-41]. According to a study in 2005 [42], Nakatake and Tanaka proposed a new designed maritime lifesaving small distiller. Their results indicated that the wind energy directly converted to frictional thermal energy had a higher efficiency than indirect convert energy which first converted wind energy to electricity and then turned it into thermal energy. In order to reduce the energy loss due to wind-electricity conversion according to a study done by Fadigas and Dias in 2009 [43], in order to desalinate water using RO method, the gravitational potential energy of the water stored in a reservoir above a certain height, was converted by wind energy from wind turbines. Ali *et al.*, in 2018 [44], reviewed the recent progresses and developments in employing renewable energy sources in membrane-based desalination with special attention on coupling membrane operations with established capability in order to generate energy from wastewater streams.

As discussed, wind power has a great potential in order to merge with other renewable sources and conventional desalination methods. Since RO is the desalination method with the lowest energy requirements which windy and coastal areas possess a high accessibility of wind power resources, according to previous research

works, wind powered RO plants occur to be one of the most promising alternatives of renewable energy desalination [45-48]. Despite the low energy consumption of wind driven RO method compared to MVC (Mechanical vapor compression) technique-which are the major thermal desalination method driven by wind the MVC systems have less issues due to fluctuation of the energy source than RO and they are more suitable in remote regions, since they are more powerful, need fewer skilled workers and less chemicals than RO. ED (Electro dialysis) is another technique which is more suitable than RO method in remote regions due to its high adaptation ability to energy source power changes and fluctuations [17].

Due to the variation and interruption of wind energy, some potential factors need to be considered in order to how configure the type of employing direct or indirect conversion of wind energy associated with desalination methods and it has to be improved. The solar and wind energy can be considered as popular and reliable renewable energy sources. Quteishat *et al.*, in 2004, reported the relative distribution of global usage among desalination processes operating by renewable energy sources which is presented in Figure 8 [49]. As seen, the solar energy and in special case the solar PVs are the most widely used among other renewable energies.

Figure 8. Global usage distribution of renewable energy resources desalination



According to Figure 8. The less usage of wind energy compared to solar thermal energy could be result of two facts. Firstly, the limited usage of wind energy in low windy areas and its variations and interruptions which discussed before, requires serious consideration of economic effects. Secondly, the wind energy can only be utilized to provide electricity for a desalination plant and compete with other electricity production techniques.

It is concluded that the wind power source has become a reliable and more competitive with conventional electric power sources, especially in windy and coastal areas, and therefore it is the preferred option for desalination process among other renewable energy sources.

Geothermal energy

Measurements indicate that the ground temperature below a certain depth remains relatively constant throughout the year. This is due to the fact that the temperature fluctuations at the ground surface are diminished as the depth of the ground increases due to the high thermal inertia of the soil [2].

In the period between summer 1999 to spring 2001 in Poland, Popiel *et al.* [50] reported the temperature distributions measured in the ground. By considering the point of view of the temperature distribution, they distinguished three ground zones:

1. Surface zone; reaching a depth of about 1 m which the ground temperature is very sensitive to short time variations of weather conditions.
2. Shallow zone; extending from the depth of about 1–8 m (for dry light soils) or 20 m (for moist heavy sandy soils), where the ground temperature is almost constant and close to the average annual air temperature. The ground temperature distributions depend mainly on the seasonal cycle weather conditions in this zone.
3. Deep zone; below the depth of the shallow zone, where the ground temperature is practically constant and very slowly increasing

with depth according to the geothermal gradient.

