ASSESSING GEOTHERMAL ENERGY'S ROLE IN SUSTAINABLE WATER DESALINATION CURRENT STATUS, KEY PARAMETERS, AND CHALLENGES

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Abstract: Because of both climate change and a rise in population, there is less fresh water available in a lot of different areas of the globe. This is causing a lot of problems. The ever-increasing need for energy is the primary motivating factor behind the global shift away from fossil fuels and towards renewable energy sources. Desalination plants will need to be constructed in large numbers all over the globe since freshwater resources are decreasing. Geothermal energy is one of these alternative energy sources that is currently being researched. While new desalination technologies are being developed, conventional methods are becoming more effective while also becoming less expensive. This page provides a summary of the many uses of geothermal energy found all around the world. It presents a specific scenario for desalination using a geothermal source, which has the potential to be free of both pollution and energy consumption at the same time. The benefits of geothermal desalination over other techniques, the present status of geothermal desalination around the globe, the method of choosing desalination technologies, and the challenges inherent in installing desalination systems powered by geothermal sources are extensively discussed in this article.

Keywords: desalination; freshwater production; geothermal energy; state of the art; sustainability; water problem; energy savings; present situation

1. Introduction

Water scarcity is a most crucial matter all over the world [1,2]. Global warming causes more water to evaporate from sources [3,4], which necessarily reduces the amount of drinkable water and increases the need for additional water sources [5,6]. Our future safety is likely at stake, so we should take precautions now [7,8]. There is no more sensible approach to dealing with the organization of freshwater supply than desalting water for all its intended purposes [9,10]. Nearly 97.5% of the world’s water is found in the oceans and along the coasts of land and is potentially drinkable if its salt content is reduced [11,12]. Undoubtedly, all desalting methods rely on energy to either remove salt from saltwater or purify it [13,14]. Recently, desalination has gained much attention as one of the most effec- tive ways to deal with the problem of freshwater shortages [15]. Desalination, with current technology, will need consuming copious amounts of non-renewable energy sources [16,17]. Nonetheless, recent studies suggest that petroleum resources will deplete somewhat later in the long run [18].

Fresh water is found in lakes, glaciers, ponds, reservoirs, streams, rivers, groundwater, and wetlands. Desalination processes have access to an infinite supply of water when they use seawater as their source. A second possible brackish water source comes mostly from various subterranean sources. This type of water is an option in many countries. The typical amount of salt found in one liter of saltwater is 35,000 mg. The level of saltiness in brackish waters is lower [19]. Nonetheless, there are some locations, particularly reservoirs, such as geothermal reservoirs, that have a salt concentration that is greater than that of saltwater. Geothermal waters can have a salinity that ranges from as little as 500 mg/L up to as high as 120,000 mg/L [20]. The WHO’s recommendations for drinking water ask for a salinity of less than 600 mg/L because of concerns over palatability; however, no health-based guideline value has been recommended for TDS [13]. In today’s desalination procedures, membrane technologies play a preponderant role, accounting for 69–73% of all systems deployed worldwide [21], whereas thermal approaches only account for around 27% [21]. The membrane process known as reverse osmosis (RO) has the majority of the market share worldwide. At this time, RO is the most cost-effective method for dealing with a broad spectrum of salinity (seawater and brackish water). Electrodialysis (ED) and electrodialysis reversal desalination (EDR) are two established techniques that are considered for desalinating low-salinity feeds. Several new techniques, such as membrane distillation (MD), forward adsorption desalination (AD), and forward osmosis (FO), are now in the process of being developed and have the potential to have a significant impact in the future [22]. Capacitive deionization (CDI), a procedure that may be regarded as a method of desalination technology for brackish water, is also an intriguing technique. This technique relies on the movement of ions from salty water to electrodes with a large capacity for retaining ions; nevertheless, the electrodes themselves are the primary factor that dictates the technology’s application and longevity [23].

Naturally occurring water typically contains a wide variety of pollutants [24,25]. Physi- cal pollution alters the appearance of water (turbidity, color, odor, and taste), while chemical pollution alters its mineral content and acidity (early and later impacts of debasement). Organic defilements include parasites, pathogenic bacteria, and algae, among others [26]. Therefore, removing the taint of contamination has become one of the most difficult chal- lenges for modern society. The salinity of seawater ranges from 36,000 to 46,000 parts per million [27], whereas the salinity of fresh water on land can reach up to 10,000 parts per million. As per the WHO [26], the highest level of salt in water that may be considered safe is 500 parts per million (ppm). However, in exceptional circumstances, this can go to 1000 ppm.

Global geothermal energy resources are divided into two groups: high- and low- enthalpy reservoirs [28,29]. Geothermal reservoirs are categorized according to the local geology and temperature [30,31]. About 1000 meters down is where you can find lower enthalpy geothermal sources, which have temperatures lower than 150 ◦C. About 1000 m down is where you can find the high temperature geothermal reservoirs with temperatures above 200 ◦C [32]. Major nations involved in geothermal energy development include Iceland, Kenya, New Zealand, Italy, Philippines, and Mexico. Geothermal water in Iceland may be anywhere from 200 to 350 ◦C. Fumaroles and Hot springs are the geothermal resources of this area. A greater variety of surface activities occur in regions where temper- atures are high compared to those in regions where temperatures are low [33]. Like mud pots, geysers, and hot springs, fumaroles have been discovered in Iceland [34]. Geothermal energy accounts for over 80% of Iceland’s electricity production. About 2100 meters below in Kenya, the geothermal water temperature is 250–300 ◦C. Space cooling and heating, agriculture, aquaculture, and other uses are only a few examples of their direct and indirect applications [35].

The geothermal fields of Italy may be broken down into four distinct regions: (1) Water hotter than 150 ◦C at depths of fewer than 3 km; this region stretches from the northwest to the southeast of Genoa and includes the Aeolian Islands. There are three types of geothermal potentials below 3 km in depth: (1) little potential, and no economic use;

(2) water temperatures between 30 and 60 ◦C; and (3) water temperatures between 90 and 150 ◦C. Spas, farms, factories, and municipal heating systems all benefit from Italy’s

low-temperature geothermal potential. Abano, a spa town in Italy’s northeast, accounts for a disproportionate share of the country’s residential heating demand. New Zealand’s geothermal fields may be broken down into three distinct types. There are 14 geothermal fields with between 70 and 140 ◦C temperatures, 7 with 140–220 ◦C temperatures, and 15 with over 220 ◦C temperatures. Geothermal water now supplies around 17% of the country’s power [36]. Its significant geothermal fields are Cerro Prieto, Los Azufres, Los Humeros, and Las TresVirgenes. These fields often have temperatures between 120 and 400 ◦C [37]. Among the Philippines’ many geothermal fields, Tiwi, Makiling-Banahaw, and Tongonan are the largest. Temperatures of 186 to 325 ◦C can be found here deep inside the Earth. Philippines geothermal water is utilized for producing energy and high-purity salt for industry [38].

India’s geothermal potential has a lower enthalpy when matched to other countries. India’s geothermal zones are broken down in five distinct groups: So-Na-Ta Lineament, Northwestern Himalaya, Thermal Field in the East and Northeast, West Coast Margin, and Other Geothermal Regions. India’s low-enthalpy geothermal reservoirs have 30–120 ◦C ranging temperatures. Geothermal water in Puga is the highest in enthalpy of any other field. Geothermal resources are only accessible through hot springs. Very little exploration or exploitation has been done thus far because the industry is still in its infancy. However, groups like NGRI, GSI, Thermax, CEGE, etc. are actively investigating this energy's potential uses.

