Sustainable desalination as a Water Source for the Western Cape

A Consultancy Report

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Abstract

Western Cape, South Africa is currently facing great challenges trying to deal with the rapidly shrinking water sources for the industry and public. Day Zero marks the day when the capital city Cape Town completely runs out of water. To slow down the arrival of Day Zero the government implemented strict rules on water usage. However, new water sources must be found to create a long term solution. This report focuses on the possibility of using desalination to create drinking water using the constant availability of seawater. Multiple desalination systems using thermal and membrane based technologies will be introduced and evaluated considering the situation in Western Cape. The highest focus in the evaluation is paid to the energy consumption, the cost, running time and capacity of these technologies in respect to the requirements of the Western Cape.

Thermal desalination technology is concluded to be too energy consuming for the implementation in the Western Cape, even though these technologies account for a large portion of today's desalination plants. Thermal processes relying on renewable energies to lower the operational costs seem to be in an early stage of research or only applicable for small scale implementation. Membrane desalination technology has a lower energy consumption, as the aggregation state of the water is not changed. In comparison to other countries using desalination and current results in research, reversed osmosis is considered as the best fitting option for Western Cape. In regards to long-term implementation, sustainable alternative sources of energy are considered in combination with the desalination plants. Long-term, large scale wind-powered seawater reverse osmosis plants are concluded to have the greatest benefits in cost-effectiveness compared to other systems and, hence, it proposed as the most viable solution.

Key Words: Seawater Desalination, Western Cape, Sustainability

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1 Introduction

Cape Town, South Africa, is experiencing a severe lack of water and day zero is approaching, which would be the day that the city is forced to turn off its water outlets across the city [1]. In face of this threat, the South African city has to find an effective long-term solution to the water crisis [2]. The high reliability of Western Cape on dams as fresh water sources brings its own problems, such as the dependency on decreasing rainfall. Factors such as water pollution and climate change will make the water supply more difficult in the future, which can already be observed today: in the week of the 23rd of April 2018, the average daily production of all water sources in the city of Cape Town was 507 000 m^3/day and the average daily collection of "The Western Cape Water Supply System", WCWSS, large dams was only 476 000 m^3/day [3]. 94% of Western Cape's water supply is dependent on large dams. Further decrease in rainfall and evaporation of the stored water endangers this source. Therefore, Cape Town cannot rely only on these dams anymore, and new water sources must be found.

The total coastline of South Africa is over 2500 kilometers, and the seawater would offer an almost infinite supply of water which does not dependent on rainfall. The desalination of seawater in order to extract useful drinking water is a solution for cities like Cape Town, which have limited natural freshwater resources and are located close to the sea. However, this technique is not undisputed. The desalination of seawater is regarded as energy intensive and polluting, due to the production of highly saline and polluted wastewater [4]. For this reason, critics do not necessarily regard seawater desalination in large plants as a suitable instrument to counteract water scarcity [5]. Rather, they focus on the sparing use of water, modern water management, the renovation of drinking water networks or the treatment of wastewater. However, the desalination of water in arid areas is currently arguably the only available method to secure the freshwater supply of the population [6]. So in areas like Cape Town, which are threatened by a severe lack of available water, desalination could be the solution [7].

All desalination plants currently implemented in Western Cape use Reverse Osmosis, RO, desalinate seawater. These RO plants are not seen as a permanent solution to the water crisis, as most contracts for the plants run out after two years when the plants will be demolished by the company in charge. South Africa has multiple small to medium sized plants in different regions [2]. This is necessary due to the weak water infrastructure that is not adapted to the new technology. Each smaller plant only generates water for that specific region located at the coast. One of the largest SWRO plants of Western Cape is situated in Mossel Bay with a capacity of 15.000 m^3 /day of which $\frac{2}{3}$ are destined for domestic use while $\frac{1}{3}$ goes into the industry [8]. On a world scale, this is a medium sized SWRO plant [9]. The whole project costs around 210 Million ZAR ($\tilde{1}$4 Million Euro) [8]. For comparison, the SWRO plant in Spain produces 200.000 m^3/day and was build for 230 Million Euro [2].