There are different geothermal energy sources. They may be classified in terms of the measured temperature as low (<100 °C), medium (100–150 °C), and high temperature (>150 °C). The thermal gradient in the Earth varies between 15 and 75 °C per kilometer depth nevertheless, the heat flux shows irregular behavior in different continental areas. Moreover, local centers of heat exist between 6 and 10 km deep which are created due to the disintegration of radioactive elements [2]. Geothermal energy sources are unique in their applications due to their physical and chemical characteristics. These can be employed both in membrane and thermal desalination processes dependent on the location, geothermal water physical and chemical characteristics. Geothermal desalination is cost-effective, and water production and simultaneous power is possible. Geothermal resources possess the potential to serve as excellent heat sources for thermal desalination processes. Geothermal production technology which is extracted of hot water from underground aquifers is mature and uninfluenced by the seasonal and weather changes. Geothermal sources have relatively lower surface area or land requirements per unit (MW) of all renewable energy sources (for example: $20\text{MW}_{\text{th}} = 10\text{ m} \times 10\text{ m}$ well size) and energy demand can be matched from smallest to the largest energy-consuming utilities [13, 51,52]. A complete review of geothermal energy technology is presented by Barbier *et al.* [53,54]. Baldacci *et al.* [55] reported that the cost of electrical energy is competitive with geothermal energy resources produced in year 2000.

Thus, geothermal energy can be used as a highly reliable with high efficiency power input for water purification. Energy extracted from the earth is conventionally supplied with the aim of ground heat exchangers. These heat exchanger constituting material is extraordinarily durable but permits heat to pass through efficiently. A review of ground heat exchangers is completely

discussed in [56]. Ground heat exchanger manufacturers usually use high-density polyethylene which is a tough plastic, with heat fuse joints. This material is usually guaranteed for as much as 50 years. Water or an environmentally safe antifreeze solution is the fluid circulating in the loop. Other types of heat exchangers utilize copper piping placed underground. The length of the loop depends upon a number of factors such as the type of loop configuration, the soil conditions, the thermal load, local climate and many other factors [56]. The schematic of a heat exchanger used for desalination process is drawn in Figure 9. which is adapted from the schematic of a heat exchanger in the simple vacuum desalination system [4].

Geothermal energy can be considered as a limitless energy source if it can be applied in a

closed loop configuration. Geothermal sources vary in temperatures providing flexibility for different process applications. These applications may include unified configurations to provide additional benefits while supporting desalination process. Capacity factor is an important factor of the energy sources which is related to the availability of an energy source in both quantity and quality which is defined as the actual energy generated by a system to the available energy source. Capacity factor is an important variable to be considered for scalability and a technology operation. The capacity factors for various renewable energy sources are shown in Figure 10 [57,58]. As seen, geothermal energy has the highest capacity factor of 95% among the other renewable energy sources such as solar, wind, and biomass sources.

Figure 9. A schematic of a heat exchanger used for desalination process

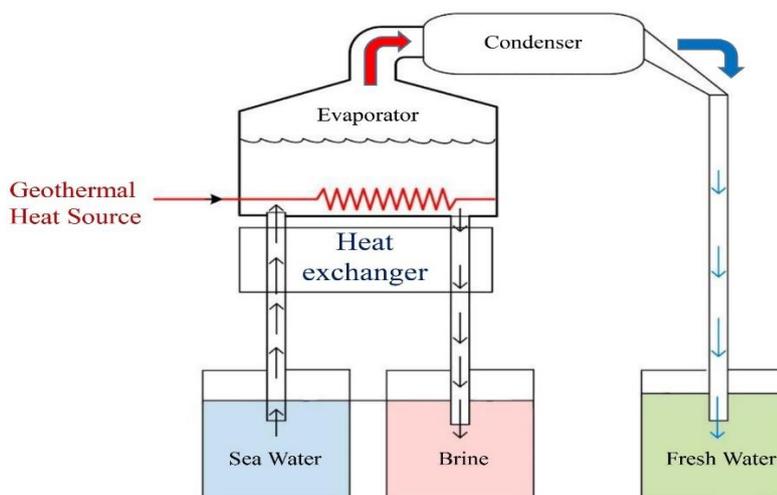
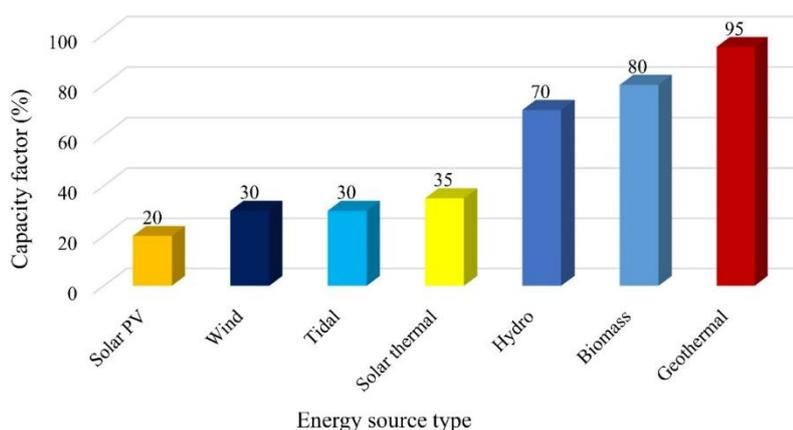


