WWF Desalination Study

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Brief project description	This is a desktop study on the topic of desalination in South Africa. It includes an overview of existing local and international desalination plants and the utilisation of renewable energy for desalination. The aim is to identify replicability potential for the South African market.		
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EXECUTIVE SUMMARY

Desalination refers to a process of extracting the mineral components from saline water to produce fresh water. More generally, desalination refers to the removal of salts and minerals from a target substance, as in soil desalination, which is an issue for agriculture. This technology might assist with the alleviation of worsening worldwide water scarcity. This report reviews the current state of desalination plants in South Africa, focussing on the plants commissioned by municipalities. The report also includes an analysis of a small scale private desalination plant in Cape Town as a case study.

The study further describes the state of desalination worldwide, showing the trends and giving examples of the costs, technology choices and problems seen in specific large scale plants, with an emphasis on the cases where renewable energy is integrated at the plants. The potential for implementation of desalination plants in South Africa is discussed, including the suitability of coupling these with energy from renewable sources.

This research reveals that desalination is expensive, energy intensive and has potentially harmful environmental effects. However, there are certain situations where desalination may be viable and if they are to be implemented, it is advised that they are done so on a large scale (100 – 250 Ml/day) and in areas of water crisis or high water demand (so the plant may run continuously over its lifetime). The research also shows that energy usage of the plant could be offset by a combination of large scale wind- and/or solar-photovoltaic farms around the country. It is however, important to ensure that full environmental impact studies are done at each potential site to mitigate negative environmental effects, such as the disposal of highly saline brine.

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LIST OF ABBREVIATIONS

AD	Adsorption Desalination
Capex	Capital Expenditure
CRSES	Centre for Renewable and Sustainable Energy Studies
CSP	Concentrated Solar Power
ED	Electro-dialysis
EDR	Electro-dialysis Reversal
GHG	Greenhouse Gas
GWI	Global Water Intelligence
HDH	Humidification-dehumidification
MD	Membrane Distillation
MED	Multi Effect Distillation
MESS	Multi Effect Solar Still
Ml	Mega Litre
MSF	Multi Stage Flash
MVC	Mechanical Vapour Compression
NPV	Nett Present Value
Opex	Operational Expenditure
PV	Photovoltaic
RE	Renewable Energy
RO	Reverse Osmosis
ROI	Return On Investment
TVC	Thermal Vapour Compression
VAT	Value Added Tax
VC	Vapour Compression
ZAR	South African Rand

TERMINOLOGY

Absorption desalination (AD)	**Thermal technology:** desalination process that uses heat to evaporate saline or brackish water before passing the vapour through a bed of silica. The silica absorbs water until fully saturated, after which the water is evaporated out of the silica and condensed into desalinated water.
Brackish water	Water containing more salinity than what is accepted for potable use but not as much as seawater. This may be as a result of seawater contamination of a freshwater source.
Concentrated solar power (CSP)	Reflective material is used to concentrate solar irradiance to be captured as thermal energy, which can then be used in a thermal process or converted into electrical energy.
Electro-dialysis (ED)	**Membrane technology:** desalination process that involves the electrochemical separation of salt ions from saline water through a membrane.
Groundwater	Water held in underground aquafers.
Humidification–dehumidification (HDH)	**Thermal technology:** Desalination process involving the evaporation of saline or brackish water in a humidification chamber. The vapour is passed into a dehumidification chamber where it is condensed into desalinated water.
Mechanical vapour compression (MVC)	**Membrane technology:** mechanical compression of vapour in a VC process (see VC terminology).
Mega litre (Ml)	One million litres.
Membrane distillation (MD)	**Thermal technology:** Distillation process involving the transfer of water vapour through a micro-porous hydrophobic membrane, requiring the heating of the saline water rather than using pressure as in the RO (see RO terminology) process.
Multi effect distillation (MED)	**Thermal technology:** Similar to MSF (see MSF terminology), however the condensate from the first chamber is used to heat salt water in the following chambers.
Multi effect solar still (MESS)	**Thermal technology:** Similar to solar still technology (see solar still terminology) but utilising the latent heat of condensation for further distillation in a staged configuration.
Multi stage flash (MSF)	**Thermal technology:** Distillation desalination process involving the heating of saline water under large pressure before being passed through multiple chambers that promote evaporation. This evaporated water is collected and condensed into fresh water.
Reuse / reclaimed water	The recycling of wastewater or greywater through treatment for the recharging of potable water resources or without treatment for applications that do not require potable water such as flushing toilets.

Reverse osmosis (RO)	**Membrane technology:** Membrane desalination which uses pressure to force saline water through a semi-permeable membrane which filters out enough salt to produce potable water.
Solar-photovoltaic	Solar energy (irradiance) is converted to electricity with the use of photovoltaic (PV) cells.
Solar still	**Thermal technology:** Distillation of saline water using solar energy to aid evaporation. Angled glass is used to trap heat energy inside a collector containing saltwater, the vapour is condensed on the inside of the glass panel and is collected as potable water.
Thermal vapour compression (TVC)	**Thermal technology:** Thermal compression of vapour in a VC process (see VC terminology).
Vapour Compression (VC)	Utilises the heat from compressed vapour to evaporate saline water in a desalination process

1: Introduction

Key factors affecting water supplies worldwide include; climate change related drought; poor water management and; exponential population growth. Figure 1.1 illustrates the worldwide water stress by country, with South Africa ranked as being in high stress, withdrawing 40 – 80% more water than can be supplied by resources. At the time of this study, the Western Cape is experiencing the worst drought in at least 300 years and is, much like many other parts of the world, facing extreme water scarcity. This situation is not sustainable and the Western Cape faces a state of emergency as the water scarcity worsens.

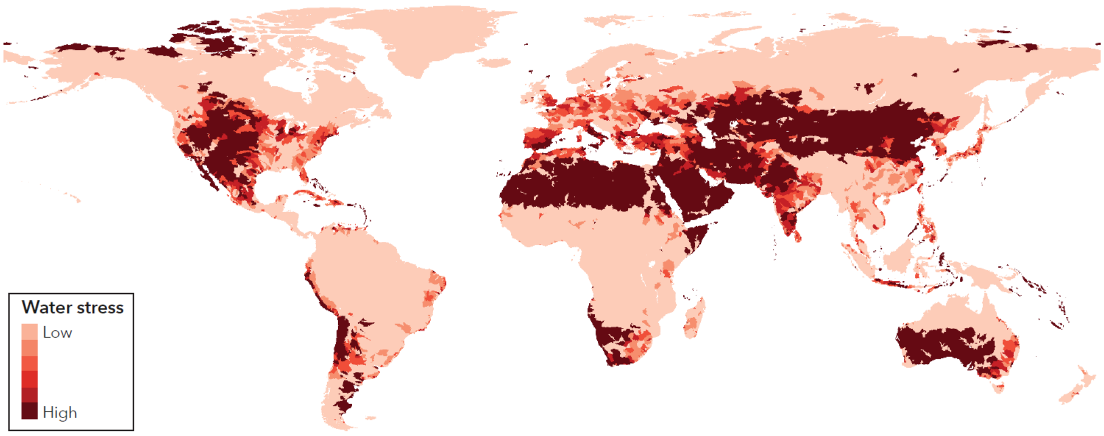

Figure 1.1: World water stress indicator (World Resources Institute, 2015)

Figure 1.2 shows the worldwide water sources in 2011 as well as the prediction for 2030. The majority of water is sourced from surface and ground sources as these are the cheapest options. However, in drought situations these sources are not sufficiently recharged naturally. A key technology to consider for artificial recharge of natural water sources in these situations, is the desalination of brackish- and seawater. Due to the large coastline and suitable infrastructure, South Africa could be a suitable country to explore desalination implementation.