Time and cost constraints are key criteria for the construction of new desalination plants in Western Cape. As day zero is approaching, which is calculated to happen in August 2019 [10], solutions have to be found and implemented within a decreasing time frame. Furthermore, due to the decreasing financial means of South Africa, partly caused by the drought [11], a high focus needs to be paid in increasing the cost-efficiency of possible solutions. The means for the initial investment of desalination plants and for the production of water are relatively limited when compared to countries which currently use desalination technology [12]. In addition, the water distribution in Western Cape can be described as problematic, due to high water loss and unequal distribution [4]. As this report is focusing on desalination technology, the distribution of the water will be neglected.

1.1 Global Situation

Cape Town's water crisis can be compared to a number of other countries, which implemented desalination plants after the first attempts to desalinate water in 1600 and the world's first commercial traditional desalination plant built 1881 in Malta [13]. Nowadays, there are three countries that use desalination extensively and, therefore, can be taken as an example for Cape Town: Saudi Arabia, Spain, and Israel. All three countries were able to increase their drinking water production by desalination in a timely and cost-effective way [2].

In Saudi Arabia, the Ras Al Khair hybrid desalination plant has a drinking water output of 1036000 m^3/ day [14]. This plant was built between 2011 and 2014 and had a total cost of 7.2 billion US dollars [14]. This kind of system, a hybrid desalination plant, relies on both multi-stage flash distillation and reverse osmosis technology [2]. The multi-stage flash desalination has been the most common within the desalination industry with a market share of close to 60% of the total world production capacity in 1999 [15]. However, due to its reliance on the thermodynamic cycle, this hybrid method is more energy intensive compared to other methods [2]. Nonetheless, Ras Al Khair is the biggest desalination plant of its kind, capable of serving approximately 3.5 billion people in the city of Riyadh.

In response to a drought in 2006 , Barcelona built a seawater desalination plant with a drinking water output of 200 000 m^3 / day [16]. It supplies drinking water to around 1.3 million people in the region [17]. Hence, this system has a lower drinking water output as the Ras Al Khair hybrid desalination plant. However, the system is less energy intensive due to the use of reverse osmosis technology [18], which also makes it more feasible for the government to implement. To improve the sustainability of this plant more than 5200 photovoltaic modules are installed on the roofs which generate around 1 MW of electricity annually [2], see figure 1.

The Sorek desalination plant located in Israel has a drinking water output of 624 000 cubic meters per day [19]. It is the largest seawater reverse osmosis desalination plant in the world and opened in 2013 at a construction cost of around USD $500 million [20]. As such, it is the largest and most cost efficient reverse-osmosis desalination plant in the world. The desalination plant in Tel Aviv profitably sells water to the water authority located in Israel for 58 U.S. cents per cubic meters, which is a lower price than most of today 's desalination plants can provide. Furthermore, its energy consumption is among the lowest in the world for large-scale desalination plants [20].

Figure 1: Desalination Plant Barcelona [17]

Overall, there is an ever growing number of desalination plants with around 18.000 desalination plants worldwide in June 2015, which are able to produce more than 86.8 million cubic meters of drinking water each year for more than 300 million people which relying on them [21]. All of them could be an example for Cape Town, helping to find a suitable desalination technology and overcoming the lack of water.

This consultancy report summaries the different kinds of desalination technologies that can be used as a solution to the water scarcity in Cape Town, of which some are already in use, and others are in a developing phase. The focus is to find a suitable desalination technology for the city, which for example could result in multiple small scale or one large scale desalination plant as the perfect solution. This report limits itself to industrial desalination plants, as the eventual solution should be able to generate drinking water for the whole city of Cape Town. After the working of different types of technologies have been be discussed, the technologies will be evaluated and compared to the situation in the Western Cape to find applicable technologies. In consideration of these findings, this report will give an in-depth explanation and evaluation implementation. The related opportunities and challenges of the technologies, desalination as a whole, as well as the environmental and social aspects will be discussed. The report will end with a summary and proposed outlook to the future implementation of desalination plants in Cape Town.

