THE SUSTAINABILITY IMPACTS AND OPPORTUNITIES OF REVERSE OSMOSIS (RO) PLANTS ON THE QUADRUPLE BOTTOM LINE PERSPECTIVE: A CASE OF THE EASTERN CAPE PROVINCE, SOUTH AFRICA

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By: Cwayita Mfihlo

SUPERVISED BY:

Ms. Leticia Greyling

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ABSTRACT

Water scarcity is a pressing global issue exacerbated by factors such as population growth, urbanisation, and climate change. This challenge is particularly acute in water-stressed regions where a substantial portion of the world's population resides. Desalination, particularly through reverse osmosis (RO), has emerged as a viable solution to address this demand, providing a stable and high-quality water supply without overburdening natural freshwater ecosystems. This research focuses on the sustainability impacts and opportunities of RO desalination plants, specifically examining the Cerebos SA plant in Gqeberha and the Amatola Water plant at Bushman's River, to provide insights into their environmental, social, economic, and governance impacts and opportunities from a life cycle perspective. In addition to investigate the key sustainability considerations relevant to RO desalination plants to potentially augment available water provision sources in the Eastern Cape.

Ten participants were purposively sampled from Ndlambe Municipality, Cerebos S.A, and Amatola Water. Semi-structured interviews and document analysis were used to collect data. The research design was grounded in the post-positivism paradigm, emphasising the incorporation of diverse perspectives and the search for valid and reliable evidence within existing phenomena. Three strategies were used to ensure credibility data for this study, these were triangulation, diverse participant selection, and audio interview transcription using Otter.ai. The results from the research offered valuable insights into the sustainability impacts and opportunities of the RO desalination plants from the Life Cycle perspective, although the respondents demonstrated a clear understanding of sustainability, the concept of QBL was less familiar to many. Furthermore, the respondents unpacked QBL impacts and opportunities from a life cycle perspective and augmentation consideration for RO desalination plants.

Key recommendations included conducting thorough environmental impact assessments, transitioning to renewable energy sources, energy recovery systems, inventory management, and enhancing community engagement and workforce training. Despite limitations in scope and participant diversity, the findings fill a gap in the literature, offering valuable insights for stakeholders to enhance water provision sustainability.

DECLARATIONS

I declare that the Dissertation/Thesis entitled, 'The sustainability impacts and opportunities of reverse osmosis (RO) plants on the quadruple bottom line perspective: a case of the Eastern Cape province, South Africa', which I hereby submit for the degree, Master of Business Administration at Rhodes University, is my own work. I also declare that this thesis/dissertation has not previously been submitted by me for a degree at this or any other tertiary institution and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

Cwayita Mfihlo

c.mfihlo

Name Surname (signed)

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TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

CIP	Cleaning In Place
C2C	Cradle-to-Cradle
C2G	Cradle-to-Grave
ERS	Energy Recovery System
GHG	Greenhouse Gas
LCA	Life Cycle Assessment
MED	Multiple Effect Distillation
MSF	Multi-Stage Flash
QBL	Quadruple Bottom Line
RO	Reverse Osmosis
SDGs	Sustainable Development Goals
TBL	Triple Bottom Line

LIST OF APPENDICES

Chapter 1: Introduction and Background

1. Setting the context of the study

Water is a natural resource that is valuable for humans and the ecosystem (Danoun and Jones, 2007). Water is a crucial issue that is addressed within the framework of the Sustainable Development Goals (SDGs). The SDGs serve as a blueprint for achieving a better and more sustainable future for all by addressing various global challenges such as poverty and inequality (United Nations, 2015). Among the 17 SDGs, Goal 6 specifically focuses on ensuring access to clean water and sanitation for all individuals. It recognises that the water demand is increasing due to factors such as rapid population growth, urbanisation, and the growing water needs from sectors like agriculture, industry, and energy (United Nations, 2015).

One of the most serious global issues is water scarcity, with over one-third of the world's population residing in water-stressed regions (Elimelech and Phillip, 2011). There are two main types of water scarcity: physical and economic scarcity (Kumar and Ladha, 2011). Physical scarcity occurs when population demand exceeds the region's available water resources, whereas economic scarcity occurs when water is plentiful but inaccessible owing to a lack of major investment in water infrastructure (Kumar and Ladha, 2011). Economic scarcity is a major challenge because of the intensifying climate change. Water plays a significant role in a country's economy and drives most economic activities. An increase in population size, industrial activities, drought frequency, and intensity caused by climate change have increased the demand for clean water (Danoun and Jones, 2007).

Globally, the demand for freshwater will exceed the supply by 40% in 2030 (Harvey, 2023). In South Africa, the water demand is projected to exceed the supply by 17% in 2030 (CSIR, 2021). To manage this increase in water demand, it is essential to ensure that additional water sources are available as the existing sources are unpredictable, with so much uncertainty due to climate change (no rainfall) or decline in quantity or quality (Cooley, Gleick, and Wolff, 2006). Desalination of seawater has been identified as a possible response to meeting the increased water demand, specifically in water-stressed areas near the coast (Cooley et al., 2006). Seawater desalination provides an infinite and consistent high-quality water supply while not compromising natural freshwater ecosystems (Elimelech and Phillip, 2011).