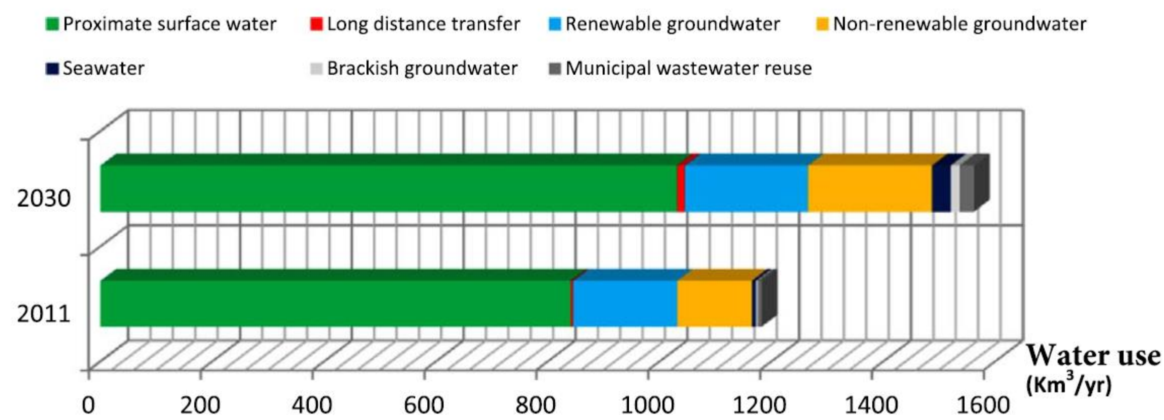

Figure 1.2: The worldwide raw water sources in 2011 compared to the predicted raw water sources in 2030 for utilities and industry (Pinto & Marques, 2017)

There is some hesitance in the implementation of desalination plants due to high costs, high energy consumption and negative environmental impacts, especially the high greenhouse gas (GHG) emissions associated with the high energy demand as well as the discharge of high salinity brine back into the environment.

Figure 1.3 shows the cost breakdown of establishing and operating a desalination plant. The capital cost required to build the plant and the large amount of energy needed to run the plant, constitute the majority of the expenses. The high energy requirement often results in companies turning to cheaper fossil fuels to achieve financial feasibility and this in turn results in a larger carbon footprint.

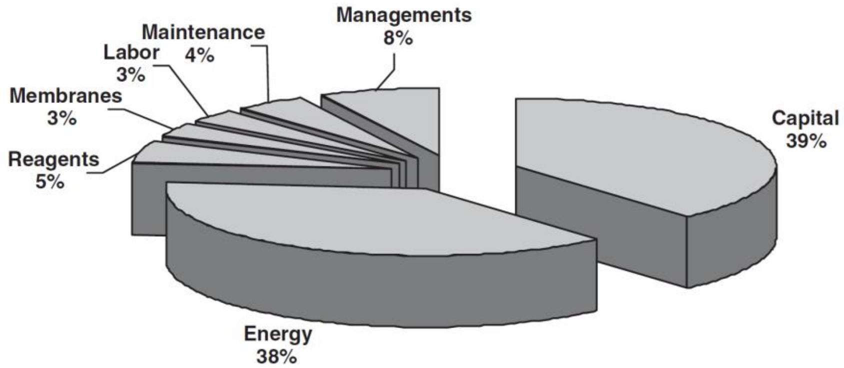

Figure 1.3: Cost distribution of establishing and operating desalination plants based on seven medium to large scale desalination plants constructed along the Segura River Basin in Spain (Lapuente, 2012)

Desalination technologies can be categorised into thermal- or membrane-based technologies, which are defined by their primary energy input. Thermal technologies primarily require heat as the input energy, whereas membrane technologies require pressure, which is most commonly created using electricity. An exception to this is Mechanical Vapour Compression (MVC), which doesn't make use of a membrane but still requires pressure and/or electricity to operate and is thus categorised under membrane technologies. Figure 1.4 illustrates the trend in the use of desalination technologies over the years, migrating from mostly thermal- towards more membrane-based technologies, reverse osmosis being by far the most common of these membrane technologies. Advancements in membrane technology, which is typically a very high consumer of electricity, coupled with the low cost of fossil fuels, has driven the trend towards using fossil fuels (electricity) as the predominant source of energy in desalination plants.

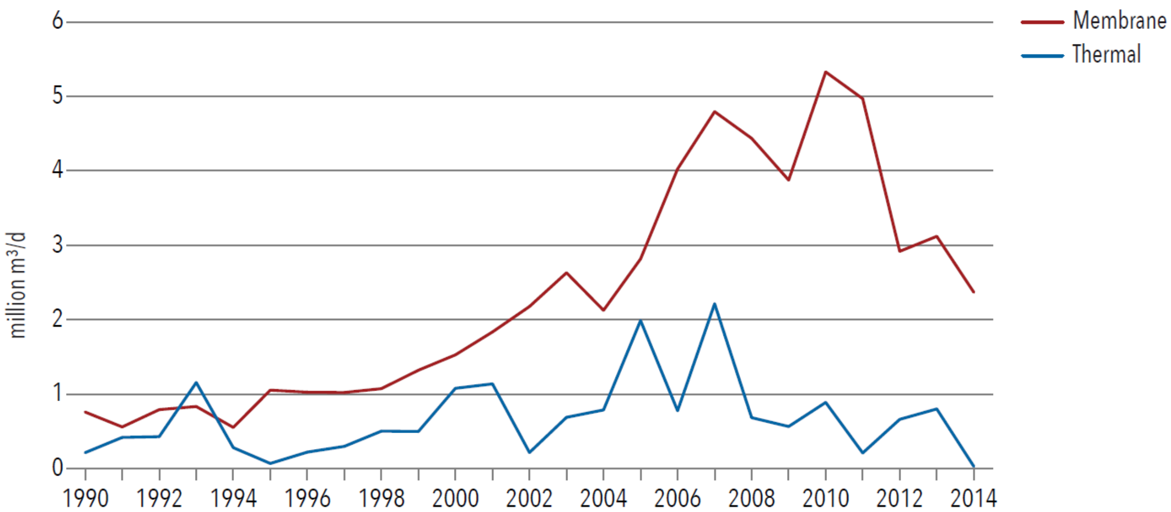

Figure 1.4: Evolution of membrane (electrical) and thermal desalination technologies (Global Water Intelligence, 2017)

A combination of different renewable energy sources and technologies can power desalination plants. This can be done either directly or indirectly. The chosen desalination technology as well as the choice of power source is informed by the optimal financial feasibility of the plant as well as the reduction of adverse environmental impacts. Figure 1.5 shows how renewable energy sources and technologies could be integrated with desalination technologies.

Membrane technologies include; Mechanical Vapour Compression (MVC), Reverse Osmosis (RO) and Electro-dialysis (ED)/ Electro-dialysis Reversal (EDR). Thermal technologies include; Multi Stage Flash (MSF), Multi Effect Distillation (MED), Thermal Vapour Compression (TVC), Adsorption Desalination (AD), Membrane Distillation (MD) and Humidification-dehumidification (HDH). For a short description of each of these technologies, see the terminology section at the beginning of this report.