2 Theoretical Background

Desalination technologies use energy to separate the dissolved salts from the water. This leads to two end products, one being the desired fresh water and the other being a concentrated salt water, brine stream [22]. The United State Geological Survey (USGS) [23], uses the following classifications for dissolved salts in water:

Water classification	**Salt concentration in parts per million**
Fresh water (drinking water)	> 1,000 ppm
Slightly saline water	1,000 ppm - 3,000 ppm
Moderately saline water	3,000 ppm - 10,000 ppm
WHighly saline water (seawater)	10,000 ppm - 35,00 ppm

The following section lists the most common procedures divided in thermal and membrane based processes and in order of economic importance in each part. A thermal process, namely multi-stage flash evaporation (MSF), is the most widely used for a large scale applications. However, reverse osmosis, a membrane process, is widely regarded as the most promising technology in future use.

2.1 Thermal Technology

2.1.1 Principle

Thermal technologies, as the name implies, involve the heating of saline water and collecting the condensed vapor (distillate) to produce pure water [24]. What remains is a salt brine, which is reintroduced into the sea. In order to evaporate water, it must have a suitable temperature, which in turn depends on the ambient pressure. If the water stops to evaporate, either more heat or a lower ambient pressure can be supplied. The specific enthalpy of evaporation of water is significantly high, as it takes 700 kWh [25], which is almost the average energy use of an american family household per month [26], to evaporate one cubic meter of water. To reduce the energy required, multiple chambers are vaporized in succession, each operating at a slightly lower temperature and pressure. The three most important thermal processes are Multi Stage Flashing (MSF), Multi Effect Distillation (MED), and Vapor Compression Distillation (VCD) [24].

2.1.2 Multi-Stage Flash Distillation (MSF)

The Multi Stage Flash process was the first desalination process used on an industrial scale in 1960. Today, it still accounts for a large share of the global output [22]. This process involves distillation through several (multi-stage) chambers, see figure 2. First, the seawater flows through a heat exchanger into the heater, where it is brought to a temperature of 90 to 115 °C. It then flows into a chamber with a lower pressure, where it evaporates. The water vapor condenses at the coldest part of the chamber - the heat exchanger - recovering part of the energy needed for the evaporation.

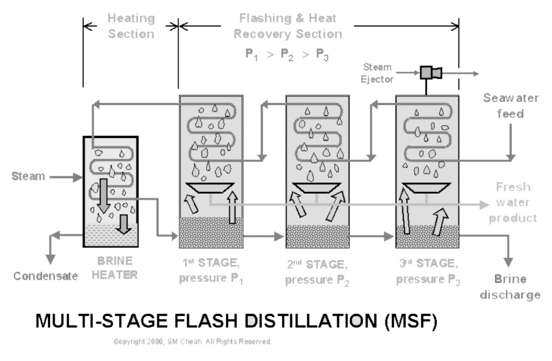

Figure 2: Simplified structure of the Multi-Stage Flash Distillation Process [27]

The remaining brine flows into the evaporator chamber of the next stage, in which an even lower pressure and a lower temperature prevail. This process is repeated, with decreasing pressure and temperature from stage to stage, so that in each evaporator chamber, a flash evaporation takes place [28]. In the upper part of each stage, the steam is condensed on a cooler surface and the distillate is withdrawn. The plants currently in operation typically have 20 to 40 stages depending on the targeted size [29].

2.1.3 Multi-Effect Distillation (MED)

In multi-effect distillation, the seawater is first heated to a temperature of about 65 ° C [28]. In the chamber of the first stage the seawater is trickled along the outside of heated evaporator tubes, on which the water partly evaporates, see figure 3. This steam is supplied into the tubes of the second stage and condenses in them with heat release. The remaining brine of the first stage is sprinkled on the evaporator pipes of the second stage from the outside. Due to the lower pressure level in the second stage chamber, some of the trickling brine evaporates again. This process repeats until the last stage with the highest salt concentration, the lowest pressure and the lowest temperature is reached. The number of stages is between 8 and 16 depending on the size of the plant [30]. MED systems have a better energy efficiency due to a higher energy recovery by reusing the released heat in the condensation process for evaporating the remaining water. However, despite the better efficiency of the MED systems, they have not been able to prevail over the MSF technology. On the one hand, this is due to the developmental advantage of the MSF technology, which resulted from the longer existence of this technology [30]. On the other hand there have been problems with the incrustation of the heating surfaces in the past [31].