The research aims to provide valuable insights into the sustainability impacts and opportunities of reverse osmosis (RO) plants. Furthermore, it will explore how RO desalination plants can be augmented to the available water provision sources, helping to inform the decision-making process, improve water resource management strategies, and contribute to achieving water security and SDG Goal 6 (ensuring access to clean water and sanitation for all individuals).

1.1. Desalination technologies: Overview of the processes

Seawater desalination is a process that separates seawater from salt into freshwater components and concentrates (Fthenakis, Atia, Morin, Bkayrat and Sinha, 2016). There are over 18,400 desalination plants worldwide (International Desalination Association, 2016). Figure 1 shows a summarised schematic diagram of the reverse osmosis (RO) desalination process. In this process, seawater serves as the input along with energy, resulting in the production of freshwater, brine water, and greenhouse gas (GHG) emissions as outputs (Dawoud and Mulla, 2012).

Figure 1: Schematic presentation of the desalination process (Source: Dawoud and Mulla, 2012).

There are different desalination techniques, and these different techniques are used in different parts of the world (Fischer, Kühl and Govender, 2019). These are outlined in Figure 2 hereafter. Desalination technology is classified into two groups: thermal distillation (Multi-Stage Flash (MSF) and Multiple Effect Distillation (MED)) and membrane separation (Reverse Osmosis), with some hybrid plants combining thermal and membrane technology (Mezher, Fath, Abbas and Khaled, 2011).

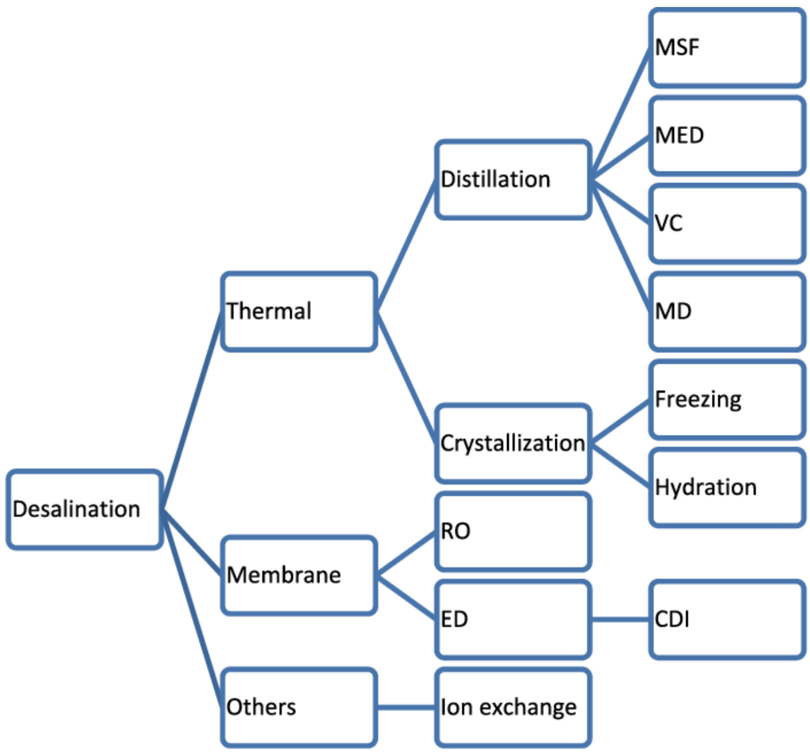

Figure 2: Different desalination plant technologies (Source: Zain and Fath, 2012).

Thermal technologies imitate the natural water cycle's evaporation and condensation process to produce water that is low in salt concentration, though in smaller quantities, and membrane technologies work by permitting or blocking some salt ions (Mezher et al., 2011). Reverse Osmosis (RO) is the most used desalination technology, as highlighted below in Figure 3.

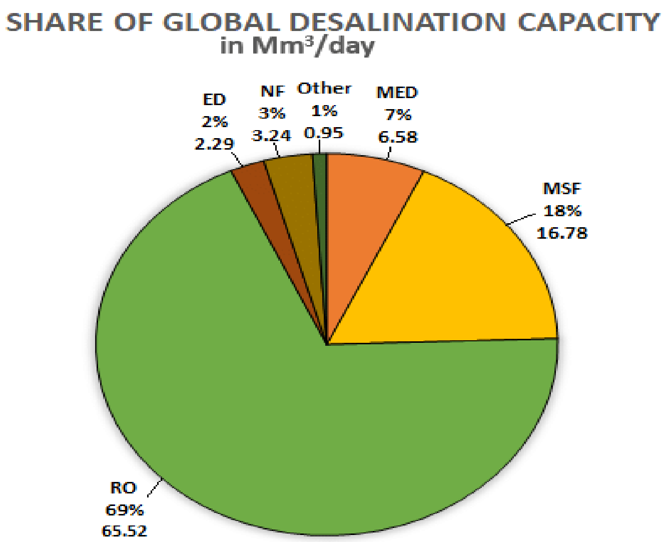

Figure 3: Desalination capacity of the world (Source: Miller, 2003)

RO uses membranes to separate salt from the water and is powered by pressure (Mezher et al., 2011). During the process, seawater is pumped at high pressure into a sealed high-pressure vessel containing a membrane. Permeate (pure water) passes through the membrane, while the brine is blocked and discarded as reject brine, a key byproduct of the RO process (Mezher et al., 2011). Globally, reverse osmosis accounts for 53% of desalination technologies, and this process is simple and requires less energy to run (Lee and Jepson, 2021).