Droughts are expected to become more common as a result of climate change because of changes in rainfall patterns and the rate of evaporation caused by rising temperatures. Water usage by agriculture, municipalities, and industries may all rise as a result of this warming, increasing the intensity of existing water scarcity issues. Desalination is one strategy to strengthen resistance to the effects of climate change. Desalination is politically and economically significant because it helps communities become self-sufficient. As a result of their geopolitical situations, countries like Israel and Singapore have made investments in desalination to lessen their reliance on water imports. Additionally, as urban populations rise, policymakers have increasing difficulty in meeting citizens' demands for clean drinking water. It is economically important to provide water to the commercial and industrial sectors of the economy. If these industries do not have access to water, it has significant economic, social, and political consequences. It is widely accepted that desalination provides the safer, more reliable source of water for these needs.

Therefore, desalination is increasingly being considered as a viable and cost-effective solution to address water demand in a variety of regions. About 1% of the world's drinking water comes from desalination plants [39], which are used in more than 150 nations throughout the world [40]. Desalination using renewable resources and wastewater reuse placed top in a multi-criteria review of Kuwait's management strategies and strategic policies [41] for meeting future water demand. Figure 1 shows that the majority of the world's desalinated water supply is used in municipal and industrial applications [42].

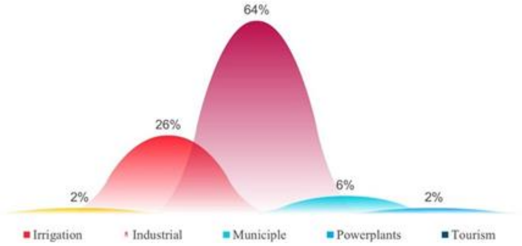


Figure 1. The percentage of the world's desalinated water supply used by each country's total installed desalination capacity.

However, the US Department of Energy predicts that global energy consumption will rise by 44% between 2006 and 2030 [43]. Desalinization uses a lot of power. Commercial desalination procedures consume energy at a rate between 10 and 20 kWh/m3 (multistage flash) and 2.5 and 4.75 kWh/m3 (reverse osmosis) [44]. Increases in desalination capacity are predicted to drive a dramatic increase in a water sector's proportion of Middle Eastern energy consumption from 9% in 2015 to 16% by 2040 [29], as reported by the World Energy Outlook 2016. It takes roughly 37 barrels of crude oil and results in about 10 tons of CO2 emissions [45] to desalinate 1000 m3 of saltwater using current technologies. Additionally, energy-related water usage is expected to rise by roughly 60% between 2014 and 2040. Researchers have looked at several questions about the long-term viability of our water and energy infrastructures [46].

Using a multi-objective optimization approach, Pakdel et al. [47] developed a strategy for efficient use of renewable energy sources, groundwater for agriculture, and seawa- ter for industrial purposes. Other writers [48] used system dynamics to foresee a rise in China's water and energy needs from 2015 to 2030 based on technological and economic considerations. Next, this analysis looked at any links between potential water and power shortages. Sustainable energy, water, and environmental system development were exam- ined in depth across 12 Southeast European towns in a recent research study [49]. While the energy and water sectors were assessed separately, the research examined cities based on variety of metrics without evaluating the relationship or linkages between the indicators. Others [50] have created a method to figure out how much power the water industry in California, USA. To measure the water sector's energy intensity, the research presented a bottom-up approach to compute and depict power usage per person and per cubic meter of water. Due to geographical and climatic variations across the state, the study found that treating the entire state as a single unit for the purpose of analyzing electrical intensity in the water sector was not feasible. The water sector's greenhouse gas (GHG) emissions are frequently the primary focus of environmental impact assessments. Another report [51] outlined an easy way to monitor the water–energy nexus in a Chinese metropolis. Using this technique, anyone can compare an average acquired from government data with a detailed calculation of how much water is needed for the generation of energy and how much energy is necessary for a water sector.

Saltwater desalination, imported water, recycled water, and brackish groundwater desalination were all included by Stokes et al. [52] in their life cycle assessment analysis of greenhouse gas emissions from water resources in California, USA. These results show that desalination using a concentrated solar power (CSP) system produces fewer greenhouse gas emissions than recycled and imported water. Researchers [53] looked into city-level measures to reduce CO2 emissions and better manage water resources. Thirteen cities' proposed budgets in United Kingdom and United States were analyzed. This research provided suggestions for enhancing current and future carbon and water budget programs by pointing out that these initiatives place too much emphasis on reducing greenhouse gas emissions and not enough on water–energy connections and the difficulties posed by diminishing water supplies. To illustrate the lack of social consideration in quantitative technical models of sustainability, researchers analyzed quantitative modeling scenarios for sustainable energy pathways [54]. Several models presented a concept of employing system dynamics stating that social factors (such as technological adaptation by society) made paths more plausible. The water system in Mexico City, Mexico, was analyzed for its energy use and carbon dioxide emissions in a study [55]. The water system was broken down into two sections for this analysis: potable water and wastewater. The city gets its water from two places: underground and above ground. Approximately 90% of overall energy usage in the water sector was connected to water delivery because of the great distance between the two water sources. Non-revenue water, water price changes, and widespread use of rainwater harvesting are among the most promising strategies for cutting back on water use. Leakage and other losses were estimated to account for around 40% of Mexico City's non-revenue water. This model does not take into consideration potential shifts in the patterns of water demand or the mix of energy resources (this city now derives more than 90% of its energy from fossil fuel resources). To investigate the connections between urban energy systems and water, De Stercke et al. [56] created a system dynamics model. London, UK was used as a case study to examine the impact of final users on the supply side of the water and energy industries. Findings showed that including policy goals like decarbonization plans and social considerations like quality of life helped to bring about more realistic simulations. Economic growth, technical progress, and policy decisions were all shown to have significant roles in determining the nature of energy transitions at the national level [57].

These studies all pointed out how the energy and water industries are intertwined for environmental sustainability. The sustainability of desalination systems remains an open subject, although their deployment rate has increased in recent years, and new ad- vancements mentioned in the literature suggest that desalination can be inexpensive. In this age of water stress, sustainable desalination can only be achieved via contributions that comprehensively address the process's technical, economic, environmental, and social challenges. The purpose of this article is to provide a broad overview of the contribution of geothermal energy technologies to the long-term viability of desalination-heavy water systems of the future. In other words, the connectivity between geothermal energy and desalination is emphasized. In the sections that follow, several facets of energies will be covered. Section 2 describes the global energy scenario using renewable energy. Technical considerations and the characteristics of existing desalination methods are discussed in Section 3. In Section 4, geothermal energy, specifically for desalination systems, is elabo- rated on. The significance, need, and important parameters associated with geothermal desalination are studied in Section 5. Section 6 then explored challenges associated with the development of geothermal energy. Lastly, Section 7 concludes with a brief summary of the study's major findings and suggestions for future research approaches.

2. Global Energy Scenario

Given the widespread use of electricity in today's society and economy, ensuring a steady and reasonably priced supply of power is a top priority when discussing energy security, and achieving net-zero emissions requires prioritizing the decarbonization of electrical generation. Most of the world's coal in 2021 was used for producing electricity, while around 40% of the world's natural gas consumption went towards that purpose. Several nations are increasing their reliance on coal to generate power as a short-term measure to deal with the energy shortage. Figure 2 depicts the expected decline in the proportion of coal and natural gas used in electricity generation through 2030 under four different scenarios.

Coal accounts for a significant portion of the energy mix, contributing to global average carbon intensity of power generation of 460 g CO2/kWh. To lower intensity of carbon for energy generation up to 160 g CO2/kWh by mid-century, the STEPS predicts that unabated coal will decline from its current 36% to 12%. As negative emissions in electricity sector counterbalance remaining emissions in transport and industry, the NZE Scenario reaches this position 20 years early, in 2050.