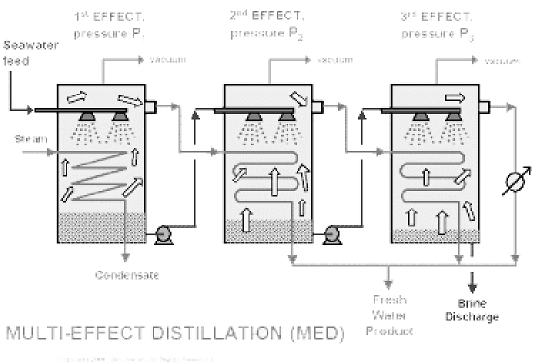

Figure 3: Simplified structure of the Multi-Effect Distillation Process [27]

2.1.4 Vapor Compression Distillation (VCD)

In the vapor-compression system, heat is provided by the compression of vapor rather than by a direct heat input from a boiler [32]. When the vapor is rapidly compressed, its temperature rises. Some of the compressed and heated vapor is then recycled through a series of tubes passing through a reduced-pressure chamber, where evaporation of the water occurs, see figure 4. Electricity is the main source of energy for this process. The vapor compression distillation (VCD) process is used either in combination with other processes such as the MED, or by itself [33]. Vapor compression (VC) units have been built in a variety of configurations. Usually, a mechanical compressor is used to generate the heat for evaporation [32]. The VC units are generally small in capacity, and used for small-scale desalting applications—for example, at coastal resorts [34].

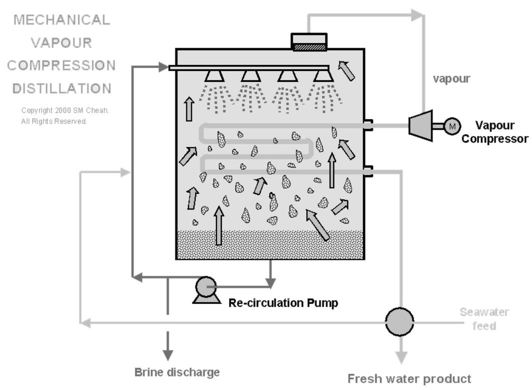

Figure 4: Simplified structure of the Vapor Compression Distillation Process [27]

2.1.5 Additional Processes

Two other significant thermal processes are solar humidification and freezing [35][36]. In solar humidification, salt water is collected in shallow basins in a "still," a structure similar to a greenhouse [37]. The water is warmed as sunlight enters through inclined glass or plastic covers. Water vapor rises, condenses on the cooler covers, and trickles down to a collecting trough. Thermal energy from the sun is free, but a solar still is expensive to build, requires a large land area, and needs additional energy for pumping water to and from the facility. Solar humidification units are suitable for providing desalted water to individual families or for very small villages where sunlight is abundant [36].

The freezing process, also called crystallization, involves cooling salt water to form crystals of pure water [35]. The ice crystals are separated from the unfrozen brine, rinsed to remove residual salt, and then melted to produce fresh water. Freezing is theoretically more efficient than distillation, and scaling as well as corrosion problems are lessened at the lower operating temperatures. However, the mechanical difficulties of handling mixtures of ice and water prevent the construction of large-scale commercial plants [35]. In hot climates, heat leakage into the facility is also a significant problem [35].

2.2 Membrane Technology

2.2.1 Principles

Membrane technologies, as the name implies, make use of membranes as a filter to sort out unwanted substances. Different types of membranes can be used depending on the size of the unwanted particles. Most commonly known are porous membranes that have microscopic gaps which only let particles of a specific size through [38]. The dissolved salt ions of saline water, however, are too small for this technique and, therefore, most desalination technologies use nonporous membranes. A permeate can be transported through such a dense membrane due to diffusion which is encouraged by pressure, concentration difference, or electrical potential [38].

2.2.2 Seawater Reverse Osmosis (SWRO)

RO takes the phenomenon of osmosis, which describes the natural diffusion of a solvent through a membrane from a high concentration to a low concentration to form an equilibrium, and inverses the process. By using pressure the water is forced to flow from high concentration to low concentration through the membrane leaving the salt solvents behind in the concentrated water, which becomes more concentrated over time [9] Figure 5 shows a simplified structure of the basic process using RO. The membranes used for seawater reverse osmosis SWRO have to reject 99,3% of the salt to produce acceptable permeate [38]. The pressure applied has to be greater than the osmotic pressure to create a positive net pressure that prevents the natural flow of diffusion. The osmotic pressure is dependent on the concentration difference between the two solutions. Seawater can have an osmotic pressure of 2300–2600 kPa, for comparison atmospheric pressure is at 101.325 kPa. During the process this pressure will rise and, therefore, most RO plants work with a hydrostatic pressure of 6000 - 8000 kPa [9].