1.2. Sustainability consideration of RO desalination plants

The water supply sources, and the environment are not resistant to change caused by increased urbanisation, pressure, and governance challenges (Johannessen and Wamsler, 2017). RO desalination plants have the potential to address the increasing water demand, as seawater is a more stable water source. However, as with any process, it is important to understand the impacts and opportunities thereof. The term 'sustainability' has been defined by numerous authors. In 1987, the Brundtland Commission published a report defining sustainability as a development that meets the needs of the present generation without compromising its ability to meet the needs of future generations (Brundtland, 1987). Besides the Brundtland definition, there have been other definitions of sustainability. Alibašić (2017) defines sustainability as "a set of effective and efficient actions taken by an organisation through good governance to ensure the economic sustainability, growth, and financial success with the most positive societal outcome and least negative environmental impact" (Alibašić, 2017; pg. 40).

Sustainability is a fundamental concept that mandates the balance of social, economic, environmental, and governance factors to ensure the planet's continued existence (Aras and Crowther, 2008). As a result of pressure from stakeholders and society, sustainability is gaining prominence, and becoming one of the most important topics debated in the world today (Correia, 2019).

Sustainability and Triple Bottom Line (TBL) can be used interchangeably. The TBL concept is under sustainability and was first conceived by Elkington in 1997. Quadruple Bottom Line (QBL) is an extension of the TBL. Governance was added as the fourth pillar in the TBL (Alhaddi, 2015). To better understand the RO desalination plants, the economic, social, environmental, and governance impact of these plants will be explored, and all these concepts will be explained in more detail in Chapter 2.

1.3. Research problem

Water scarcity is a pressing global issue exacerbated by factors such as population growth, urbanisation, and climate change. This challenge is particularly acute in water-stressed regions where a substantial portion of the world's population resides. The demand for clean water continues to escalate, driven by diverse sectors, including agriculture, industry, and energy. Ensuring universal access to clean water and sanitation remains a goal, as outlined in Sustainable Development Goal 6 (SDG 6).

In response to this critical issue, the Reverse Osmosis (RO) desalination process has emerged as a promising solution (Cooley et al., 2006). RO desalination plants can deliver constant and high-quality water, potentially alleviating the strain on conventional freshwater sources (Elimelech and Phillip, 2011). However, while RO desalination holds promise as a water supply solution, its sustainability implications are not yet fully understood (Shokri and Sanavi Fard, 2022).

The concept of sustainability has multiple dimensions, including environmental, social, economic, and governance factors (Aras and Crowther, 2008). To effectively address water scarcity and ensure responsible resource management, it is important to assess the impact and opportunities of RO desalination plants across these dimensions. This study's main aim is to understand the sustainability impact and opportunities of RO desalination plants with emphasis on two RO plant facilities located in the Eastern Cape of South Africa: the Cerebos SA desalination plant in Gqeberha and the Amatola Water desalination plant in Bushman's River.

The research aims to bridge a critical knowledge gap by investigating how these RO desalination plants influence the environment, society, economy, and governance approaches in their respective areas. By doing so, this study seeks to provide valuable insights that can inform decision-makers, policymakers, and stakeholders involved in water resource management. Ultimately, the goal is to contribute to the effective and sustainable augmentation of existing water supply sources using RO desalination technology, thereby enhancing water availability, and promoting progress towards achieving SDG 6.

1.4. Why the Cerebos SA desalination plant in Gqeberha and the Bushman River Mouth desalination plant in Bushman's River?

These two plants were chosen as a convenience sample (Etikan, Musa and Alkassim, 2016). Stratton (2021) defines convenience sampling as a technique used to select clinical cases or participants based on their availability near a specific location, on an internet platform, or from a customer membership list (Stratton, 2021). The reason for choosing these two plants is that they were in proximity with the researcher, and the researcher was able to access their information. Figure 4 below shows the municipalities where these plants are situated. The researcher resides in Gqeberha within the Nelson Mandela Bay municipality, and the Cerebos plant is also located in the Nelson Mandela Bay municipality. The second study plant is the Amatola Water Plant, situated in the Ndlambe municipality, which is an hour and 30 minutes away from the Nelson Mandela Municipality.

