

Desalination within the water-energy-climate nexus

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ABSTRACT

Population growth and increasing urbanisation, deteriorating infrastructure, poor water governance and climate change have the potential to further exacerbate water scarcity in South Africa. As such, the country has become increasingly interested in the potential to utilise large-scale seawater reverse osmosis (SWRO) plants to augment existing water supply options. This particularly applies to growing coastal metropolises such as eThekweni, the City of Cape Town (CoCT) and Nelson Mandela Bay Municipality (NMBM) where water demand increasingly steadily. While SWRO has been touted as a means of alleviating water scarcity, within South Africa's coal dominated energy mix, it is energy intensive and could indirectly account for a significant increase in national greenhouse gas emissions (GHGs). With this in mind, the authors describe some of the background trends accentuating water scarcity in South Africa, how SWRO might be used as an adaptive response measure and some of the key consequences related to GHG emissions from SWRO water production. The analysis concludes that coupling SWRO with renewable energy technologies presents a more sustainable solution to water scarcity that conventional water production sourced from carbon intensive energy sources.

INTRODUCTION

South Africa is water-stressed and already uses existing freshwater resources intensively (DEA, 2013). The poor water endowment makes sound water management and major investment in water infrastructure a necessity for economic growth and poverty reduction. As such, seawater reverse osmosis (SWRO) in growing coastal cities is becoming an increasingly attractive option for water purveyors who have a constitutional mandate to supply potable water of a sufficient volume and quality to the populous. The sparked interest in SWRO is particularly evident in three growing South African metropolises - eThekweni, the City of Cape Town (CoCT) and Nelson Mandela Bay Municipality (NMBM). However, SWRO is energy intensive and South Africa's current energy mix is carbon intensive. It is something of an irony that a water supply technology to increase resilience to climate change would, in turn, contribute to climate change. At the same time, South Africa has an abundance of renewable resources which become increasingly cost-competitive. If large-scale SWRO plants are deployed along growing metropolises in coastal regions, how will these plants contribute to climate change adaptation and the ability to alleviate water scarcity? What will the consequences be for the national GHG emissions inventory? What is the potential to mitigate these consequences through planning for large-scale SWRO by considering renewable energy alternatives?

FACTORS AFFECTING WATER AVAILABILITY IN SOUTH AFRICA

Population growth and water governance

Coastal metropolises play a significant role in South Africa's landscape and economy. In 2013, of the national population, CoCT housed 7% (4 million people), eThekweni 6.6% (3.5 million people) and NMBM just over 2% (1.2 million people) (SACN, 2016; StepSA, 2015). eThekweni and CoCT showed significant growth over the last few years, due to natural population growth and significant national and international in-migration (SACN, 2016). This has been prompted partly by a national developmental agenda to increase the economic productivity of large ports and expand the national economy around identified port industrial nodes.

Water supplied into the three bulk distribution networks range from 200 to 260 liters per person per day (l/p/d) (see Table 1 – DWS, 2015) versus approximately 100-150 l/p/d in European countries and

400 l/p/d for the United States. Although water is a capital intensive industry requiring a large capital outlay prior to cost recovery, South Africa has developed multi-year water storage capacity and an extensive system of inter-basin transfers to increase resilience to water scarcity. Most infrastructure has been developed, and is managed, by the national Department of Water and Sanitation. These require ongoing maintenance and investment in rehabilitation but have proven reasonably tolerant to underinvestment over protracted periods. Therefore, water utilities in South Africa can decline considerably but still ‘function’, albeit poorly.

In South Africa, ‘non-revenue water’¹ provides a proxy indicator for management efficacy. Table 1 shows non-revenue water, water losses and Infrastructure Leakage Index (ILI) data for CoCT, NMBM and eThekweni. There is some variability between metropolises and performance ranges from average in the case of CoCT; to poor in the case of eThekweni and NMBM.

Table 1: Water management efficiency (DWS, 2015; City of Cape Town, 2016; NMBM, 2006; Moodliar 2015)

Metro	2013-2014					Forecast
	System input volume (MI per day)	System input volume (l per capita per day)	% NRW	% Water losses	ILI	System input volume (MI per day)
Cape Town	863 (940 in 2015)	196	21.1	13.9	2.3	1 480 in 2035
eThekweni	912	257	39.4	38.2	6.8	1 455 ^(*) in 2035
Nelson Mandela Bay	295	244	42.3	40.3	6.2	450 in 2025

(*) Given a 0.5% water loss reduction from 2016/2017

A recent review of water infrastructure serving South Africa’s cities, undertaken for National Treasury in 2016, concluded that “*there is increasing evidence that the water reticulation network (through which water is distributed to customers) is becoming less reliable, resulting in more frequent and more severe unplanned water disruptions in many of South Africa’s cities and towns.*” This suggests that while climate change and increasing population growth will play a significant role in accentuating water scarcity in South Africa, the ‘root’ cause of shortage of supply must be attributed to poor governance and lack of effective leadership (Auditor-General, MFMA 2014-15 consolidated general report on audited outcomes).