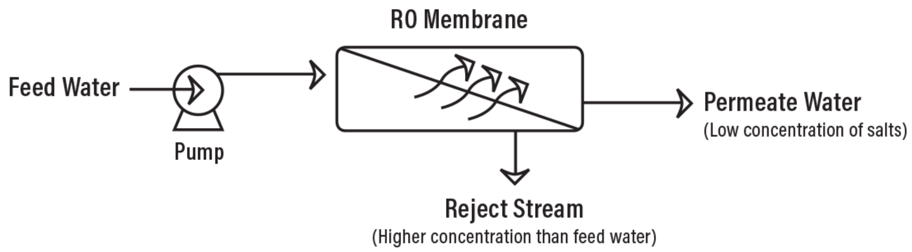

Figure 5: Simplified structure of the basis process using Reverse Osmosis [39]

The flow rate of the water through the membrane is defined as the fluid flux which is dependent on the net pressure as well as the dimensions of the membrane. The fluid flux over the volumetric flow rate of the feeding stream defines the recovery rate of the water and is an indication of performance [40]. Nowadays, the recovery rates can vary between 35% to 85%, depending on multiple factors, that can highly influence the overall cost of the RO plant [9]. A higher recovery also causes a higher salt concentration in the brine stream, which increases the osmotic pressure. Many plants work at a 50% recovery creating a brine that is twice as saline as seawater [41], which creates an imbalance of the salt concentration when released causing negative effects on the environment.

Another important factor for the efficiency of a RO plant are the components of the feeding stream. Directly using seawater without any pre-treatment causes the feeding stream to carry much more than only dissolved salts, that also need to be filtered out. Especially the organic matter can cause surface fouling on the membranes. This causes a decrease in the fluid flux and overall productivity goes down [42]. Regular check ups and exchanging of the membranes adds to the running costs of the treatment plant.

2.2.3 Electrodialysis (ED)

As already mentioned, electrical potential can also be used as a motivation for ions in solution to move through a semipermeable membrane, which are either cation or anion selective. A cation selective membrane holds fixed cations and therefore only anions can permeate the membrane, which makes this technology charge selective as opposed to the more common size selective processes. Neutral particles are not affected by these membranes. This is a relevant approach since many dissolved salts in water are ionic and therefore, carry a charge. The voltage creates a cathode and an anode which attract cations and anions respectively. By stacking the membrane types in an altered fashion all charge carriers can be removed in a cycled process of water treatment. Pre-treatment of the feeding stream is needed to filter out particles that might harm the membrane due to size or their ability to neutralize them, like colloids or ion oxides [43].

3 Application

Desalination technology is a controversial topic, partly due to the variety of processes as discussed above. The technologies are often connected to several drawbacks, which have the potential to significantly influence the feasibility of this form of water supply. High capital cost and high energy demand are often associated to constructing large scale desalination plants, as needed in South Africa [44]. Once constructed, many technologies are associated with high production costs due to the high energy consumption of the plants [44]. In addition, large scale desalination plants may cause environmental problems on the marine, land, underground, and air environment, including brine emission, noise pollution, etc. [45]. Furthermore, desalination plants may cause social rejection of the resulting rise in water prices or by the owners of the project land and of the neighboring land [46].

Desalination, nonetheless, offers a considerable solution for the water shortage in South Africa, as desalination is an alternative water supply not dependent on the rainfall. Desalination is regarded to have a relatively high security production rate, compared to lower reliability of the conventional water supply systems, as the availability of seawater is constant. The achievable water quality of desalination plants may be designed to meet potable and industrial standards [47] and, hence, is applicable to the requirements in South Africa. Furthermore, desalination plants can be installed in areas on the coastline where conventional water supply is not available and its construction time can be relatively short if compared to other alternatives [48].