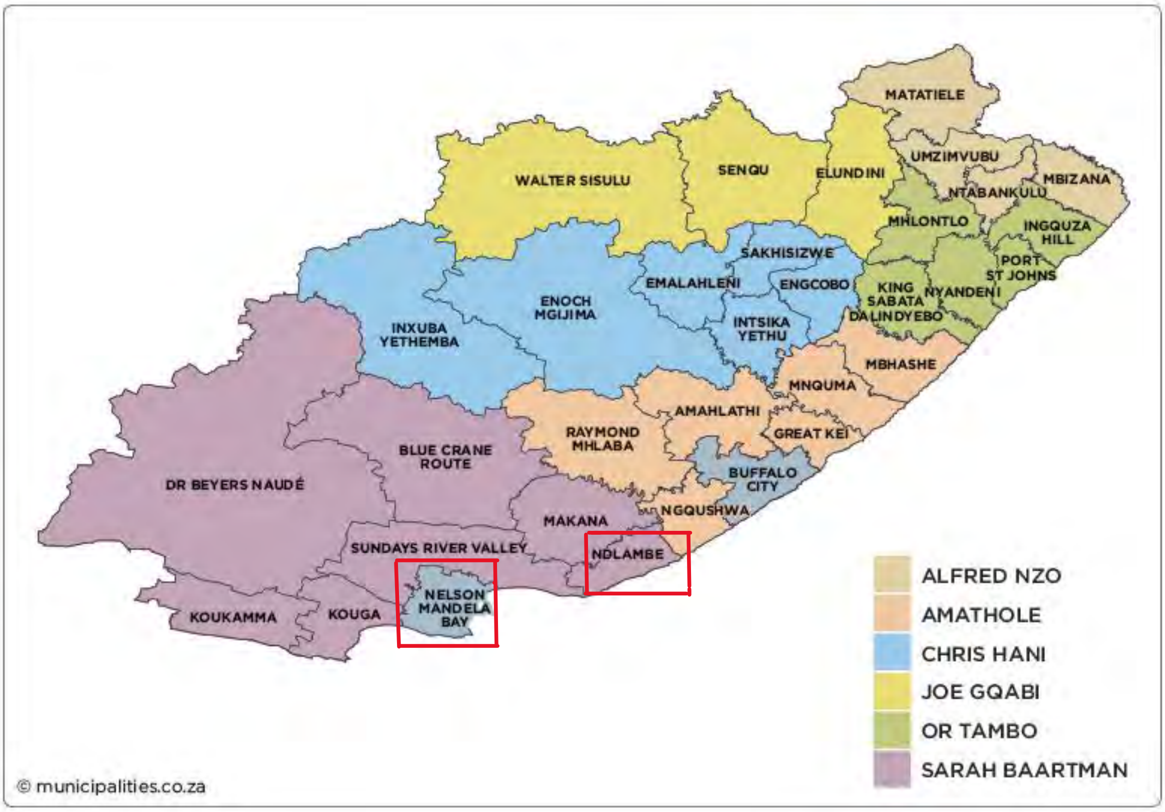

Figure 4: Map showing municipalities of the Eastern Cape (Source: South African Government, 2023).

1.5. Research aims and objectives

This research aims to investigate the sustainability impacts and opportunities of RO desalination plants, from a life cycle perspective and to investigate the key sustainability considerations relevant to RO desalination plants to potentially augment available water provision sources in the Eastern Cape.

1.5.1. The specific objectives of the study:

1. To identify the sustainability (quadruple bottom line) impacts and opportunities associated with RO desalination plants in the Eastern Cape, from a life cycle perspective.
2. To investigate the key sustainability considerations relevant for RO desalination plants to potentially augment available water provision sources in the Eastern Cape.
3. To make recommendations on how RO desalination plants could potentially augment the available water provision sources, considering all four pillars of the quadruple bottom line.
4. To formulate recommendations on the QBL outcomes of the desalination plants (from a life cycle perspective) for better utilisation and management of these plants.

1.6. Outline of the study

This study is made up of six chapters, outlined below.

Chapter 1 presents the introduction and the context of the study. It provides the context of the study, research problems, research aim and objectives, and the outline of the chapters to follow.

Chapter 2 is the presentation of the literature review on Life Cycle Assessment, sustainability, quadruple bottom line, RO desalination plants, and how these can be used to augment the available water provision sources.

Chapter 3 discusses the research methodology adopted and outlines the goals of the research and the research paradigm in detail. It explains why the method was chosen for the study. The research participants, data gathering tools, and the method of analysis and ethical consideration are also outlined.

Chapter 4 presents findings of the research on sustainability, sustainability (QBL) impacts, and opportunities of RO plants from a life cycle perspective and key considerations for augmentation.

Chapter 5 discusses findings on sustainability (QBL) impacts and opportunities of RO desalination plants from the life cycle perspective and key considerations for augmentation.

Chapter 6 offers a conclusion of the study. It provides a summary of the study, suggests sustainability and augmentation recommendations for improvements, presents research limitations, contributions of the study, recommendations for future research, and concludes the research.

CHAPTER 2: Review of Literature

2. Introduction

This chapter begins with a review of the literature on Life Cycle Assessment (LCA). The life cycle of the RO desalination plant consists of three phases: Construction, Operation and Maintenance, and Disposal. After the life cycle, it looks at the Quadruple Bottom Line (QBL) sustainability and criteria to consider before using Reverse Osmosis (RO) technologies to augment existing water supply sources. The QBL sustainability assesses the organisation's performance by looking at four pillars: environmental, social, economic, and governance. These four pillars will be unpacked in detail within this chapter. Lastly, it looks at resilience theory, which is the underpinning theory for this study.