Because of fluctuating energy demand and increasing penetration of renewable sources like solar photovoltaics (PV) and wind, power system flexibility has become essential to reliable power delivery. For example, in the APS, flexibility requirements double by 2030 and nearly double again by 2050 [58]. Power systems rely on four primary types of flexi- bility providers: grids, generating plants, and energy storage and demand-side responses. Although thermal power plants now make a majority of changes to balance energy supply and demand, their importance as a source of litheness is expected to decline as alternative types of flexibility emerge and expand, particularly those involving coal and gas-fired facilities. The elimination of existing sources of flexibility before the expansion of additional sources poses a significant threat to the reliability of power supplies. One example is the need for sufficient funding to build and modernize the grid infrastructure. Our STEPSforecasts predict USD 770 billion yearly investments in storage and infrastructure until 2050, when grids will have grown in length by almost 90%. On average, the APS invests close to USD 1 trillion per year in grids and storage, which is 30% more than the global average. However, challenges exist and must be overcome. Permitting and building a single high-voltage overhead line (>400 kilovolts) can take as long as 13 years in practice, with the greatest lead times often found in developed nations. There are already many inefficiencies and dangers due to transmission bottlenecks [58].

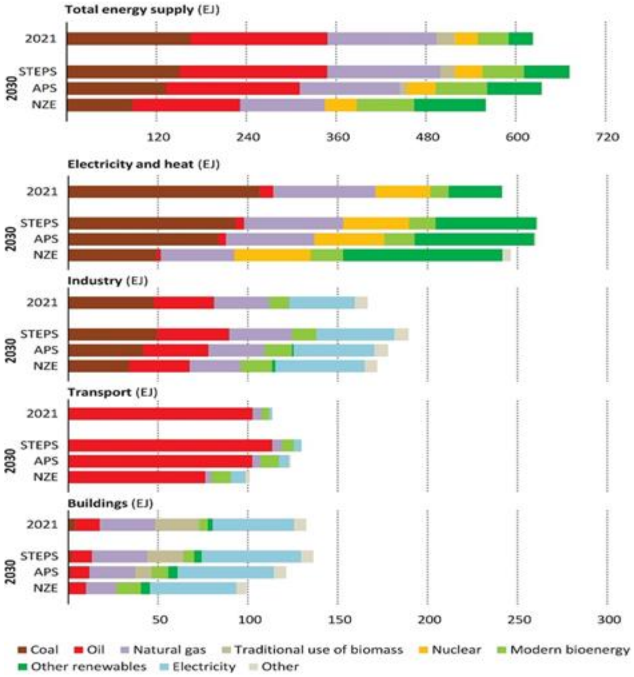


Figure 2. Global demand and supply for energy by scenario, sector, and fuel [58].

Currently, scenarios represent arranged procedures of development in which markets are stable, with assets fluctuating across sectors to maintain the balance between demand and supply. Nevertheless, the current energy crisis has highlighted the likelihood that the energy markets future will be fragmented. Specifically, the crisis has undermined the critical trust and teamwork required to facilitate the transition to a system with net-zero emissions. A lack of sequencing and coordination, both domestically and globally, would be extremely detrimental to the chances for a people-centered reform process. In all WEO scenarios, there is an orderly shift in the global fuel mix, with the key difference being the rate of transition away from fossil fuels. Figure 3 depicts the 2020–2050 non-fossil and fossil energy supply by scenario.

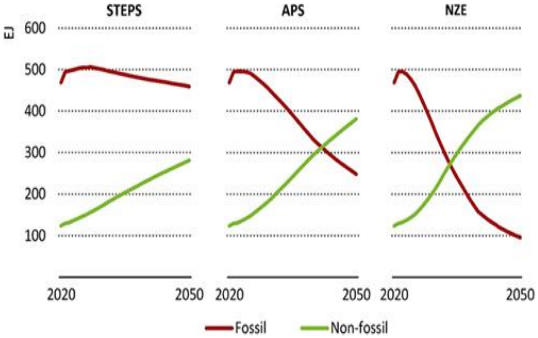


Figure 3. Supply of non-fossil and fossil energy by scenario, 2020–2050 [58].

Global energy mix experiences the radical transition as lower emission sources replace unrestrained sources across the entire energy industry. Figure 4, from 2021 to 2030, lower emission supply sources grew approximately 125 exajoules (EJ). As energy access objectives are met, the conventional usage of biomass is phased away. Modern bioenergy and solar will rise by approximately 35 and 28 EJ by 2030, respectively, the largest among sources with low emissions. Even while the global economy increases by roughly a third between 2021 and 2030, the overall energy supply decreases by 10% as a result of behavioral changes, improvements in energy efficiency, and electrification. The yearly rate of improvement in energy intensity roughly triples when it surpasses 4% per year. It is impossible to follow the decarbonization route outlined in the NZE Scenario unless there is an immediate and widespread implementation of measures that cap the rate of increase in energy consumption. In the absence of such regulations, the rapid increase in demand for energy services would cause the deployment of renewable energy sources to fall behind. These measures include improvements in energy efficiency, transitions to other fuels (most notably electrification), and shifts in behavior; together, they reduce demand by 110 EJ compared to the baseline level in 2030 [58]. By 2030, unchecked sources of supply will diminish by over a third, with coal falling by nearly half and natural gas by more than a quarter. The NZE Scenario is based on a substantial shift in the world energy supply, with low-emission sources growing by around 125 EJ by 2030.

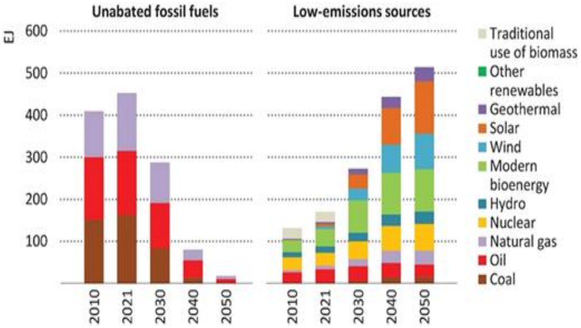


Figure 4. The NZE Scenario's 2010–2050 fossil fuel and low-emission energy supply [58].

3. Desalination Technologies

As indicated in Figure 5, desalination methods fall into two categories: desalination thermal processes or with phase change and desalination with membrane processes or single-phase methods. Multistage flash (MSF), multiple-effect distillation (MED), vapor compression (VC), and freezing are the phase-change desalination processes. Single- phase desalination methods include electrodialysis (ED), reverse osmosis (RO), membrane distillation (MD), and capacitive deionization (CDI). Multistage flash, reverse osmosis, electrodialysis, multiple-effect distillation, and hybrid technologies are economically viable and widely utilized desalination methods, accounting for 63%, 22%, 8%, 3%, and 3% of the market share, respectively [59].

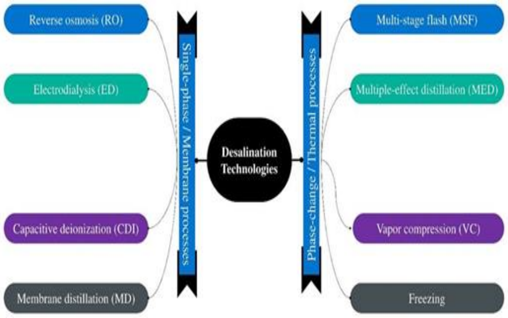


Figure 5.Different methods of water desalination.