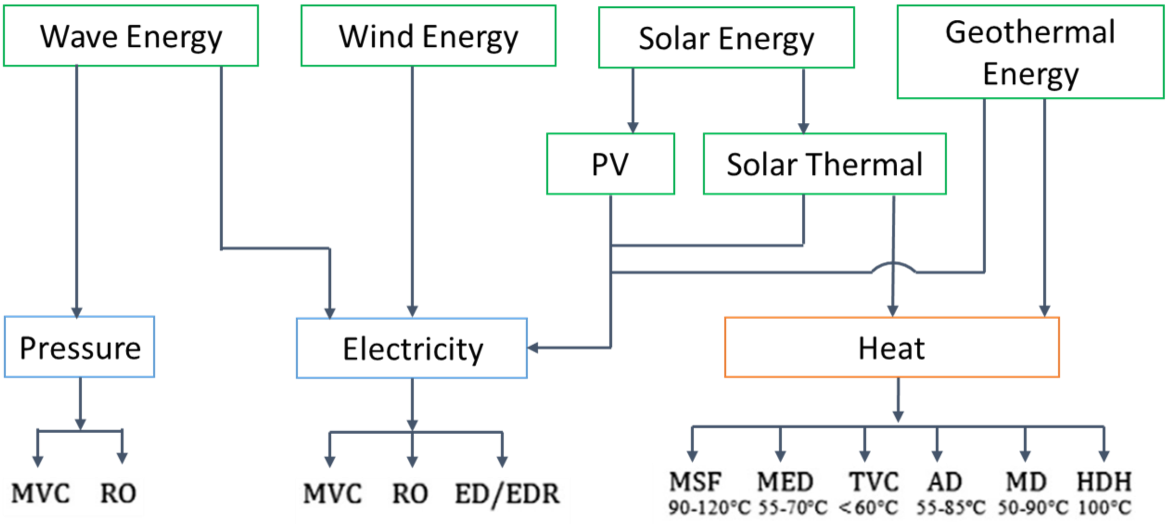

Figure 1.5: Renewable energy resources and technologies integrated with desalination technologies, namely membrane technology (pressure and electricity) and thermal technology (heat) (adopted from Ghaffour, et al., 2013)

2: Overview International Desalination Plants

The installation of desalination plants is growing internationally at a substantial rate, with a worldwide production of potable water from desalination plants almost doubling from approximately 45 000 Ml/day in 2006 to 85 000 Ml/day in 2016 (Pinto & Marques, 2017). The key factors driving this are; water scarcity due to drought (influenced by climate change) and; an increased demand for water from population growth. As advances in the related technologies improved, the cost of desalination decreased, making it more viable in locations that have few natural water sources. Figure 2.1 illustrates the historical and predicted capital expenditure of specific countries in desalination development, as provided by the GWI (Global Water Intelligence, 2017). This data predicts that there will be a worldwide capital expenditure of almost 4 billion US dollars in desalination technologies in 2018, which is less than 2% of the total global water capex.

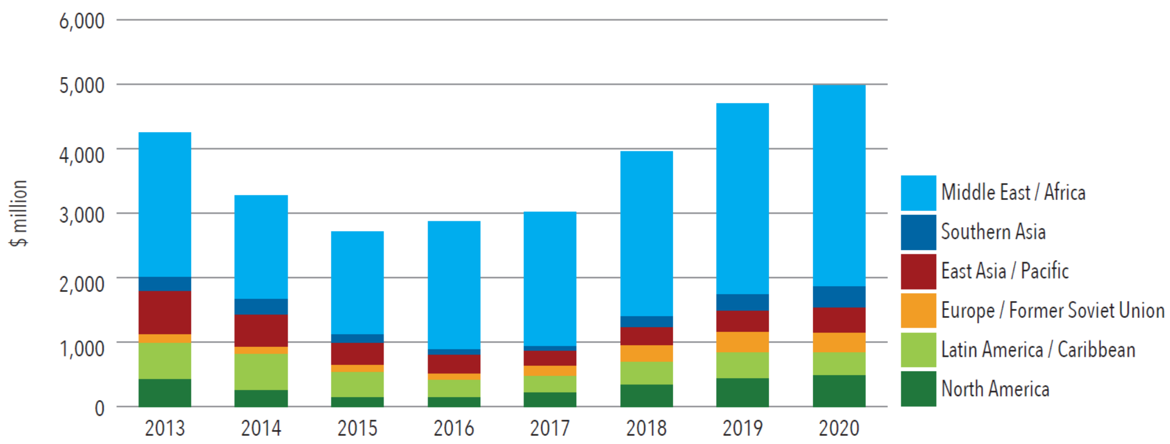

Figure 2.1: Country specific capital expenditure in USD on seawater and brackish water desalination (Global Water Intelligence, 2017)

The financial feasibility of desalination plants are improving dramatically with the decrease in the cost of relevant technologies, particularly reverse osmosis. However, desalination still requires a large amount of energy (approximately 4 – 5 MWh per Ml water production for reverse osmosis (Fairhurst & van Niekerk, 2018)), which is predominantly sourced from fossil fuels. This is slightly counter intuitive with respect to water shortages in drought stricken areas, as the burning of fossil fuels for energy contributes towards climate change which may, in turn, be a contributing factor in the drought itself (Muller, 2014). Solar and/or wind energy is a viable alternative but has been, in most cases, outweighed by the simplicity and affordability (from the perspective of the consumer) of fossil fuels, which is already well established in South Africa. However, an increase in interest towards renewable energy may arise due to; countries adopting stricter environmental regulations, leading to increased costs due to permitting factors, and; general awareness of the negative affects conventional desalination has on the environment (Pinto & Marques, 2017).

2.1: Desalination plant costs

Older thermal technologies such as the Multi Effect Solar Still (MESS), Membrane Distillation (MD) and Mechanical Vapour Compression (MVC) primarily operate using heat energy. As shown in Figure 1.4, the trend is moving towards membrane technology, and more specifically reverse osmosis, which has a high electricity demand.

Table 2.1 shows the costs of some desalination plants around the world, using various technologies and energy sources. The 'water cost' shown is the total cost of water production including Capex and Opex, adjusted for inflation and converted from USD to Rands (ZAR) in May 2018. There were very few small renewable energy based desalination plants established between 2000 and 2006 and those that did include RE had a very high cost of water production. Three larger desalination plants where established in Morocco and Australia in 2006 and 2007, with more competitive costs of producing water, after which the majority of plants established where fossil fuel based. It is noted that the size of desalination plants increased significantly from approximately 100 Ml/day up to 1 000 Ml/day between 2010 and 2014, but started to decrease again in 2015, clearly showing the effect of economies of scale as well as the influence of the technology improvement in especially reverse osmosis in later years.

The small scale solar-photovoltaic and wind energy driven desalination plants shown in Table 2.1 are mostly standalone systems, some with a back-up diesel generator or grid connection. This small scale and standalone combination results in a very high cost of water and is only useful as mobile emergency units.

Figure 2.2 illustrates the economy of scale, showing the cost of water dip initially as capacity increases then rise again at higher capacities as expected, indicating there is an optimal range for desalination plant size. It must be noted that even though this curve is an indication of an optimal range for plant size, it is not a good indicator of the range itself as there is too much variation in the data such as plant location and technology improvements over time.