2.1. Life Cycle Assessment (LCA)

To assess industrial systems, LCA is used. Various authors define the life cycle as a cradle-to-grave approach (Sharma, 2019) or a cradle-to-cradle approach (Pazouki, Lu, Hanandeh, Biswas, Bertone, Helfer and Swarts, 2021). The cradle-to-grave approach starts with raw material extraction from the earth for product manufacturing and stops when all material is returned to the earth (Jørgensen, Bocq, Nazarkina and Hauschild, 2008). Sherratt (2013) describes the cradle-to-cradle approach as creating and producing items in such a manner that at the end of their life, they may be fully recycled, upcycled, or returned to the environment, directly or indirectly as a safe, non-toxic, and biodegradable unit (nothing goes to waste) (Sherratt 2013). Figure 4 shows all the stages of the life cycle.

Life cycle assessment (LCA) is mainly crafted to examine the environmental effects of a product or process across its complete life cycle, spanning from the extraction of raw materials to its disposal or recycling at the end of its life (Hinton, 2021). Due to its limited scope, traditional LCA may not capture the entire spectrum of economic, social, and governance factors. Social challenges are often multifaceted and context-specific, involving aspects such as workers' safety and public health. These social aspects are more subjective and may not be adequately addressed within the framework of LCA (KPMG, 2024).

Similarly, economic factors such as production costs and market competitiveness are rarely included in LCA evaluations (Neugebauer, Forin and Finkbeiner, 2016). Furthermore, governance elements such as institutional arrangements, decision-making processes, company culture, and stakeholder interactions are frequently qualitative and context-specific (OECD, 2020). While LCA gives useful information on environmental impacts, it is not intended to address economic, social, and governance issues thoroughly.

Analysis of the product's entire life cycle enables organisations to make informed decisions about the current resource use and minimise the impact the resource use has on the environment (Fastercapital, 2024). Understanding the environmental implications over the whole life cycle allows businesses to better manage the risks associated with resource shortages, regulatory compliance, and reputational harm (Department of Environmental affairs and tourism, 2004). This proactive approach improves market resilience and competitiveness; moreover, LCA encourages lifecycle thinking, supporting innovation and the creation of long-term solutions that fulfil current demands without jeopardising future generations' capacity to meet their own (APA engineering, 2024).

Figure 5: Life cycle assessment of desalination plant (Source: Cherif and Belhadj, 2018).

To study RO desalination plants, it is essential to have an idea of their life cycle. The life cycle of the RO desalination plant consists of three main phases: Construction, Operation and Maintenance, and Disposal (Lee and Jepson, 2021). The construction phase includes infrastructure and facilities. RO desalination plants need infrastructure to aid the desalination process and support the plant's operation (Lee and Jepson, 2021). Some key infrastructures are intake structures, i.e. screens and filters; reverse osmosis infrastructure, i.e. high-pressure pumps; and post-treatment infrastructure, i.e. water reservoir. Additionally, facilities are required to house various plant components and support the plant's operation. Some facilities are desalination buildings, control rooms, laboratories, and storage facilities (Lee and Jepson, 2021).

The operation and maintenance phase encompasses a broad range of activities, from seawater extraction to its distribution and disposal (Lee and Jepson, 2021). The overall process of desalination, starting from seawater extraction and ending with disposal, involves several steps. First, seawater is extracted from its source, usually the ocean, using intake structures or pumps. The seawater is then transported to a desalination plant through a pipeline conveyance system (Aziz and Hanafiah, 2021).

At the desalination plant, the seawater undergoes treatment to remove impurities and salt, producing freshwater. The most used technology in desalination is reverse osmosis, which forces saltwater through a membrane that selectively permits water molecules to pass while preventing salt and other contaminants (Aziz and Hanafiah, 2021). This process requires energy to pump and maintain the pressure to separate freshwater from seawater (Aziz and Hanafiah, 2021).

Chemicals are commonly used at different stages of the desalination process (Aziz and Hanafiah, 2021). Disinfection chemicals may be added to kill bacteria and other microorganisms present in the seawater. Chlorine removal agents eliminate residual chlorine, which can be harmful if consumed. Mineralisation processes may add beneficial minerals to the desalinated water, improving its taste and nutritional content. Finally, potabilisation treatments guarantee that the water meets the required drinking water standards and is safe for human consumption (Aziz and Hanafiah, 2021).

Once fresh water is obtained, it is typically stored in reservoirs or tanks before being distributed to consumers or used in various industries. The distribution system may involve pipelines, pumping stations, and other infrastructure to transport the freshwater to its intended destinations (Aziz and Hanafiah, 2021).

The last step of the process is disposal. As for the disposal of byproducts, the main residual from desalination plants is brine, which is a highly concentrated salt solution. This brine is carefully managed and disposed of in an environmentally responsible manner. Depending on local regulations and environmental considerations, various methods can be employed for brine disposal, such as dilution and discharge into the ocean, deep well injection, or evaporation ponds (Aziz and Hanafiah, 2021). The life cycle of RO desalination will be used to guide the impact assessment of these plants on the QBL because it depicts all the process stages (Goel, 2010).