3.1. Single-Phase Desalination

Hydraulic pressure and electricity are the main forms of energy required for membrane- based desalination. In this category, membrane distillation (MD), electrodialysis, and reverse osmosis are the most often employed technologies. In the RO procedures, high- pressure pumps must be driven by electricity or shaft power. Two streams are produced during the MD process: one cool, freshwater stream and one hot, salty stream. A tempera- ture differential between these two streams causes the transfer of water vapor. Mechanical pressure is used in the RO process to counteract osmotic pressure and extract salt from salty water. In the ED process, electricity is utilized to ionize the salts present in saltwater. With a water recovery rate of 80%, ED technology outperforms RO technology, which recovers between 40 and 50% of the water [60]. Capacitive deionization (CDI) is a revolutionary desalination process appropriate for low-salinity brackish water treatment. CDI technique functions by delivering a relatively low potential to transport ions from brackish water to a charged, porous electrode using static electrical force, thereby separating salt from brackish water [61].

3.2. Phase-Change Desalination

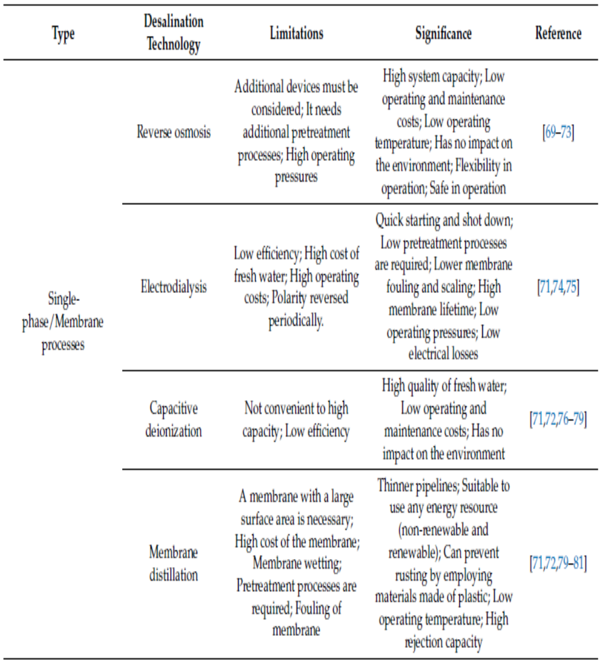
The mechanisms involved in thermal desalination are quite comparable to the standard approach for the formation of precipitation. In this process, salty water is heated to a temperature at which it evaporates into water vapor, and the resulting vapor is condensed to produce distilled water [62]. Multiple-effect distillation (MED), multistage flash (MSF), vapor compression, and freezing are the four steps that make up the thermal desalination process (VC). These technologies have a high price tag and need a technique that consumes a lot of energy. This energy might be either thermal or electrical. The traditional energy sources (products derived from petroleum) that were utilized to power such systems were the primary contributors to the emission of toxic gases, which led to an increase in the level of pollution [63]. According to Ghaffour et al. [64], around 70–80% of the globe’s desalination processes are utilizing two technologies: reverse osmosis (RO) and multistage flash (MSF). Multistage flash (MSF) units are widely used in the countries of the Middle East, such as the United Arab Emirates (UAE), Saudi Arabia, and Kuwait. Around 40% of desalination plants generate clean water by using multistage flash units (MSF). MSF and MED procedures both include a stage arrangement that takes place at progressively lower pressures and temperatures.

3.3. Hybrid Desalination

Typically, hybrid desalination facilities are found near power plants to utilize waste heat for the RO desalination plant and a thermal desalination facility (MED or MSF). Combined RO and thermal systems are often suited for significant seasonal or diurnal fluctuation in the request for electricity or water. In such nations, summer peak electricity consumption is 30 to 40% greater than winter peak electricity demand. This disparity reaches up to 50% in the Middle East, whereas demand for desalinated water remains nearly constant. Substituting between thermal and RO plants enables the utilization of inexpensive energy, resulting in the most affordable desalination process [65–67].

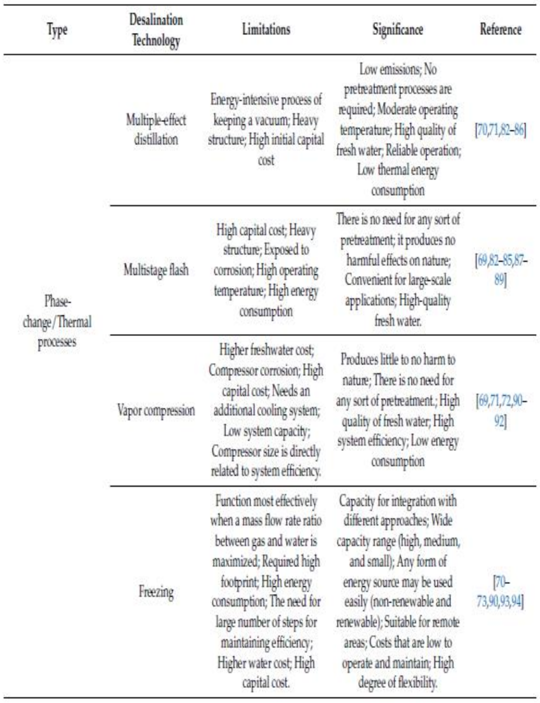
Table 1 outlines the principal advantages and downsides of various desalination systems. Thermal desalination technologies account for around 35% of the global market, while RO membrane technology accounts for over 61%. However, in Gulf Cooperation Council nations, thermal technology accounts for 70% of national desalination production, while RO membrane technology accounts for the remaining 30% [68].

Table 1. Limitations and significance of several water desalination technologies



Type	Desalination Technology	Limitations	Significance	Reference
Single-phase/Membrane processes	Reverse osmosis	Additional devices must be considered; It needs additional pretreatment processes; High operating pressures	High system capacity; Low operating and maintenance costs; Low operating temperature; Has no impact on the environment; Flexibility in operation; Safe in operation	[69–73]
	Electrodialysis	Low efficiency; High cost of fresh water; High operating costs; Polarity reversed periodically.	Quick starting and shot down; Low pretreatment processes are required; Lower membrane fouling and scaling; High membrane lifetime; Low operating pressures; Low electrical losses	[71,74,75]
	Capacitive deionization	Not convenient to high capacity; Low efficiency	High quality of fresh water; Low operating and maintenance costs; Has no impact on the environment	[71,72,76–79]
	Membrane distillation	A membrane with a large surface area is necessary; High cost of the membrane; Membrane wetting; Pretreatment processes are required; Fouling of membrane	Thinner pipelines; Suitable to use any energy resource (non-renewable and renewable); Can prevent rusting by employing materials made of plastic; Low operating temperature; High rejection capacity	[71,72,79–81]

Table 1. *Cont.*



Type	Desalination Technology	Limitations	Significance	Reference
Phase-change/Thermal processes	Multiple-effect distillation	Energy-intensive process of keeping a vacuum; Heavy structure; High initial capital cost	Low emissions; No pretreatment processes are required; Moderate operating temperature; High quality of fresh water; Reliable operation; Low thermal energy consumption	[70,71,82–86]
	Multistage flash	High capital cost; Heavy structure; Exposed to corrosion; High operating temperature; High energy consumption	There is no need for any sort of pretreatment; it produces no harmful effects on nature; Convenient for large-scale applications; High-quality fresh water.	[69,82–85,87–89]
	Vapor compression	Higher freshwater cost; Compressor corrosion; High capital cost; Needs an additional cooling system; Low system capacity; Compressor size is directly related to system efficiency.	Produces little to no harm to nature; There is no need for any sort of pretreatment.; High quality of fresh water; High system efficiency; Low energy consumption	[69,71,72,90–92]
	Freezing	Function most effectively when a mass flow rate ratio between gas and water is maximized; Required high footprint; High energy consumption; The need for large number of steps for maintaining efficiency; Higher water cost; High capital cost.	Capacity for integration with different approaches; Wide capacity range (high, medium, and small); Any form of energy source may be used easily (non-renewable and renewable); Suitable for remote areas; Costs that are low to operate and maintain; High degree of flexibility.	[70–73,90,93,94]

4. Geothermal Energy Used for Desalination Processes

Geothermal power is a form of renewable energy [95] that may be used with other sources. It is often found as steam or extremely hot water far below the Earth's surface [96]. It has potential use in power plants, such as steam generation and desalination of saltwater through alternative heat sources. An example of a geofluid is a liquid in heated form, which may be vapor or mixture that includes heat energy [97,98]. Concentrations of the most regularly found elements in geothermal water, such as Ca2+, Mg2+, Na+, K+, CO2, and CO3−, which are reflected by microelements. Important micropollutants include mercury (Hg), cadmium (Cd), arsenic (As), nickel (Ni), copper (Cu), zinc (Zn), lead (Pb), boron (B), iron (Fe), and silica (Si) [99]. The efficiency of geothermal wells, the composition of the rocks, the temperature and availability of geothermal fluid, and the presence of geofluids all have a role in the uniqueness of geothermal resources at different locations [9]. Using desalination plants running on geothermal energy means we can forego installing thermal storage facilities. Typically, yields are steady because of the continual temperature gradient [100], making this a preferable renewable energy source to geothermal compared to wind and solar power.