Table 2.1: Cost factors for international desalination projects

Location	Year	Technology	Primary Energy Source	Capacity [Ml/day]	Water Cost [R/m^3]	References
Egypt	2000	RO (Brackish)	Solar-PV (Electricity)	0.001	68.06	1
Jordan (Irbid)	2005	MD (Brackish)	Solar-PV (Electricity)	0.0001	235.48	2
Tunisia	2005	MESS	Solar (Heat)	0.001	797.98	3
Tunisia	2005	MD	Geothermal (Heat)	0.001	2093.24	3
Jordan (Aqaba port)	2006	MD	Solar-PV (Electricity)	0.0005	274.73	2
Morocco	2006	RO	Wind (Electricity)	1.2	12.92 – 16.89	4
Morocco	2006	MVC	Wind (Electricity)	1.2	16.64 – 22.85	4
Australia (Perth)	2007	RO 2-pass	Wind (Electricity)	143.7	18.13	5
Israel (Palmachim)	2010	RO	Fossil fuel (Electricity)	110	11.30	5
Algeria (Beni Saf)	2010	RO	Fossil fuel (Electricity)	200	11.30	6
Israel (Hendera)	2010	RO	Fossil fuel (Electricity)	347.9	9.07	5
Saudi Arabia (Shuaiba)	2010	MSF	Fossil fuel (Electricity)	880	13.79	5
Saudi Arabia (Ras Al Khair)	2014	MSF-RO	Fossil fuel (Electricity)	1 000	16.02	6
US (Carlsbad)	2015	RO	Fossil fuel (Electricity)	190	11.67	6
Algeria (Tenes)	2015	RO	Fossil fuel (Electricity)	200	8.69	6

[1] (Ahmad & Schmid, 2002)

[2] (Banat & Jwaied, 2008)

[3] (Bouguecha, et al., 2005)

[4] (Rizzuti, et al., 2007)

[5] (Ghaffour, et al., 2015)

[6] (Pinto & Marques, 2017)

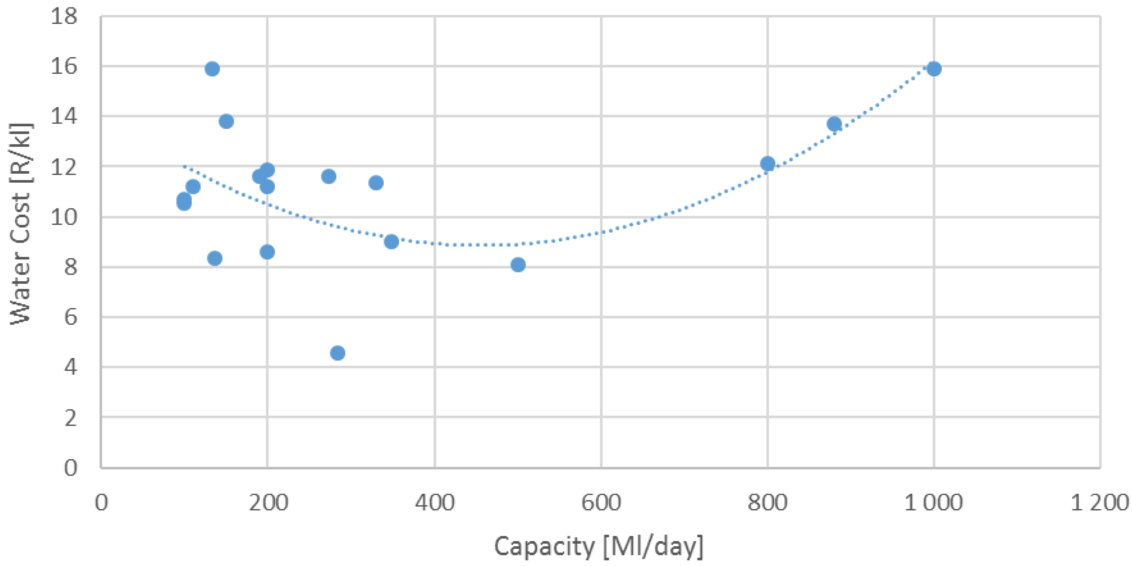

Figure 2.2: Seawater desalination plant comparison between capacity and cost of water (created using data from Pinto & Marques, 2017)

Many researchers have recognised the need for the coupling of renewable energy and desalination in the future. Manju and Sagar (2017) discuss the likely water scarcity that will occur in India as the population is predicted to increase from 1.3 to 1.6 billion in the next 30 years. Their proposed solution is desalination offset by renewable energy sources.

2.2: Qatar

A small (100 kl/day) off-grid desalination plant was built on a small remote farm in Qatar by the Monsson Group. The plant uses a 20 kW_p PV system, a 20 kW backup diesel generator, a 10 kWh battery storage system and reverse osmosis technology. This system produces water at a high cost, but due to the remote location of the plant it is less than the cost of water transportation via truck, and therefore it is financially feasible for this specific case. As expected, off-grid systems are suitable for emergency or remote location applications.

2.3: Spain

Table 2.2 shows the investment cost of four desalination plants established along the Segura River Basin in Spain. The investment costs are adjusted for inflation and converted into South African Rand (ZAR) in May 2018. According to Table 2.2, the investment costs were an average of R20.1 per litre/day capacity installed. This is a generalised approximation, as economy of scale, sourcing of material, permitting factors, local policy and other factors relating to specific locations affect the cost of individual desalination plants.

Table 2.2: 2009 investment cost analysis of various desalination plants in Spain [1, 2]

Desalination plant	Capacity	Investment cost in 2009	Approximate investment cost in ZAR in 2018	Investment cost in ZAR in 2018 per litre/day capacity
Águilas	210 Ml/day	€ 221.3 mil	R3 647 mil	R17.37
Alicante I	65 Ml/day	€ 81.9 mil	R1 350 mil	R21.10
Torrevieja	240 Ml/day	€ 302.5 mil	R4 985 mil	R20.77
Valdelentisco	140 Ml/day	€ 179.3 mil	R2 955 mil	R21.11

[1] (Lapuente, 2012)

[2] (Triami Media BV in cooperation with HomeFinance, 2018)

2.4: Australia

Many large scale desalination plants where commissioned between 2006 and 2009 in Australia in areas such as Adelaide, Sydney, Melbourne, Queensland and the Gold Coast as a result of persisting drought. However, since there is no longer a drought in these areas, all these plants are now on care and maintenance mode, operating at a minimum production level, and will only be started up again when the next drought hits these areas and the water scarcity might call for expensive desalinated water again. Keeping these plants in care and maintenance mode is costing the Australian government a significant amount of money. Out of the six large scale desalination plants in Australia, only two located in Perth are running at capacity.

The **Sydney Desalination Plant** in Australia is a large scale (250 Ml/day) reverse osmosis plant. The energy use of this plant is fully offset by the 140 MW Capital Hill Wind Farm. The plant requires 46 MW at full production, but, depending on the dam levels, is not always required to operate at full capacity. At the time of this study, the plant is in a care and maintenance mode, which means the plant is not producing water, but is being maintained so it may be operational when needed. The plant will only operate once dam levels fall below 60% and will continue to produce until dam levels are above 70%. As of May 2018, the dam levels where at approximately 77% (Sydney Desalination Plant Pty Limited, 2018).

The **Perth Seawater Desalination Plant** is a 140 Ml/day large scale reverse osmosis facility that is upgradable to 250 Ml/day. The plant requires 24 MW of power at full operation. The energy use of the plant is offset by the 80 MW Emu Downs Wind Farm, using smart grid technology (Water Corporation, 2018). This plant is currently producing at full capacity.

The **Victorian Desalination Plant is a** 410 Ml/day reverse osmosis facility that is currently operating at minimum production as there is sufficient water sourced from natural sources in the area. The plant is not directly powered by renewable sources but uses RECs to offset their large carbon footprint.

2.5: United States of America

The **Carlsbad Desalination Plant in California**, USA, is currently producing 190 Ml/day of potable water using reverse osmosis. The facility requires 31.3 MW of power at full capacity. This is drawn from the Encina Power Station (950 MW natural gas power station). In July 2015 the San Diego Coast keeper sued the water authority for violating the California Environmental Quality Act. The claim was that the Carlsbad project did not provide a true account of both the energy demand and carbon emissions involved in the large desalination plant (Desalination & Water Reuse, 2015). This action later failed and the Carlsbad Desalination Project claims they are striving for carbon neutrality through the purchase of carbon offsets or renewable energy certificates (RECs), improving energy efficiency within the plant, on-site rooftop solar generation and recovery of carbon dioxide (Carlsbad Desalination Project, 2017).