To ensure that the advantages of desalination technologies outweigh the related drawbacks an in-depth evaluation of the technologies in consideration of local requirements is necessary. In the coming sections, the presented technologies will be evaluated based on a set of criteria including financial costs, energy requirements, source water characteristics, efficiency of the technology, geographical and local constraints, product water quality, environmental factors and waste disposal options, operational and maintenance issues, and utilization rates. The financial costs are further divided into capital costs, such as the purchase of equipment, land, construction charges, as well as annual operation and management costs, such as costs for labor, energy, chemicals, consumables and spares [48].

Reconsidering the described technologies, the large energy consumption of thermal processes based on evaporation is reason to not consider multi stage flash distillation, multi effect distillation, and vapor compression distillation for desalination of seawater in South Africa, unless sufficient waste heat (e.g. from a nuclear power generation) or low cost energy is available [49]. Both multi stage flash distillation and multi effect distillation consume at least three times as much energy per produced cubic liter of water than reverse osmosis (RO). Considering the relatively high costs and low availability of energy in the Western Cape, multi stage flash distillation and multi effect distillation are not feasible for long-term implementation. As vapor compression is mainly used in combination with multi effect distillation, it can be neglected for the same reason. Nonetheless, the reliable performance of thermal processes make these technologies highly competitive against the RO process [49], if the availability of energy in South Africa can be increased.

Electrodialysis is in theory well suited to desalinate seawater, but it is mostly used for wastewater recycling. The reason is very straightforward and relates to the efficiency of the system. When dealing with slightly saline water, it is mostly the flow rate of the feeding stream that determines the rate of desalination. However, when using seawater, the salt concentration is significantly higher, so it starts to have an even larger impact on the efficiency than the flow rate. As the conductivity of seawater is proportunaly linked to the amount of ions in it, more energy is required with decreasing amount of ions, for example by desalination [50]. Hence, the cost of an ED plant is proportionally linked to the amount of salt that is filtered and, therefore, does not fulfill the criteria of a cost efficient system.

The experimental technologies that are considered nowadays are mostly very cost efficient, which, however, only applies on a small scale which makes them not applicable on an industrial level [51]. Solar humidification and freezing are therefore not feasible as a solution for the water crisis in the Western Cape.

RO is a well researched and tested technology which is mostly implemented in other countries like Israel, Saudi Arabia or Spain. Furthermore, it is seen as a cheaper and less energy consuming technology compared to MFD [2]. The popularity of RO increased once the technology was combined with Energy Recovering Devices (ERD) that allow to lower the total energy consumption. The pressure difference between the applied pressure of the RO and the concentrated brine can be used to activate turbines to regain a small percentage of energy by their movement. This and the further development of the membranes helped to reduce energy consumption from 10 kWh/m^3 to 4 kWh/m^3 [52]. These numbers represent the total energy needed and, therefore, also include the pre- and after-treatment of the water, while the actual process of RO only contributes 85% to the required energy. Due to the global interest in the technology investments drove the development of SWRO plants further and new technologies are being tested in the field. A recent pilot study successfully tested the potential to operate a small scale SWRO plant with only 1.8 kWh/m^3 at a recovery of 50% [41].

The costs of a SWRO plant are related to the capacity of the plant. The relation between capacity and capital cost is linear concluding from cost analysis of existing plants [2, 8]. Capital costs are mostly dependent on the materials involved. The larger a desalination plant has to be the more membrane material is needed which sets a clear limit for capacity when being on a tight budget. Operation and Management costs of a SWRO, however, reach saturation with increasing plant capacity. The relative unit water costs (Euro/m^3) is higher for small SWRO plants (< 5000 m^3/day) compared to larger ones [9]. The only costs that differ during this period are the ones for maintenance since it goes back to the material usage and they are not as significant. Concluding, large SWRO plants have a higher cost-efficiency in long-term use compared to multiple smaller plants producing the same amount of water in total.