In distillation systems, the geofluid's enthalpy may be utilized for heating saltwater, and in integrated geothermal desalination, the geofluid's enthalpy may be utilized indirectly for providing electricity to run RO units [101]. A high-temperature geothermal energy desalination evaporator is driven by a main heat exchanger (HE). Once HE has absorbed the geothermal fluid's heat, it is reinjected into the Earth via an injection well. North and South America, Mexico, Central America, Caribbean, and parts of Africa and the Middle East are home to some of the world's most active geysers [102]. Depending on the temperature of the geothermal source, a variety of desalination techniques can be used with it [103]. Geothermal desalination, in which geothermal brines produce water and electricity, was first suggested and analyzed by Awerbuch et al. [104]. This process required the utilization of an evaporator, steam turbine, and MSF system. The separator redirected hot brine from a geothermal output well into a steam generator, where it was used to produce steam.

In 2004, plans were created to use desalination to provide power and supply fresh water to Greek island of Milos. This system was hybrid since it used both solar and low- enthalpy geothermal energy. A MED system is used to desalinate water at the facility, which has a capacity of around 80.0 m3/h. The ORC unit at this facility had thermal capability of 7%, allowing it to generate 470 kW of energy. The average price of producing 1 cubic meter of fresh water is 2 USD [101]. In 2008, a saltwater desalination facility in the Mexican state of Baja California was powered by geothermal energy. The multiflash heating system is the hybrid of the MSF and MED systems (MFWH). The plant output is maximized at around 1.0 m3/day at a input water of 14.0 m3/day of geothermal water available [100] when there

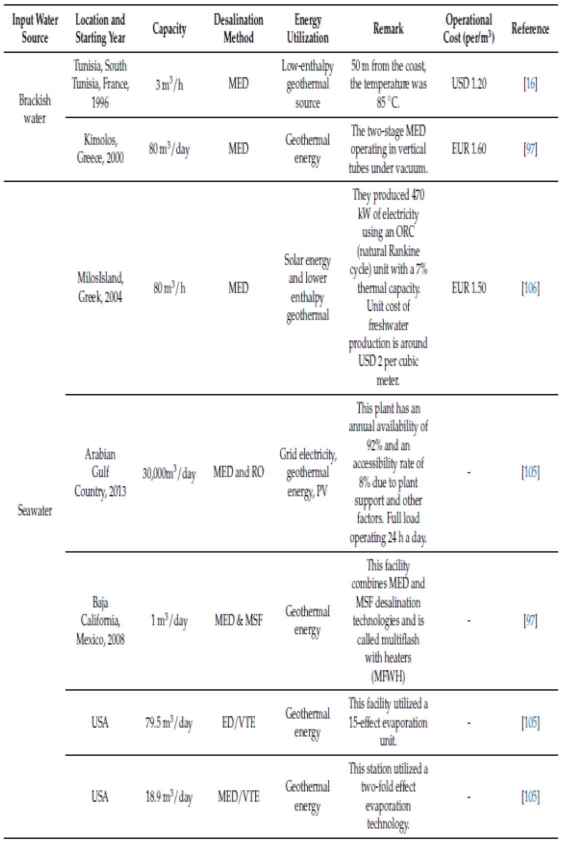
are 4 m3 of seawater available at 150 ◦C, a corresponding temperature of 80 ◦C, and 14.0 m3 of geothermal available water. As per Abdelkareem et al., in 2013, low-enthalpy geothermal energy was utilized in conjunction with two different geothermal desalination technologies (RO desalination and geothermal MED) to create desalted water. The geothermal RO and MED processes utilize heat of a geothermal dual power plant for creating 30,000 m3/day of drinkable water. In this instance, a combined RO and MED unit powered by geothermal heat is more operative at providing fresh water than a desalination unit by conventional energy sources. As can be seen, both of these techniques stay for showing potential as a low-cost means of desalinating seawater in the coastal regions of GCC nations [102].

One American firm ran many trials replicating treating variables in a 15.0 effect VTE system [83] as part of a pilot project involving geothermal energy. A VTE distilla- tion method, if implemented in the MED plant format using low-cost non-commercial geothermal heat as the energy source, may prove to be more economical than conventional desalination methods. Each pound of geothermal steam used by a 15.0 effect system has the potential to produce up to 14 pounds of fresh water. Using this technique, you can often recover 80% or more from the saltwater source. The salinity of the Salton Sea was reduced with the help of MED, which used a VTE distillation technique for geothermal desalination powered by electricity from a geothermal power plant. The consumption rates of the prototype and demonstration systems were 454 kg per hour and 79.50 m3 per day, respectively [105]. Karystsas outlines a study of a desalination system powered by lower enthalpy geothermal energy in Greek island of Milos. The proposed system links MEDs to a source of geothermal groundwater between 80 and 85 ◦C in temperature.

The research showed that lower enthalpy geothermal power might save an average of 5000.0 TOE/year for a specified plant capacity of 600.0–800.0 m3 per day of fresh water. Thermal desalination processes, including single-stage flash distillation (SF), MED, thermal vapor multistage flash distillation (MSF), and compression (TVC), would save a lot of energy since they require less energy for pre-heating [106]. Mahmoudi et al. [107] reported a geothermal-powered desalination technique for salty water. As a result of the dry and chilly climate, this approach is ideal for use in desert regions such as Algeria. Both the humidifying and dehumidifying of air were connected processes. Specifically, a field heat exchanger was incorporated for increasing a temperature of a geothermal fluids to a point where they could be desalinated using the predetermined condensing and evaporative surfaces. Desalinating fresh water from brackish water is most effective when using geothermal energy. In evaluating a potential project in Baja, California, Mexico, which would use geothermal energy sources, an integrated arrangement like an MSF and a MED unit system was considered. At 80 ◦C, the geothermal energy source is usable as a heating system. The optimal ratio of fresh water to geothermal source water for this kind of heating was determined to be 1 to 14. A further study looked at a coastal MSF–MED- style geothermal desalination plant. A geothermal source temperature of 80 ◦C was used throughout development and verification of the model. According to this research, there is just one freshwater source for every 5.9 geothermal ones [96].

From a geothermal “production well” and back into a ground via “injection well,” it is clear that the geofluid flowed in the HE. The scalability problem may be addressed in one of two ways: either by heating the desalination system directly with geothermal energy or by heating the desalination framework indirectly with geothermal energy via a heating medium loop, such as an ORC [101].Table 2 shows the global status of desalination stations employing geothermal energy resources.

Table 2. Various desalination stations employing geothermal energy resources.