2.2. Evolution of the sustainability concept: From TBL to QBL

In 1987, the Brundtland Commission published a report defining sustainability as a development that meets the needs of the present generation without compromising its ability to meet the needs of future generations (Brundtland, 1987). There have been many definitions of sustainability. Alibašić (2017, pg. 40) defines sustainability as "a set of effective and efficient actions taken by an organisation through good governance to ensure the economic sustainability, growth, and financial success with the most positive societal outcome and least negative environmental impact" (Alibašić 2017; pg. 40).

Sustainability is a fundamental concept that mandates the balance of social, economic, environmental, and governance factors to ensure the planet's continued existence (Aras and Crowther, 2008). As a result of pressure from stakeholders and society, sustainability is gaining attention and becoming one of the leading topics discussed in the world today (Correia, 2019). There are three conditions that society must meet to be considered sustained: The utilisation rate should not surpass the regeneration rate; the consumption of non-renewable resources should not outpace the development and substitution rate of renewable resources; the emission of pollutants should not exceed the environmental capacity for assimilation (Elkington, 1997).

Sustainability and Triple Bottom Line Sustainability (TBL) can be used interchangeably. The TBL concept is under sustainability and was conceived by Elkington in 1997. Conceptual sustainability dates back 130 years (Alhaddi, 2015). QBL is an extension of the TBL. Governance was added as the fourth pillar in the TBL. Figure 5 shows the four pillars of QBL. Governance enhances the value of other components, ensuring sustainability efforts that leave no part is missed in the aim of establishing more sustainable organisations and communities (Alibašić, 2017).

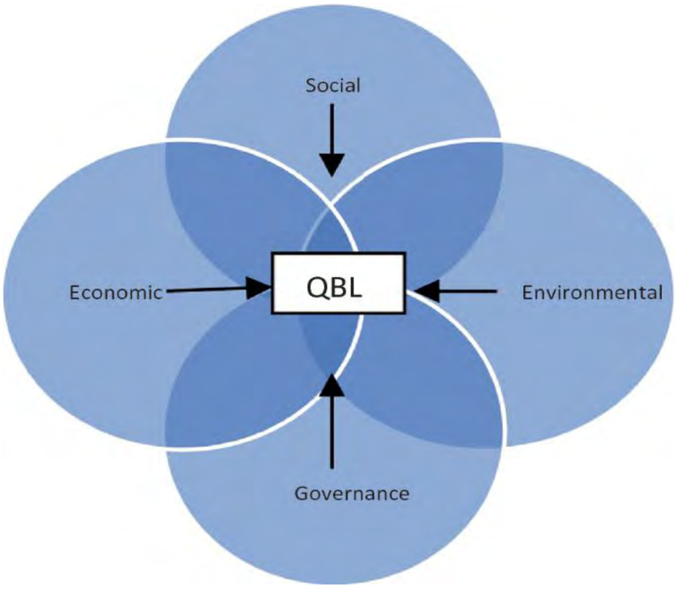

Figure 6: Quadruple Bottom Line sustainability (Source: Goel, 2010).

QBL provides tools organisations can use to assess their performance by scrutinising four sustainability pillars: economic, environmental, governance, and social (Goel, 2010). These pillars are discussed in more detail in the later sections. The quadruple bottom line holds the economic performance, natural environment, society, and governance at a sophisticated level. The junction of the social, economic, environmental, and governance factors allows the organisation to participate in activities that can positively affect all the factors of the QBL. Businesses are starting to adopt the QBL to assess their progress (Slaper and Hall, 2011).

2.3. Environmental impacts and opportunities of RO desalination plants

Environmental sustainability is about partaking in activities that do not pose a major environmental risk and compromise the resources for future generations. It includes using energy efficiently and effectively, reducing emissions of greenhouse gases, and reducing the ecological footprint (Goel, 2010).

In his study, Kearney (2009) analysed businesses that prioritised the natural environment. The study's outcome showed that when it comes to performance in the industry, the organisations that prioritise their stakeholders had a high survival rate and increased financial performance compared to those that disregard them (Kearney, 2009). The reason for financial performance is the reduction in operational costs, such as energy usage (Alhaddi, 2015).

As with any industrial process, RO desalination plants impact the environment, and it is crucial to understand these plants and how their impact can be mitigated (Cooley et al., 2006). The study will examine some impacts and opportunities of RO desalination plants on the environment (Cooley et al., 2006). Some impacts of RO desalination plants on the environment include the impacts of water intake, greenhouse gas emission, brine composition, brine water discharge, noise pollution, and temperature. The environmental opportunities of RO plants are increasing system reliability and induced coastal development and land use.

2.3.1. Environmental impacts of RO desalination plants

a) Impacts of water intake

Impingement or entrainment: Sea water is a habitat for organisms such as fish and invertebrates (York and Foster, 2005). During water intake (impingement) in RO desalination, many organisms are killed, and organisms that are small and can move past the impingement screen, such as eggs, larvae, and small fish, are killed during the seawater processing (entrainment). Both these types of organisms, entrained and impinged, are disposed of back to the sea. Upon the death of these organisms and disposal to the sea, their breakdown decreases the oxygen levels in the water around the discharge area, and this further causes stress to the marine environment (Cooley et al., 2006).

b) Greenhouse gas emissions

Running desalination plants requires an energy source. The most common energy source used is fossil fuels. The process of making energy using fossil fuels involves burning the fossil. Burning releases greenhouse gases (GHG) into the atmosphere (Intergovernmental Panel on Climate Change, 2008). GHG gases cause climate change by trapping heat. A carbon footprint is the sum of human-caused greenhouse gas emissions, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These emissions are standardised into carbon dioxide equivalents (CO_{2eq}) by accounting for the global warming potential of CH_4 and N_2O (Intergovernmental Panel on Climate Change, 2008).