One of the biggest concerns is the sustainability of this technology. The main factors that need to be considered include greenhouse gases, intake of marine organisms, brine disposal and material use [52]. While the energy needed for SWRO is being minimized there is a theoretical limit to any desalination process due to the laws of thermodynamics [41]. Currently SWRO uses fossil fuel based energy to function which causes greenhouse gas pollution [9]. Alternative energy sources would be wind, nuclear, and solar energy which have not been implemented into the energy system in South Africa yet. As current nuclear power plants are associated with the production of nuclear waste and a high risk of damage [53], the sustainability of nuclear plants is arguably. Since a solution to the current water crisis in South Africa has to be robust to future problems arising, nuclear power is neglected. The use of renewable energies to power SWRO desalination is of major significance for the long-term sustainability.

3.1 Energy Supply

Increasing energy efficiency and the use of sustainable energy in the desalination process has made significant progress in recent years and is predicted to result in feasible technology. A variety of combinations of Renewable Energy Sources and DESalination (RES-DES) processes have been explored and implemented. Today, commercial desalination systems (e.g. MED, MSF, RO and VC) powered by renewable energies are in operation [54, 55, 56].

Solar energy can be transformed into electricity by photovoltaic processes to power SWRO plants. This processes has been largely developed for small scale, isolated systems for which the current available technology is well suited. However, recent development in the technology enable the implementation in bigger plants, such as the one in Barcelona. The comparably high initial investment due to the need for sophisticated materials represents a significant barrier for the implementation in the Western Cape. In addition, large scale photovoltaic SWRO require extensive space, which is regarded to be less of a problem for the implementation in South Africa. It is reasonable to assume that photovoltaic SWRO plants might become a feasible option as the cost of photovoltaic solar panels has decreased within the last few years [57, 58, 59, 60].

Solar thermal energy is most efficiently used by the means of a solar organic Rankine cycle to power SWRO plants [61, 62, 63]. A Rankine cycle consisting ideally of an isobaric heat transfer, an isentropic expansion, an isobaric heat rejection, and an isentropic compression can be achieved in various setups. Most commonly, a Rankine cycle using water or an organic compound is suggested to power RO systems. The use of parabolic collectors allows a significantly high overall performance [64, 65]. Nonetheless, also stationary solar collectors are suggested in literature [66]. All relevant criteria compared, such as solar field size and capital cost, showed that Rankine cycle for RO systems is superior to photovoltaic processes for the medium to large scale plants in the Western Cape.

Wind powered SWRO are largely explored in research and, hence, can be seen as an advanced process, which in its current development stage is ready for implementation [67, 57]. As wind is often available in comparable high, and relatively stable amounts, the use of wind power in coastal areas, such as the Western Cape, or offshore is arguably high-yielding [68]. In addition, the transformation of wind into a usable form of energy is more cost-effective than the transformation of solar energy. Wind can either be converted into mechanical or electrical energy to power a SWRO. In order to make use of mechanical energy produced by wind turbines, high-pressure pumps must be connected to the turbines by mechanical coupling or an hydraulic system. Even though current research states progress, this requirement is associated to comparably large energy losses for high capacity plants. Hence, only the use of electrical energy is of significance for medium or large scale plants as required in the Western Cape [69, 70]. Due to inconsistencies in the frequency of the electrical grid provided by wind power, product water flow and conductivity are marginally impacted, which, however, counterbalances itself over time [57]. Thus, it is suggested as the most suitable RES-DES option.

Concluding, wind powered SWRO plants can be regarded as the most promising technology for the Western Cape [71]. If adequate wind energy sources are not available, solar thermal-powered RO is the best technology. Solar photovoltaic processes are likely to become a feasible option for the Western Cape, but currently are connected to higher capital costs, and, therefore, are not advisable. Further on, attention has to be paid to the reduction of RO plant investments, energy consumption, and capital costs of solar and wind energy systems [72]. Improvements in control systems to ensure the adequate operation of RO systems powered by discontinuous energy sources [73], energy storage systems, and the robustness of electricity networks to withstand heavy variable loads can be of high significance for an implementation in the Western Cape.

4 Discussion

While desalination is a very reliable option to solve the water crisis in Cape Town, it also has negative environmental and social impacts [74]. Due to the high cost, energy intensity and overall ecological footprint of desalination, most environmental advocates view it only as a last resort for providing fresh water to needy populations [74]. The following part goes into depth about these consequences of desalination, in particular of reverse osmosis. Nonetheless, many RES-DES plants have a comparable small capacity and are not yet completely developed, which limits their current significance for the Western Cape. When comparing different RES, wind, solar photovoltaic and solar thermal energy are the most advanced technologies in the current state of research [60]. Therefore, further description of solar photovoltaic powered, solar thermal powered, and wind-powered SWRO is provided below.