Climate change

Rainfall projections show a general drying pattern over South Africa, in particular in the south-west where the duration of dry spells is expected to increase (Engelbrecht *et al.*, 2013). An increase in the frequency of both heavy and extreme rainfall events is likely over the eastern parts of the country during the summer months (Figure 1).

¹ Non-revenue water refers to all the water that is lost through physical leakage or commercial losses (meter under-registration, billing errors, theft etc.) as well as any unbilled authorised consumption (fire-fighting, mains flushing etc.).

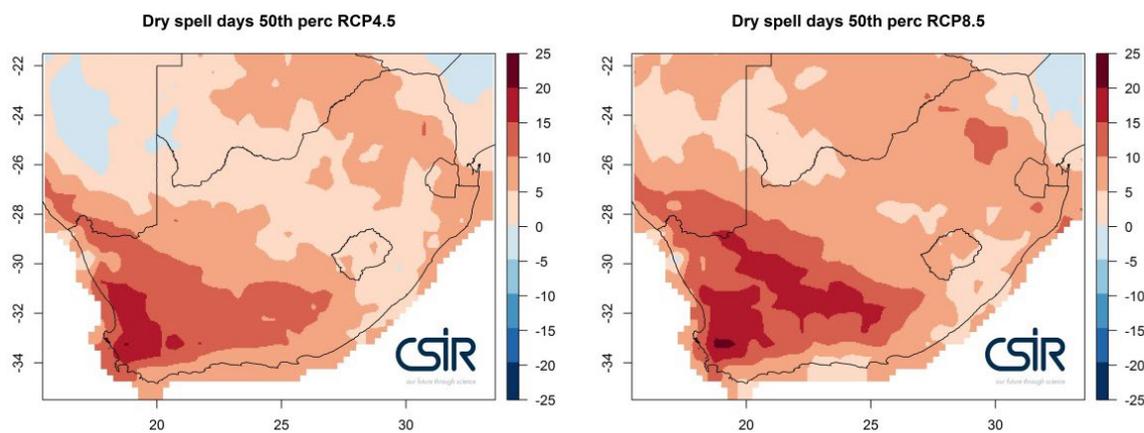


Figure 1: Projected changes in rainfall for South Africa measured as the number of dry spell days.²

SEAWATER REVERSE OSMOSIS

Global installed desalination capacity in 2016 was 88 900 Ml/day, the majority comprising one of three technologies: reverse osmosis (RO) (67.1% of which 53 429 Ml/day is dedicated to SWRO), multi-stage flash (19%) and multi-effect distillation (7.2%) (IDA, 2017). Given improvements in RO energy efficiencies, preference is now afforded to SWRO whose energy consumption, while salinity dependent, ranges from 3.5kWh/m³ (39 000ppm) to 4.25kWh/m³ (46 000ppm) including pre-treatment. This is lower than multi-stage flash and multi-effect distillation which range from 4.7 to 7.3kWh/m³ of potable water (Fichtner, 2011).

The largest SWRO plant commissioned to date is the 540Ml/day Soreq SWRO plant in Israel. A number of small-scale RO plants have been installed in South Africa. Feasibility studies for larger scale SWRO plants (150 to 450Ml/day) are underway for Cape Town and Durban. Table 3 shows average values for capital expenditure (CAPEX), operational and maintenance costs and the cost of water production for desalination plants in the MENA region³ as well as projected costs for a 150Ml/day SWRO plant in South Africa.

Table 3: Summary of average desalination costs in MENA³ Region (after ALMAR, 2016)

Desalination Plant Type	CAPEX (Million US\$/MLD)	Operational and Maintenance (O&M) Cost (US\$/m ³)	Cost of Water Production (US\$/m ³)
SWRO Mediterranean Sea	1.2	0.35	0.98
SWRO Arabian Gulf	1.5	0.64	1.35
SWRO Red Sea	1.5	0.51	1.38
Hybrid SWRO	1.3	0.35	1.03
MSF	2.1	0.26	1.44
MED-TVC	1.4	0.14	1.39
Hybrid MSF/MED	1.8	0.23	1.15

Note 1: Projections for a 150ML/day SWRO in eThekweni, South Africa show that CAPEX would range roughly between 2.0 to 2.2 Million US\$/MLD, the cost of water production is estimated at about 1.03 US\$/m³ and O&M: 0.6 US\$/m³ in 2027 when the plant would be at full production.

² Based on Representative Concentration Pathways (RCPs), RCP 8.5 and RCP 4.5, which assume different paths of development for the world. RCP 4.5 describes a future with relatively ambitious emission reductions and RCP 8.5 with no reductions in emissions (Meinshausen et al., 2011).