Input Water Source	Location and Starting Year	Capacity	Desalination Method	Energy Utilization	Remark	Operational Cost (per/m^3)	Reference
Brackish water	Tunisia, South Tunisia, France, 1996	3 m^3/h	MED	Low-enthalpy geothermal source	50 m from the coast, the temperature was 85 °C.	USD 1.20	[16]
	Kimolos, Greece, 2000	80 m^3/day	MED	Geothermal energy	The two-stage MED operating in vertical tubes under vacuum.	EUR 1.60	[97]
Seawater	MilosIsland, Greek, 2004	80 m^3/h	MED	Solar energy and lower enthalpy geothermal	They produced 470 kW of electricity using an ORC (natural Rankine cycle) unit with a 7% thermal capacity. Unit cost of freshwater production is around USD 2 per cubic meter.	EUR 1.50	[106]
	Arabian Gulf Country, 2013	30,000m^3/day	MED and RO	Grid electricity, geothermal energy, PV	This plant has an annual availability of 92% and an accessibility rate of 8% due to plant support and other factors. Full load operating 24 h a day.	-	[105]
	Baja California, Mexico, 2008	1 m^3/day	MED & MSF	Geothermal energy	This facility combines MED and MSF desalination technologies and is called multiflash with heaters (MFWH)	-	[97]
	USA	79.5 m^3/day	ED/VTE	Geothermal energy	This facility utilized a 15-effect evaporation unit.	-	[105]
	USA	18.9 m^3/day	MED/VTE	Geothermal energy	This station utilized a two-fold effect evaporation technology.	-	[105]

5. Significance, Need, and Important Parameters for Associated with Geothermal Desalination

5.1. Significance of Geothermal Desalination

Using geothermal energy in the variation of residential and commercial environments has numerous advantages. Electricity generation, district cooling and heating, and manu- facturing applications are all areas where geothermal energy has been demonstrated as a successful and widely used commercial technology [103,108].

The technology for extracting heat from subterranean aquifers (geothermal production) is now at a high level of development. It remains untouched by the changing seasons or the whims of the weather. The high-capacity factor of geothermal energy sources guarantees a consistent heat supply for thermal desalination and reverse osmosis (RO). What we mean by "capacity factor" is the degree to which we have access to a sufficient quantity and quality of a resource for a given time. Desalination with geothermal energy can save money and can generate both electricity and water at the same time. Low-temperature multi-effect desalination (MED) is ideally suited to the typical geothermal source temperatures seen in most regions of the world (70–90 ◦C). Power plants and industrial processes often use high-quality heat sources with temperatures over 100 ◦C. (vi) In addition to bolstering local energy security and environmental sustainability, the fossil fuels saved by geothermal desalination may be put to better use elsewhere. As the only renewable energy source, geothermal desalination produces no emissions of air pollutants or greenhouse gases from its use. If you are looking for a renewable energy source that can meet the needs of utilities of all sizes, look no further than geothermal power.

5.2. Need of Geothermal Desalination

5.2.1. Efficient Resource Utilization

Energy necessities of various desalination procedures may be met by the wide range of renewable energy sources. Wind energy, solar energy, wave energy, and geothermal energy are all well-explored and utilized options for desalination at present [97]. Depending on conversion technology used and the specifics of the end process, these materials can be used sustainably or not. Using the given energy supply effectively is one definition of sustainability. Sustainable energy usage is the outcome of a variety of measures, including conservation, recycling, and improvements to conversion technology. For example, the amount of solar energy available on Earth's surface every day is about 15,000 times greater than amount of energy used by entire human populace every day [109]. However, only a tiny fraction of that energy, less than 0.001%, could be used to solve the world's energy problems. However, the greatest energy conversion rate of commercially available solar modules has not yet risen over 25% [110]. Geothermal sources are a good and efficient option since they may be used for power and heat production with low waste.

5.2.2. Comparable Costs

When compared to both renewable and non-renewable sources, geothermal energy generation holds its own advantages [111]. Power plants fueled by geothermal sources have electricity costs that are competitive with those of hydroelectric plants, biomass, and wind [112]. The range aligns with what is often spent on conventional energy sources such as oil, natural gas, and coal. This shows that it may be an economical means of powering water production to create electricity or thermal energy from geothermal sources.

5.2.3. Capacity Factor

Geothermal energy is reliable in both quantity and quality, unlike other renewable energy sources. If used in a closed-loop system, geothermal power is theoretically limitless. Geothermal sources offer a wide range of temperatures, making them suitable for a wide variety of industrial processes. Integrated designs may be used in these programs to bring value beyond only aiding the desalination procedure. District heating, air conditioning, and process cooling and heating are possible advantages. The capacity factor, connected to amount and quality of energy source's availability, is another crucial aspect of geothermal sources. Efficiency is the ratio of the amount of energy a system actually produces to the amount of energy that can be produced by the system. When thinking about how technology may be scaled and put into practice, the capacity factor is a crucial consider- ation to have in mind. The capacity factor of a geothermal source is higher than that of sun, wind, and biomass. Figure 6 displays capacity factors for many alternative energy sources [111,113].

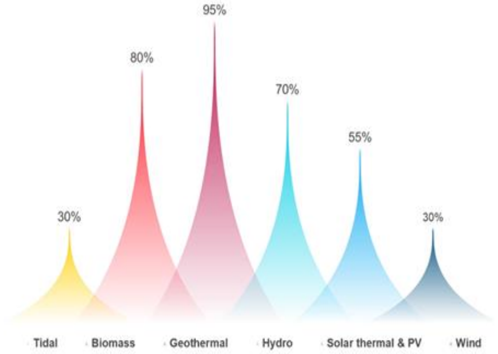


Figure 6. Reported capacity factor ranges (%) for several renewable sources.

It is possible for external influences, such as variations in the power market, to affect the capacity factor for a resource [111,114]. The quantity of energy that can be harvested from solar sources is bounded by the harvesting capacity of materials and process equipment. Likewise, the mechanical efficiency of the electrical energy converter and turbine unit will reduce the wind energy collection potential. Because of fluctuations in weather and the availability of other resources, such as water and land, biomass supplies fluctuate throughout the year. It is important to note that geothermal sources are not immune to these limitations, but they are somewhat less severe. Several factors might affect the capacity factor for geothermal sources, including limited resources, a blocked well, a shift in subsurface situations, and a decrease of available water.

5.2.4. Savings of Energy in Geothermal Applications

Cost cutting on energy use is difficult with conventional renewables [115]. Besides, providing process heat, cooling, and desalination may all be accomplished with the help of geothermal resources. Geothermal sources at 130 ◦C, 115 ◦C, and 100 ◦C are related to cost reductions for USD 90/bbl and USD 40/bbl oil prices. Based on these numbers, it is clear that using geothermal sources at 130 ◦C, 115 ◦C, and 100 ◦C might save you up to 50%, 66%, and 75%, respectively. The potential for electricity savings in various cooling applications is also evaluated by contrasting electricity-driven decentralized operating at 130 ◦C, 115 ◦C, and 100 ◦C [116]. This analysis revealed that geothermal sources at 130 ◦C, 115 ◦C, and 100 ◦C might provide a 62%, 50%, and 45% reduction in power use, respectively. MED with geothermal sources and Hybrid MED with seawater reverse osmosis (SWRO) at 130 ◦C, 115 ◦C, and 100 ◦C as heat sources will save 46%, 85%, 88%, and 89%, respectively, as compared to conventional MED [16,116]. The MED unit is compared to the MSF process since it uses less thermal energy and lower enthalpy geothermal sources are a possibility worldwide.

5.3. Important Parameters Associated with Geothermal Desalination

When choosing a desalination method appropriate for use with geothermal energy, it is vital to keep in mind the following criteria [117,118]. In geothermal desalination, it is important to keep in mind the factors shown in Figure 7.