4.1 Environmental Impacts

The primary impact of conventional open-ocean intake desalination systems is the impingement and entrainment of marine organisms [75]. However, these impacts can be minimized by locating the intake pipes in a location where oceanic production is low. Modern intake systems are elevated from the seafloor and have larger openings, covered by mesh to lower intake velocities in order to avoid impinging of small organisms such as larvae and eggs [76]. Furthermore mitigation, like environmental restoration of habitat or restocking, can also provide an acceptable solution to these impacts [75]. Nonetheless, according to marine biologists, intake pipes essentially vacuum up and inadvertently kill millions of plankton and other microbial organisms that constitute the base layer of the marine food chain [77]. This can lead to massive environmental ramification throughout many other ecosystems.

The emission of desalination plants with discharge scenarios can lead to substantial increases in salinity and temperature, and the build-up of metals, hydrocarbons and toxic compounds in receiving waters [78]. The biggest environmental and ecological impacts have occurred around older multi-stage flash (MSF) plants, which discharge to water bodies with little flushing. The processes of seawater reverse osmosis desalination is associated with further issues. SWRO plants tend to have less thermal impacts [78], but produce saltier brines [75]. These salty brines can increase the salt concentration of the seabed, which can lead to the diminishment of coral reefs, crawlers and vegetation which is not mobel [79]. Desalination powered by RES is mostly a zero-carbon emission process and the improvement in solar technology enables overcoming previously existing problems like the build-up of metals, hydrocarbons and toxic compounds and high temperatures [78], which affected the efficiency of previously used solar panels [80].

4.2 Social Impacts

The technical, economic and environmental aspects of desalination plants have increasingly received attention in recent years. However, social aspects of such units have often been neglected resulting in abandoned and dysfunctional systems [81]. For instance, the massive introduction of desalination technology has triggered fundamental cultural changes. On the one hand, desalination might transform an -up to then- rare good into an apparently endless resource, dismissing in this way the traditional and water-saving consciousness developed by the local population [74]. A risk for places like Cape Town would be that people go back to their old habits and again use too much water [81]. On the other hand, an increase of water prices resulting from higher production costs can lead to significant social reject [82]. An unright allocation of water access favoring wealthier part of the society might result, or be further strengthened as in the case of the Western Cape. As access to water is a crucial part of human basic services, the selling of water has to be seen critically.

5 Conclusion

When comparing different desalination technologies, SWRO systems proved to have a significant lower energy consumption, capital costs and environmental impacts than Multi-Stage Flash Distillation, Multi-Effect Distillation (MED), Vapor Compression Distillation (VCD), Freezing Distillation, Solar humidification and Electrodialysis. To further reduce the costs of SWRO desalination, the implementation of the technology in large scale plants is advised to increase operation and maintenance cost-effectiveness. In addition, capital cost-effectiveness can be maximised by aiming for the implementation of plants with maximal operation time. As a long-term solution needs to be found, the sustainability of the technologies must be consider to prevent new problems, such as extensive environmental pollution. Wind power can be regarded as the most promising technology for the Western Cape, which can be complemented with the use of solar energy in the future.

Currently, South Africa has multiple small to medium scale SWRO desalination plants powered by fossil fuels, which were implemented as a rapid short-term solution to the water scarcity and have contractual running time of two years. Hence, it is advised to shift to large scale wind-powered SWRO plants, which are used over maximal operation time. Adaptations to large scale wind-powered SWRO plants, such as the modernisation of the pipeline system, would need to be implemented. Furthermore, close attention needs to be paid to the environment impacts of such plants, as the emission of brine as well as the intake of seawater might significantly damage the surrounding environment. Social aspects, such as an unright allocation of water access and the dismissing of water-saving consciousness, have to be counteracted. Most likely desalination technology as described above cannot be the only solution to the current problem in the Western Cape, but has to go hand in hand with other means, such as waste water treatment, reduction of water consumption and rainwater catchment, etc. Nonetheless, desalination might pay a key role in the water supply of the Western Cape in the future.

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