³ Middle East and North Africa

COUPLING SWRO WITH RENEWABLE ENERGY

While South Africa's energy mix is still overwhelmingly dominated by domestic coal, the country has committed to developing 55 GW of renewable energy (wind and solar photovoltaic sources) by 2050 (DoE, 2016). The annual solar resource for CoCT, NMBM and eThekweni are 1900-1950kWh/m², 1700-1750kWh/m² and 1550-1700kWh/m² respectively.

Assuming a case-study of a 300ML/day large-scale SWRO plant located in or near Cape Town. Based on a ratio of 1ha solar field per ML (after ALMAR, 2016), this would require approximately a 300 ha solar field, corresponding roughly to a 150 MW solar PV farm.

Assuming 1.42 L of freshwater is used at coal-fired power stations in the production of 1 kWh electricity and approximately 1.03kg of CO₂ will be emitted to the atmosphere (ESKOM, 2012), equating to approximately 1.07kg CO₂-equivalents⁴ (CO₂eq) (Latterman, 2010) and based on an estimation of 0.11kg CO₂eq/kWh by a photovoltaic solar plant (Baldwin, 2017), coupling a large scale SWRO plant with supply from a solar farm would lead to carbon savings of 1 007 tons of CO₂eq per day. This constitutes 0.09% of South Africa's greenhouse gas emission reduction policy of 428 Mtpa CO₂eq by 2050 (RSA, 2011).

The REIPPPP solar photovoltaic electricity price was probably determined for sites with near-ideal annual solar resource levels of $\geq 2\ 000$ kWh/m². Based on the solar resources in the vicinity of the CoCT, this suggests that large-scale photovoltaic plants built for SWRO may generate electricity at costs, in the order of, of ZAR 0.64/kWh.

For Cape Town, electricity costs have been calculated at approximately 64 ZARc/kWh for solar power (= ZAR 2.24/m³ potable water) and range from ZAR 1.07 to ZAR 1.14/kWh for municipal electricity during standard demand (=ZAR3.75 to ZAR 5/m³ potable water). Supplying a SWRO plant in Cape Town with solar energy would therefore lead to roughly a 41 to 44% electricity cost savings, which can be translated to roughly 20% O&M costs savings (given that electrical energy makes up for approximately 51% of O&M costs). To guarantee a reliable production of potable water, it is however still recommended to have the municipal grid as a back-up for when supply is insufficient and as a customer of excess electricity generated on good days.

DISCUSSION

South Africa is facing significant challenges to matching increasing water demand with limited supply options, reduced water quality and inefficient use of existing infrastructure and resources.

It seems evident that significant attention should be paid to the reduction of water losses from poorly maintained infrastructure and further implementation of water conservation and water demand management strategies, including the re-use of water particularly in coastal cities where wastewater is lost to sea via marine outfall. A reduction of water losses requires better asset management and maintenance/refurbishment of infrastructure by all institutions in the country as well as an improvement in effective leadership and governance in affected municipalities (Auditor-General, MFMA 2014-15 consolidated general report on audited outcomes).

There is an increasing interest in SWRO as an option to alleviate water scarcity. This trend is intensified by the impacts of climate change on available surface- and groundwater resources. In this respect, the South African National Water Resource Strategy 2 (DEA, 2013) and the National Desalination Strategy (DWS, 2011) both envision the use of SWRO in coastal regions of the country as a long-term strategy to respond to an increasing water demand.

Climate change mitigation takes preventive actions through reduction of GHG emissions, while climate change adaptation is generally an iterative process of avoiding harm and exploiting opportunities (Field et al., 2014). SWRO can be seen as an adaptation option, as it strives to augment

⁴ CO₂eq is a measure used to compare the emissions from various greenhouse gases based upon their global warming potential.

existing water supplies that may be vulnerable to a changing climate. However SWRO is energy intensive and thus with a majority of South Africa's energy coming from coal, is also emissions intensive (DEA, 2016). Without use of low-emission energy sources such as renewable energy sources, an increased use of SWRO with the current energy mix would increase GHG emissions and contribute negatively to climate change mitigation efforts.

The extent to which energy requirements are likely to place constraints on the adoption of SWRO plants in line with national commitments to carbon emission reduction is to be considered. Cape Town, Port Elizabeth and Durban are known for suitable solar and wind energy. The coupling of SWRO desalination plants with renewable energy in the studied coastal cities and the continuous improvement in energy efficiency of desalination technologies therefore has the potential of providing a sustainable and environmental friendly source of potable water. Additionally, where there is sufficient waste heat available, desalination technologies such as multi-effect distillation, may also be considered, for example, adjacent to a nuclear power station facility or a refinery, as it is the case for Cape Town and Durban respectively.

Although resources are not an absolute constraint, South Africa's low economic growth and high indebtedness constrain the availability of government grants and more reliance will need to be placed on commercial finance to support investments in urban water infrastructure. Urban water projects lend themselves to project finance and a desalination plant serving a city could be financed this way.

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