3: Overview of existing desalination plants in South Africa

South Africa has 16 publicly owned desalination plants (see Table 3.1). The majority of these plants are considered very small, with the largest plant in in **Mossel Bay**, with a capacity of 15 Ml/day. This constitutes 21% of the potable water needed in Mossel Bay. The plant is, however, in care and maintenance mode at the time of this report and not producing any water as the dams in the area are sufficiently full. There is a 2 Ml/day desalination plant in **Knysna**, which is currently shut down for maintenance and repairs. During normal operation, the plant is used at the discretion of the municipality. Currently there is sufficient water in Knysna, so use of the plant is minimised due to the high operational costs. **Plettenberg Bay** has an operational desalination plant producing 2 Ml/day, which is approximately 7% of the potable water needed by the municipality. There are two desalination plants in the **Ndlambe** municipality, the Bushman's River Mouth plant that produces 1.8 Ml/day and the Cannon Rocks plant that produces. 0.75 Ml/day. Both plants are currently in operation and producing at full capacity. The Cederberg municipality has a plant in **Lamberts Bay** with a capacity of 1.7 Ml/day (upgradable to 5 Ml/day); however, this plant is not operational yet. **Richards Bay** has a desalination plant that was installed to provide 10 Ml/day of water during the drought in 2016/2017. This is less than 2% of the water demand in that municipality. On average it has only been producing 6 Ml/day. A few problems experienced by the plant include cable theft and excessive pressure, which burst pipes in the supply areas.

There is potential to power the above mentioned desalination plants using a combination of wind and solar-photovoltaic with a grid connection as backup. The problem comes into play when the plant goes into care and maintenance mode if water scarcity decreases. This will affect the financial feasibility of the renewable energy source. Therefore it would be more beneficial to establish a larger scale solar-photovoltaic or wind farm that feeds into the grid and the power needed for the desalination plants may be offset by this renewable energy when the plant is in operation, otherwise the renewable power is sold to the municipality.

Table 3.1: South African public desalination plants [1]

Desalination Plant	Owner/ Water Authority	Capacity (Ml/day)
Sedgefield	Gouritz Municipality	1.5
Robben Island	City of Cape Town	0.48
Bushman's River Mouth	Albany Water Board	1.8
Cannon Rocks	Albany Water Board	0.75
Rietpoort	West Coast District Municipality	0.04
Kheis	Kamiesberg Municipality	0.04
Lepelfontein	Kamiesberg Municipality	0.04
Klipfontein	Kamiesberg Municipality	0.04
Spoegrivier	Kamiesberg Municipality	0.04
Soebatsfontein	Kamiesberg Municipality	0.04
Bitterfontein	West Coast District Municipality	0.91
Plettenberg Bay	Bitou Municipality	2
Mossel Bay	Mossel Bay Municipality	15
Knysna	Knysna Municipality	2
Lamberts Bay	Cederberg Municipality	1.7
Richards Bay	uMhlathuze Municipality	10

[1] (adapted from Kitley, 2011)

Large scale desalination plants (150 – 200 Ml/day) have been proposed to the city of Cape Town by the Monsson Group, which are integrated with renewable energy sources with or without storage. Storage is vital for power independence in a desalination plant, however this raises the cost of water significantly. Another option is to oversize the renewable energy source and sell excess electricity into the grid. This is however a very complicated process as there needs to be independent power producer agreements signed with the municipality. Another major issue with having both a desalination plant with a dedicated renewable energy farm is that the life span of the project could be 15 to 20 years, during which the drought may very well be relieved in Cape Town. This will then cause the city to turn to more affordable natural sources of water and both the desalination plant and renewable energy farm run the risk of becoming idle.

There is currently a small desalination plant (300 kl/day) planned for installation in **Witsand,** situated in the Hessequa Municipality in the Southern Cape. This plant will be 50% funded by the French government and 50% funded by the Western Cape Government drought relief fund (R4.1 million each). The plant will use reverse osmosis technology and the energy will be partially supplied by a 70 kW_p solar-photovoltaic system installed on sight. This solar system should account for around 100 kl/day of the total plant capacity on optimally sunny days. The plant should be operational by the end of 2018.

In addition to the publically owned desalination plants in SA, there are also a number of privately owned plants. A case study was done on a small privately owned desalination plant in Cape Town (see Appendix). The plant uses reverse osmosis technology and is currently producing up to 30 kl/day of potable water for the building owners as well as for surrounding buildings. The system is planned to be upgraded to produce 72 kl/day in the event that the City of Cape Town municipality is not able to supply the building with water. If this occurs, employees will be able to take water home. When the building does not require all the water produced by the plant, it is sold to surrounding buildings This is partly due to the fact that the longer the plant runs at, or close to, full capacity, the more efficient the system becomes.

The system is unique because seawater is already pumped into the building for cooling purposes. The saline cooling water outlet is both used to supply water to the desalination plant and to dilute the brine by-product before discharging it back into the sea. The building also has a 124 kW_p rooftop solar-photovoltaic system installed that slightly offsets the electricity consumption of the desalination plant.

Figure 3.1 shows a comparison between the cumulative costs of installing and running the desalination plant and the cost if the water is purchased from the municipality over 15 years. These calculations are based on a council cost of R21/kl for water and sewage with an assumed 10% increase per year over the 15 year life cycle of the plant. According to these calculations, the system pays for itself after 7 years, with a total net present value (NPV) of R6 711 655. For the detailed case study, see the Appendix.

Figure 3.1: Cost comparison between the desalination plant and purchasing water from the municipality over 15 years

Existing infrastructure, especially the seawater intake for the cooling of the building, assists with the feasibility of the plant. This will not necessarily be the case for all desalination systems. However, the costing system described above includes additional plumbing costs to provide neighbouring buildings with water, sold to them at 70% of the rate of municipal water. Implementing small desalination plants with no existing infrastructure may not achieve the same financial returns as seen in this plant. It may be more appealing to implement larger plants that benefit from the economy of scale.

4: Replicability potential for South Africa

Looking at the current desalination trends from around the world, membrane technology is dominating the field, specifically reverse osmosis. It would be advantageous to implement this technology, as there is a large amount of development, technical knowledge and experience available in that field. However, reverse osmosis requires a significant amount of electrical energy to operate (4 – 5 MWh/Ml), with associated large carbon footprint if coupled with fossil fuels.

Figure 4.1 shows the power production potential across the world for solar-photovoltaics. It can clearly be seen that South Africa has very good potential, especially in the Northern Cape. Figure 4.2 shows that South Africa also has good potential for wind, especially near the coastal areas, where desalination plants may be constructed. South Africa also has a good potential for ocean energy, however this is an underdeveloped technology and does not show good financial feasibility when compared to solar-photovoltaic and wind in South Africa. Large scale CSP may provide a good base load for large scale desalination, but the cost of energy from CSP is higher than from wind and solar-photovoltaic.