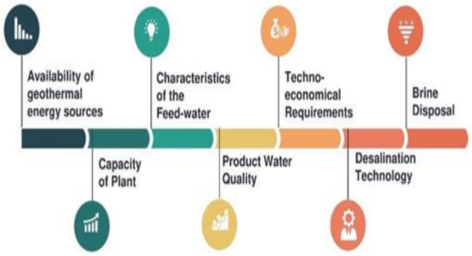


Figure 7.The important parameters in Geothermal Desalination.

5.3.1. Availability of Geothermal Energy Sources

Desalination plant design, economics, and capacity all hinge on a results of the survey of possible geothermal water sources. Geothermal waters' chemical and physical properties are essential in planning a heat extraction and usage strategy [119]. Low-temperature desalination techniques, such as those detailed in the case studies, are compatible with low-temperature geothermal fluids, whereas high-temperature geothermal waters are ideal for cogeneration schemes. In a scenario where integrated and mixed energy sources are desired for process flexibility, other renewable energy sources such as solar, wind, wave, and biomass should also be explored. There has to be a way to evaluate the potential thermal- and electrical-generating capacity and storage capacities of solar and wind energy.

5.3.2. Capacity of the Plant

The amount of water needed, the feedwater concentration, the sources available, and water storage space all factor into the overall plant size. The size of a desalination plant can be reduced by including a bypass flow into the design if a quality of a feedwater is good. To assess a viability of desalination in a given area, it is necessary to first undertake an assessment of the accessible feedwater sources. Identifying feedwater sources of sufficient quality and quantity is an important step in the desalination process. The water demand per capita may be approximated, and from there, the daily plant capacity can be calculated using data on the community's water consumption patterns over time. If there is a lack of water demand data, regional statistics can be utilized as an alternative.

5.3.3. Characteristics of Feedwater

Before settling on a desalination method, it is important to analyze the feedwater's qualities. Membrane procedures can be preferred if low-concentration TDS feedwater is readily accessible. For this reason, the temperature of the geothermal energy source is also a factor to consider. Combinations of lower temperature geothermal energy and lower TDS groundwater are amenable to nanofiltration and RO technologies. A preferable option for low TDS feedwater may be the electrodialysis method. When high-quality geothermal waters are readily available, MSF or MED methods are chosen for treating high TDS concentrations. Low geothermal water temperatures are suitable for the SWRO process.

5.3.4. Product Water Quality

Ultimately, the product's intended function should inform the level of quality that is required. High-quality distillates, such as those generated by thermal desalination facilities, may be required in several industrial operations. Membrane techniques may turn low TDS seawater into drinkable water. Product water's criteria can be satisfied with a stable procedure setup, and blending alternatives can be explored. High-quality drinkable waters shall not be necessary for further fish farms, agricultural, and animal feed enterprises. The costs associated with desalination techniques may make their agricultural uses unfeasible.

5.3.5. Techno-Economical Requirements

The desalination method relies heavily upon energy sources and desalination energy requirements. Taking into account the aforementioned data on how well energy needs of desalination procedures fit a quality and kind of geothermal sources, the method with the lowermost energy footmark while maintaining reliability and strong performance may be selected as a freshwater source alternative. When doing a techno-economic analysis, it is important to remember that the feedwater's concentration and temperature are linked to the process's performance to heat losses, performance ratio, and other monetary and operational factors.

5.3.6. Desalination Technology

Geothermal energy sources properties, like flow capabilities and temperature, in- form the selection of a suitable desalination method (thermal or membrane process) [85]. Feedwater quality (such as salinity), plant size, technical preparedness of the community, maintenance skills for the desalination plant, infrastructure, renewable energy sources, geographical isolation, grid electricity availability, and local climate all play an important part in the decision-making procedure. Small-scale desalination techniques can benefit from low-temperature geothermal sources, including membrane distillation, humidification, humidification–dehumidification, and higher temperature RO. Because of the higher temperature of geothermal waters, desalination may be combined with power generating in cogeneration schemes.

5.3.7. Brine Disposal

Any desalination facility would face challenges, including the disposal and management of brine. Desalination facilities located inland would need to consider alternative waste management and disposal strategies than those on the coast. Desalination from freshwater sources was shown to have fewer negative effects on the environment than desalination from saltwater sources. Coastal desalination facilities typically use seawater discharge, whereas inland plants might benefit from evaporation ponds or sewage discharge. There are ways to improve water recovery and reduce waste brine disposal problems, but they come at a greater cost and need special "zero liquid discharge" arrangements.

6.Challenges Associated with Development of Geothermal Energy

The goal of sustainable development energy policy is to promote energy security and economical growth without negatively impacting the natural environment. Green renewable energy like geothermal plants are important in this regard since the use of fossil fuels, a primary source of emissions and, thus, environmental degradation, is fast declining. Sustainable growth of geothermal energy requires the implementation of a set of rules, regulations, and decrees covering topics such as financial assistance, environmental protection plans, fines, and rewards. Investors in every industry need certainty that policies will be consistently implemented. Therefore, countries all over the world should create energy strategies, policies, programs, and development plans; make sure that decision makers in the energy segment apply them fairly; and see projects over to fruition.

Government plays a crucial role in advancing state-of-the-art processes, especially in the areas of R&D and the implementation of technological systems for the advancement of direct-use technologies in the field of geothermal energy production. Higher device performance and reliability can be achieved by supporting initiatives to improve the manufacturing process and produce equipment utilized for geothermal energy.

A crucial factor in advancing geothermal usage in the country is the establishment of international collaboration to bolster technical communication, exchanges, support, partnerships, and relations. Hence, private and public institutes should be fortified to work together internationally through multilateral or bilateral provisions with nations that have comparatively additional geothermal energy technologies, like United States, New Zealand, Turkey, Italy, and Iceland, to stay abreast of the latest policy, programs, and projects and to promote the geothermal energy market internationally.

In order to facilitate educational programs and scientific research, a wide variety of institutions and organizations, including technical academic universities, have been devel- oped. While geothermal energy and other renewable energy sources have great potential, current implementation methods lag far behind the worldwide best practices. In order to foster the development of future technology ownership, appropriate geothermal tech- nologies, and ultimately marketable applications, establishments should deliver economic grants.

The primary cause for poor progress in geothermal study is the apparent lack of professional, scientific, and skilled practical people in a country. Therefore, it is important to invest in the education and development of the geothermal workforce and to fortify the human capacities necessary for effective exploration, development, and application of these resources. To achieve this goal, it is necessary to work with leading scientists from leading universities and institutions worldwide who play the pivotal role in geothermal technology education and training programs. The goal of this collaboration is for the technical and professional staff to be able to drill for geothermal resources at the surface, monitor geothermal reservoirs, and assess the potential environmental implications of geothermal energy. As a result, this would aid in expanding domestic knowledge and finding indigenous answers to geothermal development challenges.

Unfortunately, most people today know little to nothing about geothermal power. The advancement of geothermal energy consumption via suitable technology is thus heavily reliant on public knowledge and acceptance. This may be done in a number of ways, including holding public scientific and awareness conferences, funding round tables, and creating a cutting-edge technology-based website to aggregate and update information on growth of geothermal energy resources into a nation. Within the context of sustainable development, substantial laws, regulations, and measures for financial assistance for geothermal energy projects should be devised and implemented. To assure the continued growth of geothermal infrastructures, technologies, and project installations, financial incentives such as tax breaks, financial subsidies, and feed-in tariff will be implemented.