Figure 10. Capacity factor (%) ranges variations with different energy source types



Selection of desalination process

Renewable energy systems offer alternative solutions to reduce the dependence on fossil fuels. The total worldwide renewable energy purification installations amount to capacities of less than 1% of that of conventional fossil fuel purification plants [59]. This is mainly due to the high finance, capital and maintenance costs required by renewable energy sources, making these purification plants non-competitive with conventional fuel purification plants [2-17]. A comparison between the conventional method with fuel source, solar and geothermal energy power and their corresponding water production cost are reported in Table 2 [60].

However, the economic advantages of conventional sources than the renewable energy sources, these renewable sources higher cost is counter balanced by the environmental benefits. Besides, the cost of renewable energy systems has been significantly reduced during the last decades. Therefore, future reductions of these new energy sources as well as the growth of fossil

fuel prices due to their increasingly depletion could make possible the competitiveness of seawater or brackish water desalination driven by renewable energies [17].

During the design stage of a renewable energy powered desalination system, the designer will need to select a

process suitable for a particular application [2]. The most important influencing factors that should be considered for such a selection are the following [61].

1. Suitability of the process for renewable energy application.
2. The effectiveness of the process with respect to energy consumption.
3. The seawater treatment requirements.
4. The capital cost of the equipment.
5. The land area required or could be made available for the installation of the equipment.
6. The amount of fresh water required in a particular application in combination with the range of applicability of the various desalination processes.

It should be noted that before any process selection, specified basic parameters should be investigated.

Table 2. Type of energy supplied and water production cost [60]

Type of feed water	Type of energy	Water cost (Euro/m ³)
Brackish water	Conventional fuel	0.21 - 1.06
	Photovoltaic cells	4.5 - 10.32
	Geothermal	2
Sea water	Conventional fuels	0.35 - 2.7
	Wind energy	1 - 5
	Photovoltaic cells	3.14 - 9
	Solar collectors	3.5 - 8

Conclusions

Nowadays, the use of renewable energies for purification appears as a reliable and technically attractive option toward the emerging and stressing energy and water problems. In this work, a review of the various renewable energy purification systems (including solar, wind and geothermal energy

systems) was presented. In addition, various solar energy systems such as solar collectors, solar ponds and photovoltaic were discussed. In solar systems, it was found that the photovoltaic (PV) process requires minimal maintenance and has a long lifetime. In addition to the solar distillation processes advantages for seawater desalination, other

renewable energy resources such as wind and geothermal energies have attracted lots of attention. In windy areas, wind-driven purification plant are preferred and also, geothermal energy in special due to its highest capacity factor among the other renewable sources, should be considered due to feasible costs for different desalination processes. It was concluded that in order to find out the proper renewable energy source for a purification plant in a particular area, important factors should be considered such as water salinity, area remoteness, plant size, technical infrastructure of the plant, process suitability for renewable energy application, capacity factor, energy consumption and capital cost of the equipment.

Disclosure statement

No potential conflict of interest was reported by the authors.

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