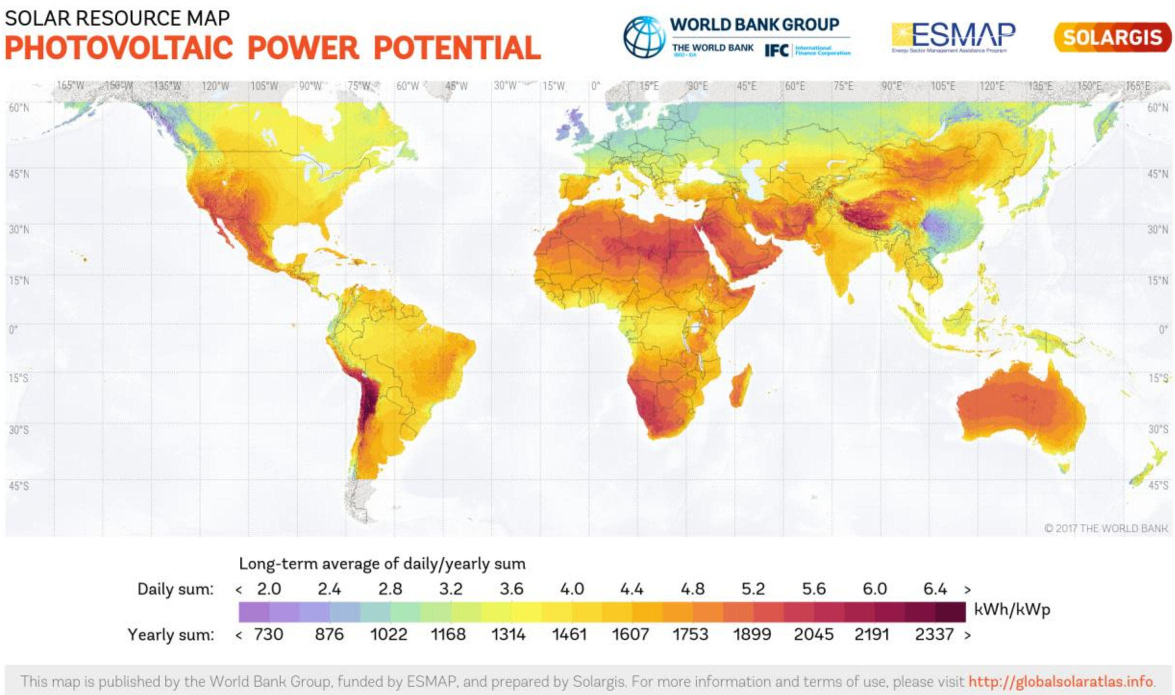

Figure 4.1: Photovoltaic power production potential across the world (Solargis 2018)

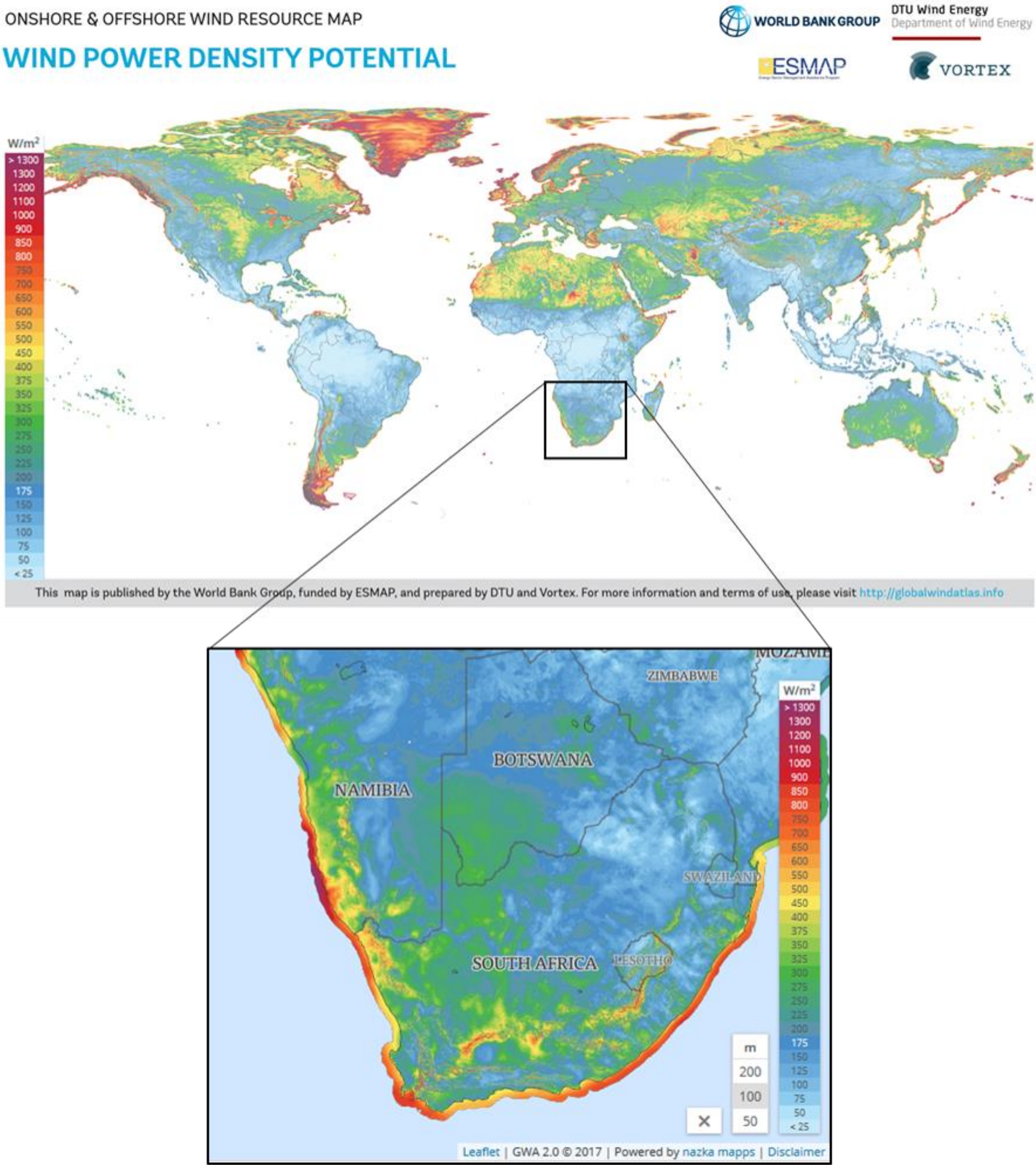

Figure 4.2: Wind power density potential across the world (Solargis 2018)

Desalination systems are optimal when running continuously at full capacity, a poor example of this is that of Australia, where plants stand idle. The problem with using the electricity generated from solar-photovoltaic and wind directly for desalination, is the intermittency and this is not optimal for the plant. Instead, as seen in the case studies of wind powered desalination in Australia, the desalination plant could be connected to a smart grid system with renewable energy offsetting the power consumed by the plant. Thus it is more efficient for renewable energy to indirectly power desalination. Another option is to purchase carbon offsets or RECs to achieve carbon neutrality.

In terms of South Africa, it is advised that extensive planning goes into the development of desalination plants. Optimally, it is advised that plants only be established in areas that will utilise the desalinated water over its full life cycle, to avoid plants entering care and maintenance mode for extensive periods of time that results in unnecessary costs, however it is extremely difficult to predict if and when a drought will be relieved. At the time of this study, the Western Cape faces an extreme drought, which has been rapidly depleting the natural sources and will, even if the drought is relieved, take many years to recharge. In areas of extreme water scarcity such as Cape Town, desalination may be viable as the high cost of water is outweighed by the necessity for water. However, it is advised that the plants be implemented at a large scale (100 – 250 Ml/day) to optimise on economy of scale. As discussed, the cost of water decreases with an increase in plant capacity up to a point where larger facilities start to raise the cost of water, the optimal range being approximately 100 – 250 ML/day. For context, the Cape Town municipality requires approximately 550 Ml/day of water as of May 2018.

Small scale systems are mainly useful in emergency situations such as disaster relief, but translate to a very high cost of water. With respect to the large power needed for desalination, a suitable solution is for the developers to sign purchase agreements with large wind and solar-photovoltaic farms to offset the energy consumed by the plants, which avoids the intermittency of power supply seen in direct renewable energy consumption.