Available statistics from the literature assume that the carbon footprint related to RO desalination ranges from 0.4 to 6.7 kg CO_2eq/m^3 (Cornejo, Santana, Hakanson, Mihelcic, and Zhang, 2014). This means that for every cubic meter of water produced using RO desalination, the associated carbon dioxide equivalent emission ranges from 0.4 to 6.7 kilograms, and the water recycling system ranges from 0.1 to 2.4 kg CO_2eq/m^3 (Cornejo et al., 2014). This means that for every cubic meter of water produced through water recycling systems, the associated carbon dioxide equivalent emissions range from 0.1 to 2.4 kilograms (Cornejo et al., 2014).

This suggests that RO desalination plants have significantly higher carbon emissions compared to water recycling systems.

Furthermore, it is essential to note that the carbon footprint results from direct and indirect emission sources (Cornejo et al., 2014). Direct emission sources are within the plant sources, indirect emission sources are the offsite sources, and other indirect emissions include fuel and chemicals within the plant (Huxley, Bellamy, Sathyanarayan and Ridens, 2009).

South Africa is not only experiencing water problems; the country is also experiencing electrical problems, and desalination plants can only be operated from an energy source. In 2021 alone, the country had 1130 hours of planned electricity cuts (Diemen, 2022). The electrical problems will cause a challenge in running the desalination plants, and alternative energy sources will need to be employed to ensure that the country avoids water-shedding and load-shedding simultaneously.

c) *Impact of brine composition on marine ecosystem*

The desalination process uses a significant amount of chemicals during pretreatment to prevent membrane fouling, deposits from forming into the pipelines, and the proliferation of microorganisms (Amalfitano and Lam, 2005). These chemicals are discharged with the brine into the open ocean (Cooley et al., 2006), and these are harmful to marine organisms (Gude, 2016).

The intake water for the RO system is chlorinated to prevent biofouling which forms hypochlorite and hypobromite in seawater (Dawoud and Mulla, 2012). To chlorinate the water, sodium hypochlorite is used, and sodium bisulfite is used to dechlorinate the water (Dawoud and Mulla, 2012). The dechlorination of water is conducted to prevent damage to the membrane (Dawoud and Mulla, 2012). The discharge level varies, depending on the intake water chlorination level. The chlorine discharge harms the ecosystem and open water (Dawoud and Mulla, 2012).

d) *Noise pollution*

Sadhwani, Veza and Santana (2005) note that desalination plants produce high noise levels due to operating pressures. A noise impact study conducted at Umngeni in Kwazulu revealed that the long-term effects of plant noise during operation are mainly localised near the facility (Sadhwani et al., 2005). The study suggested that implementing techniques such as insulating rooms housing plant equipment could significantly reduce noise levels (CSIR, 2016). In addition to that, leaving the doors open also exacerbates noise levels (CSIR, 2016).

e) Impact of temperature variation on marine life

According to a study by CSIR (2007), high temperatures within 5°C of ambient seawater temperature, adversely affect egg and larval development and alter the photosynthetic behaviour of algal assemblages (CSIR, 2007). Additionally, elevated temperatures tend to favour species from warmer climates, potentially leading to the extinction of local species and the proliferation of invasive species (van Erkom Schurink and Griffiths, 1993).

f) Impact of oil Spills from desalination plants

Available literature provides insights into the causes of oil spillages from RO plants, as shown in Figure 7 below.

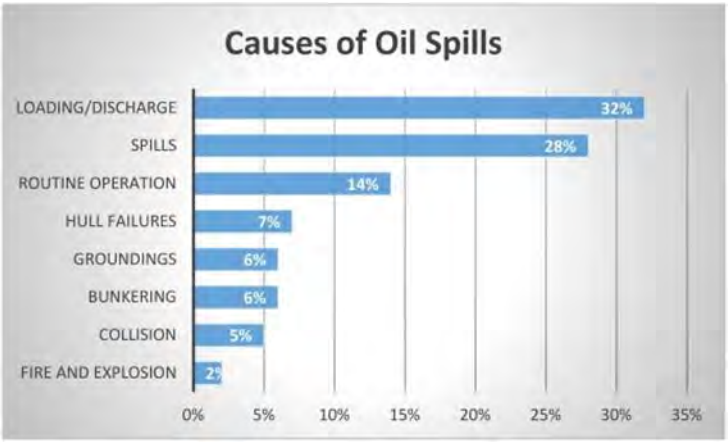

Figure 7: Causes of oil spillages (Source: Conflict Environment Observatory, 2021).

International examples of oil spillages include an oil spillage in Libya from the desalination plant itself that affected the marine population, resulting in the death of turtles and sea birds (Conflict Environment Observatory, 2021). The oil leakages not only result in the death of the marine environment, but some desalination plants have closed due to these.