7.Conclusions and Scope for Future Work

Increases in water purification processes for producing potable water from saltwater, brackish groundwater, water tainted with various inorganic or organic contaminants, or sewage are inevitable in the face of a growing global need for water. While there are several methods for treating saltwater at once, one of the biggest drawbacks is the enormous amount of energy required to run the desalination plant's motor. There are a few potential solutions to a worldwide problem of energy and water sustainability. Options such as using low-grade or waste heat sources, are included in this category. Consequently, low-carbon technology, energy security, and sustainable development have become more central to public and political debates. Geothermal energy is a cleaner renewable form of energy that may be utilized on a local scale without requiring long-distance transmission lines or expensive infrastructure upgrades. It also has a low carbon footprint and helps mitigate the environmental damage caused by fossil fuel power plants.

When comparing with other renewable energy sources, geothermal energy provides a more constant heat flow, making it a viable option for the power desalination framework. The Middle Eastern distillation method (MED) works well with geothermal energy. The excellent quality fresh water they generate has put geothermal desalination facilities out of business. The major disadvantage or difficulty of using geothermal energy to power desalination plants is that availability of geothermal heat is restricted into region. It is important to note, geothermal energy is not impacted by the elements in the same way as other renewable energy sources. It is suitable for baseload uses due to its built-in storage. Making potable water from lower enthalpy geothermal resources appears to be the perfect use of the MED method. While the plant is functioning, it has little effect on the surrounding environment. When coupled with a geothermal power plant, the MED method can boost performance by reusing waste heat, resulting the cutting back considerably on fossil fuels. Sustainability has vastly improved across the board.

Finally, geothermal energy's enormous potential on our planet is being fully realized. Providing the right amount of power could regulate a desalination system for either saltwa- ter or brackish water. There needs to be a more thorough assessment of the global opportu- nities for lower to medium-enthalpy geothermal liquids, integrating recognized thermal desalination technologies with emergent technologies, developing complex geothermal integrated desalination upon marketable scale, and the performance of extensive economic modeling to analyze all of these factors. Finally, it may be understood that an answer to a global water shortage is to be environmentally friendly and use less of it. One of the biggest problems people face nowadays is this.

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REFERENCES

1. Singh, A.; Panda, S.N.; Uzokwe, V.N.E.; Krause, P. An Assessment of Groundwater Recharge Estimation Techniques for Sustainable Resource Management.Groundw. Sustain. Dev. 2019, 9, 100218. [CrossRef]
2. Sonawane, C.R.; Panchal, H.N.; Hoseinzadeh, S.; Ghasemi, M.H.; Alrubaie, A.J.; Sohani, A. Bibliometric Analysis of Solar Desalination Systems Powered by Solar Energy and CFD Modelled. Energies 2022, 15, 5279.
3. Swain, S.; Taloor, A.K.; Dhal, L.; Sahoo, S.; Al-Ansari, N. Impact of Climate Change on Groundwater Hydrology: A Comprehensive Review and Current Status of the Indian Hydrogeology. Appl. Water Sci. 2022, 12, 120. [CrossRef]
4. Mpandeli, S.; Naidoo, D.; Mabhaudhi, T.; Nhemachena, C.; Nhamo, L.; Liphadzi, S.; Hlahla, S.; Modi, A.T. Climate Change Adaptation through the Water-Energy-Food Nexus in Southern Africa. Int. J. Environ. Res. Public Health 2018, 15, 2306. [PubMed]
5. Essa, F.A.; Elsheikh, A.H.; Algazzar, A.A.; Sathyamurthy, R.; Kamal, M.; Ali, A.; Abd, M.; Salman, K.H. Eco-Friendly Coffee-Based Colloid for Performance Augmentation of Solar Stills. Process Saf. Environ. Prot. 2020, 136, 259–267. [CrossRef]
6. Feria-Díaz, J.J.; López-Méndez, M.C.; Rodríguez-Miranda, J.P.; Sandoval-Herazo, L.C.; Correa-Mahecha, F. Commercial Thermal Technologies for Desalination of Water from Renewable Energies: A State of the Art Review. Processes 2021, 9, 262.
7. Belkhode, P.N.; Shelare, S.D.; Sakhale, C.N.; Kumar, R.; Shanmugan, S.; Soudagar, M.E.M.; Mujtaba, M.A. Performance Analysis of Roof Collector Used in the Solar Updraft Tower. Sustain. Energy Technol. Assess. 2021, 48, 101619. [CrossRef]
8. Greco, A.; Gundabattini, E.; Solomon, D.G.; Singh Rassiah, R.; Masselli, C. A Review on Geothermal Renewable Energy Systems for Eco-Friendly Air-Conditioning.Energies 2022, 15, 5519.
9. Ahmadvand, S.; Abbasi, B.; Azarfar, B.; Elhashimi, M.; Zhang, X.; Abbasi, B. Looking Beyond Energy Efficiency: An Applied Review of Water Desalination Technologies and an Introduction to Capillary-Driven Desalination. Water 2019, 11, 696. [CrossRef]

10. Milousi, M.; Pappas, A.; Vouros, A.P.; Mihalakakou, G.; Souliotis, M.; Papaefthimiou, S. Evaluating the Technical and Environ- mental Capabilities of Geothermal Systems through Life Cycle Assessment. Energies 2022, 15, 5673.
11. Lee, K.P.; Arnot, T.C.; Mattia, D. A Review of Reverse Osmosis Membrane Materials for Desalination—Development to Date and Future Potential. J. Memb. Sci. 2011, 370, 1–22. [CrossRef]
12. Huang, B.; Pu, K.; Wu, P.; Wu, D.; Leng, J. Design, Selection and Application of Energy Recovery Device in Seawater Desalination: A Review. Energies 2020, 13, 4150. [CrossRef]
13. Bundschuh, J.; Kaczmarczyk, M.; Ghaffour, N.; Tomaszewska, B. State-of-the-Art of Renewable Energy Sources Used in Water Desalination: Present and Future Prospects. Desalination 2021, 508, 115035. [CrossRef]
14. Do Thi, H.T.; Pasztor, T.; Fozer, D.; Manenti, F.; Toth, A.J. Comparison of Desalination Technologies Using Renewable Energy Sources with Life Cycle, PESTLE, and Multi-Criteria Decision Analyses. Water 2021, 13, 3023. [CrossRef]
15. Kabeel, A.E.; Sathyamurthy, R.; Manokar, A.M.; Sharshir, S.W.; Essa, F.A.; Elshiekh, A.H. Experimental Study on Tubular Solar Still Using Graphene Oxide Nano Particles in Phase Change Material (NPCM's) for Fresh Water Production. J. Energy Storage 2020, 28, 101204. [CrossRef]
16. Prajapati, M.; Shah, M.; Soni, B.; Parikh, S.; Sircar, A.; Balchandani, S.; Thakore, S.; Tala, M. Geothermal-Solar Integrated Groundwater Desalination System: Current Status and Future Perspective. Groundw. Sustain. Dev. 2021, 12, 100506. [CrossRef]
17. Jia, X.; Klemeš, J.J.; Varbanov, P.S.; Wan Alwi, S.R. Analyzing the Energy Consumption, GHG Emission, and Cost of Seawater Desalination in China. Energies 2019, 12, 463. [CrossRef]
18. Sakamoto, H.; Ronquim, F.; Seckler, M.; Kulay, L. Environmental Performance of Effluent Conditioning Systems for Reuse in Oil Refining Plants: A Case Study in Brazil. Energies 2019, 12, 326. [CrossRef]
19. Jones, E.; Qadir, M.; van Vliet, M.T.H.; Smakhtin, V.; Kang, S. The State of Desalination and Brine Production: A Global Outlook. Sci. Total Environ. 2019, 657, 1343–1356. [CrossRef]
20. Tomaszewska, B.; Szczepan´ski, A. Possibilities for the Efficient Utilisation of Spent Geothermal Waters. Environ. Sci. Pollut. Res.2014, 21, 11409–11417. [CrossRef] [PubMed]