5: Conclusion

Like many other countries, South Africa is in a high stress situation in terms of water scarcity and, together with climate change and population growth, this will only worsen over time. Desalination may provide a suitable technical solution to recharge the natural water sources, especially in the case of the extreme water scarcity currently being experienced in the Western Cape. With the large coastline and suitable infrastructure available in South Africa, desalination provides a viable option for areas of crisis such as Cape Town, however it is no 'silver bullet' as it comprises of a high cost of water, high energy consumption and negative environmental effects.

Looking at the trends from around the world, reverse osmosis (membrane technology) is currently by far the leading technology for desalination. It would be advisable to follow this trend, due to the advancements in related technologies, financial feasibility and available expertise. This technology does however require a significant amount of electrical energy, which is primarily sourced from fossil fuels internationally. The adverse effects of using fossil fuels, mainly climate change (and for South Africa, extreme air pollution in some provinces like Mpumalanga), are being realised internationally and plants are offsetting their energy requirements with renewable energy sources, striving for carbon neutrality. Solar-photovoltaics and wind energy are viable options in achieving this but, the intermittent nature of these energy sources is not optimal for desalination. Instead the desalination plants could use the energy indirectly, thus offsetting the power requirements of the plant with a large scale solar-photovoltaic or wind farm or through wheeling agreements.

Desalination plants are affected by economies of scale, with the optimal size of plants producing 100 – 250 Ml/day (large scale). Small off-grid facilities are only feasible in emergency or remote location applications where the large cost of water production is less than the cost of fresh water transport to those locations. Another factor affecting financial feasibility of the plant is the operation, with continuous operation being optimal. Desalination plants that are not utilised due to sufficient water availability from alternative sources are still costly to maintain in care and maintenance mode. It is extremely difficult to predict the necessity of a desalination plant over its 15 – 20 year life, as weather cannot be accurately predicted over this time frame. For example, if rain recharges natural water sources in Cape Town within the next 15 years, desalination will become redundant.

Desalination will always be second to acquiring fresh water from natural sources due to the cost, energy and environmental implications, but it is a viable solution in areas that suffer from extreme water scarcity resulting in crisis. As a last option, it is advised that it be implemented sustainably, in a suitable area, with optimal scale and with the energy consumption indirectly provided by renewable sources to optimise the facility financially as well as mitigate negative environmental effects.

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Appendix: Case study

A case study was done on a small desalination plant built at the V&A Waterfront in Cape Town. This company, who would like to remain anonymous, has a small reverse osmosis desalination plant (Figure 6.1) that can produce 47.3 kl of potable water per day. However, it currently only produces up to 30 kl/day due to regulatory restrictions. The plant provides 100% of the approximately 25 kl/day potable water needs for the building and also provides water to surrounding buildings. There are plans to install an additional reverse osmosis system that will increase the water production to 72 kl/day, once regulatory issues have been resolved. The efficiency of the plant increases with increased water production, making it is desirable to keep the plant running continuously and as close to full capacity as possible. The current desalination plant was built in a vacant storeroom, but the upgrade will require additional space and will most probably reduce allocated parking areas. The building also has a 124 kW_p rooftop solar-photovoltaic system installed that slightly offsets the electricity consumption of the desalination plant.

The plant has been operational since 14 October 2017 and has produced 1.6 Ml of potable water and consumed 16 634 kWh of energy up to 15 March 2018.

Figure 6.1: Reverse osmosis desalination plant

Figure 6.2 shows the seawater system currently running in the building. Seawater is pumped from the harbour into the building using up to three 265 kl/hr pumps. This water is used for cooling in the building, after which it is returned to the harbour. Seawater is taken from the cooling return line to be desalinated at a rate of 6.7 kl/hr, of which 1.97 kl/hr becomes potable water and 4.73 kl/hr is discharged as brine. Before discharging the brine back into the harbour, it is diluted at a minimum factor of 22:1, using the seawater discharge of the cooling system. On week days, the building uses 25 kl/day and the remaining water produced is sold to surrounding buildings. The water produced by the plant over weekends is sold to surrounding buildings and/or injected into the V&A Waterfront water system.

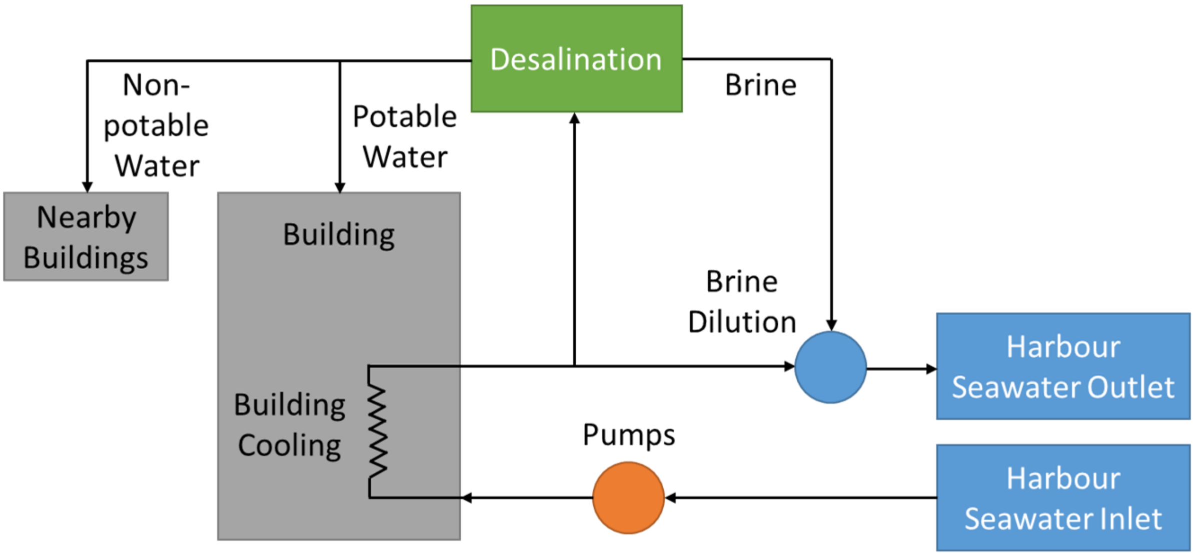

Figure 6.2: Seawater cooling and desalination schematic

The planned upgrade to the desalination system is to provide water independence in the event of the City of Cape Town water department not being able to supply water due to the persisting drought. In this event, the company would also stop selling water to surrounding buildings and allow their own employees to take home an allocated 25 l/day.

The quality of the water is checked by measuring its conductivity and acidity or basicity (pH) level. The produced water has a low pH that is immediately raised to avoid the absorption of unwanted minerals from the piping system. The water is then filtered and disinfected with sodium hypochlorite.

See Table 6.1 and Table 6.2 for a breakdown of the Capex and Opex. According to employees of the company close to the project, the total net present value (NPV) of the project over 15 years is R6

711 655, using a current cost of R21/kl as billed by the council for water and sewage and a 10% increase on this charge per year over the 15 year life cycle of the plant. The plumbing cost shown includes the infrastructure put in place to provide neighbouring buildings with water. This water is sold to them at non-potable water at 70% the rate of council water, which is done to remove liability from the company.

Table 6.1: Breakdown of the capex in establishing the desalination plant

Service	Amount
Environmental specialist	R85 000
Electrical work	R68 509
Aquamarine	R700 056
Marine engineering	R247 000
Water quality testing	R23 000
Plumbing	R56 527
Thermography consulting	R10 840
Import agencies	R92 000
Chemicals	R44 862
Total	**R1 327 794**

An important environmental concern with desalination is the discarding of high salinity brine produced by the plant. The company commissioned an environmental impact study that looked at the marine biology in the harbour, where their water is sourced, and tested the salinity of the water. The salinity of the harbour water is approximately 35g of salt per 1kg of water, which is normal for seawater. Increased salinity levels will start to affect marine life if it is increased to 38g/kg water. It was agreed with the National Department of Environmental Affairs that the salinity of the water at the seawater inlet as well as 10m away from the brine outlet is continuously monitored. The salinity difference between the inlet and outlet may not deviate more than 1g/kg water from the original salinity (35g/kg water).

Table 6.2: Breakdown of the Opex and predicted total cash flow impact of installing the desalination plant

Year	Maintenance Cost [R/year]	Electrical Cost [R/year]	Depreciation [Rand]	Total Annual Opex [R/year]	Water Cost if no Desalination Plant were Installed [R/year]	Cash Flow Impact [R/year]
2017 [1]	R13 382.65	R21 614.40	R55 325	R90 322	R125 807.50	-R1 305 607
2018	R70 660.39	R111 847.68	R265 559	R448 067	R456 706.25	R486 379
2019	R77 726.43	R125 269.40	R265 559	R468 555	R502 376.88	R533 367
2020	R85 499.07	R140 301.73	R265 559	R491 360	R552 614.56	R584 855
2021	R94 048.98	R157 137.94	R265 559	R516 746	R607 876.02	R641 270
2022	R103 453.88	R175 994.49	R210 234	R489 683	R668 663.62	R703 079
2023	R113 799.27	R197 113.83	R0	R310 913	R735 529.98	R770 790
2024	R125 179.19	R220 767.49	R0	R345 947	R809 082.98	R844 961
2025	R137 697.11	R247 259.59	R0	R384 957	R889 991.28	R926 200
2026	R151 466.83	R276 930.74	R0	R428 398	R978 990.41	R1 015 171
2027	R166 613.51	R310 162.43	R0	R476 776	R1 076 889.45	R1 112 603
2028	R183 274.86	R347 381.92	R0	R530 657	R1 184 578.39	R1 219 286
2029	R201 602.34	R389 067.75	R0	R590 670	R1 303 036.23	R1 336 090
2030	R221 762.58	R435 755.88	R0	R657 518	R1 433 339.85	R1 463 958
2031	R243 938.84	R488 046.58	R0	R731 985	R1 576 673.84	R1 603 924
2032	R268 332.72	R546 612.17	R0	R814 945	R1 734 341.22	R1 757 116

[1] 2017 was not a full year, the facility started operating on 14 October 2017

Figure 6.3 and Figure 6.4 show the cash flow and cumulative costs comparisons between installing the desalination plant and continuing to purchase water from the municipality over 15 years. It is clear that the desalination plant has a high capital cost, however the cost of operation is lower than the cost of municipal water, currently and in the future, and therefore the plant is expected to break even by 2024 (7 years) according to Figure 6.4, after which the company will see the financial benefits of the desalination plant for the remaining 8 years.

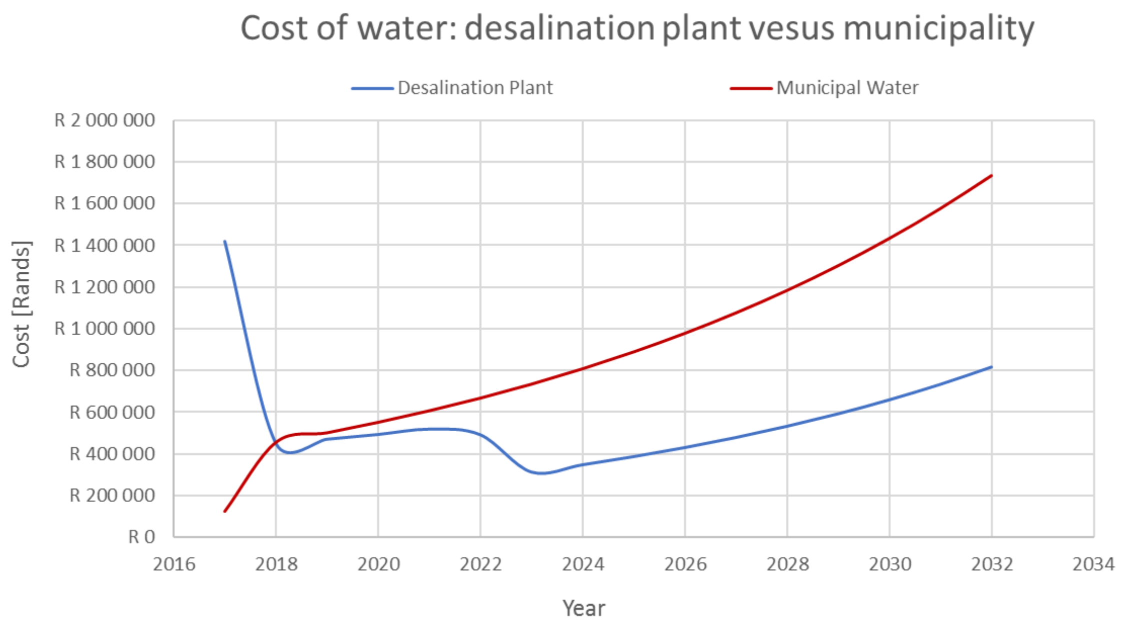

Figure 6.3: Comparative cost of water each year between the desalination plant and purchasing water from the municipality over 15 years

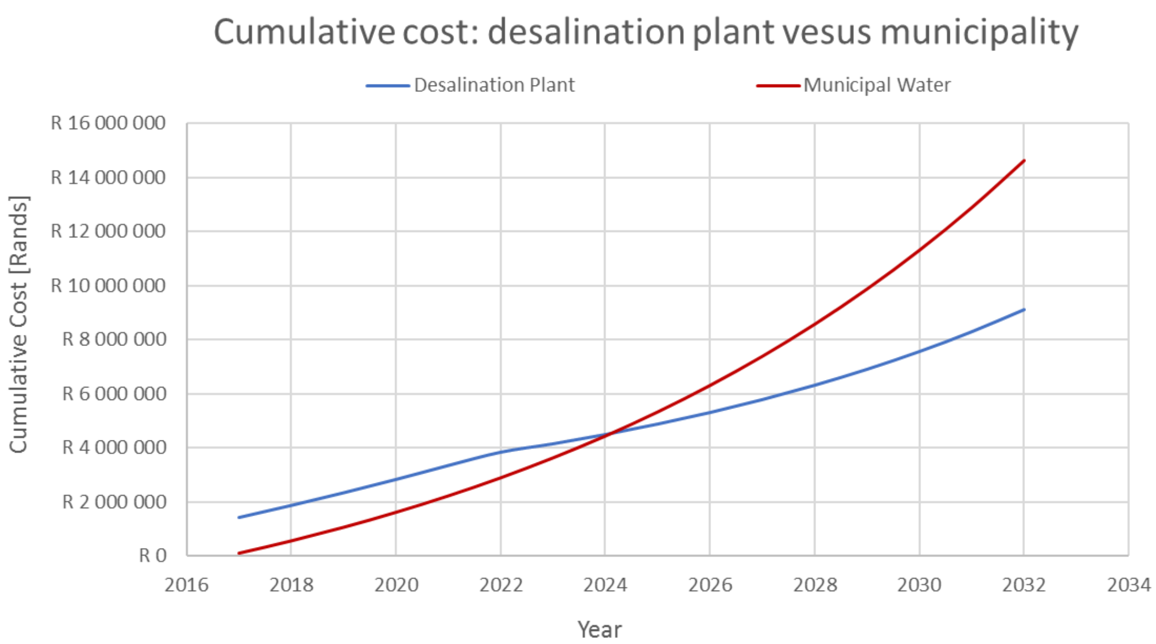

Figure 6.4: Cumulative cost comparison between the desalination plant and purchasing water from the municipality over 15 years