In 2001, a shipwreck resulted in the release of over 1300 tons of fuel oil, forcing the shutdown of two desalination plants in the United Arab Emirates (UAE, 2001). A comparable incident occurred in Israel when approximately 100 cubic meters of oil spilt into the sea, forcing the RO plant to stop operations for three days (Ogunbiyi, Al-Rewaily, Saththasivam, Lawler and Liu, 2023).

2.3.2. <u>Environmental opportunities of RO desalination plants</u>

a) Increase water system reliability

Usually, desalination plants are operated during drought seasons, and in wet seasons they are switched off. Switching off desalination plants is costly and requires maintenance. Instead of switching these off during wet seasons, these can be operated to supply additional water (Cooley et al., 2006). Using desalination plants increases system reliability and creates water surplus during average and wet years. Ideally, customers cover the cost incurred when running desalination plants as they pay for reliability and supply expansion (Cooley et al., 2006).

Introducing desalination plants as an additional water source will alleviate pressure from the municipal lines as most of the municipal cities have exhausted most of the dams that supply the city. If the municipality utilises the available desalination plants to alleviate the water pressure, these plants will be explicitly beneficial (Cooley et al., 2006).

b) Coastal development

Several coastal areas might have developmental hindrances (e.g., developments unable to proceed due to lack of sufficient water resources); therefore, the establishment of desalination plants could alleviate the dependency on the current water supply and induce coastal area growth (Cooley et al., 2006). This induced growth will give the environment a competitive advantage as this will result in the improvement of infrastructure (Cooley et al., 2006)

2.4. Economic impacts and opportunities of RO desalination plants

Economic sustainability assesses the business impacts on the economy. Economic sustainability is about using the economy to withstand challenges and progress into the future, and assist future generations (Spangenberg, 2005). Economic sustainability merges the population economy and the organisation economy. It examines the organisational economy value to determine whether it currently improves the community and its ability to improve the future generation economy (Alhaddi, 2015).

The impact of RO desalination plants on the economy includes energy cost, plant size, location, raw water quality, pre-treatment costs, local infrastructure, and water distribution. The economic opportunities of RO desalination plants are that they ensure water supply reliability, water quality, and an increase in water availability.

2.4.1. Economic impacts of RO desalination plants

a) Energy costs

Electric energy costs account for 44% of the water costs of RO plants ((Feo-García, Pulido-Alonso, Florido-Betancor, Florido-Suárez, 2024), and the rest come from operation, maintenance, and expenses (Pinto and Marques, 2017). The energy cost among the different types of desalination plants varies; for example, in thermal desalination, energy accounts for 60% of the total cost, whereas in RO, the energy cost accounts for 44%. Generally, the energy cost of desalination plants is volatile and is greatly influenced by state energy costs (Chaudhry, 2006).

The energy cost volatility is a major disadvantage of desalination; some plants were cheaper during the commission stages, and their cost has increased over the years. The energy cost increase can potentially drive up the cost of desalination plant water. Beyond that, there is a limit to achieving improved energy efficiency (Chaudhry, 2006). The potential energy required to desalinate one litre of seawater using the RO system is about 2.8 kilojoules. Even the most efficient desalination plants use only four times this theoretical minimum, while other systems can consume up to 25 times the minimum amount (Chaudhry, 2006).

b) Plant size

Cost curves are used to predict the desalination plant's cost as a function of size. Previous cost curves have shown that the production of water by smaller desalination is costly compared to the production of water by larger desalination (Cooley et al., 2006). Furthermore, RO plants produce water at a lower cost than thermal desalination plants; the difference in production costs may be attributed to each plant's energy usage (Cooley et al., 2006).

c) Location

The desalination plants located closer to the sea are less costly compared to those far away from the sea. The construction site further away from the sea requires complex structures and longer pipelines, which might increase the production cost of these plants (Herber, 2024 (b)). The construction site must also be in proximity to electrical sources to prevent long cables and power transmission costs (Herber, 2024 (b)).

d) Local infrastructure cost

The infrastructure cost varies depending on plant location and individual item costs. These infrastructure costs include concrete, steel, structure, drainage, and building materials (Herber, 2024 (a)). Plants closer to the cities usually have a higher cost than those built close to concrete-producing areas and areas that sell building materials (Herber, 2024 (a)).

2.4.2. Economic opportunities of RO desalination plants

a) Water supply reliability

The reliability of the water supply is defined as a constant water supply based on the water demand. Water users determine reliability based on the availability of alternatives and production costs (Pinto and Marques, 2017). Water customers expect a consistent and ample supply of high-quality water and are prepared to pay a premium for it (Pinto and Marques, 2017).

Desalination plant functionality is unaffected by weather conditions and depends on desalination plant infrastructure capabilities. The available water sources are overused, highly volatile due to climate change, and less reliable (Cooley et al., 2006). This decrease in the reliability of available water sources has promoted an increase in desalination plant water reliability as their water is readily available. Proponents of desalination plant technology favour more reliable water supplies, and the reliability of these plants justifies high costs (Cooley et al., 2006).

b) Water Quality

The desalination plant water goes through several pre-treatment stages, is of good quality, and is free from contaminants. Customers are frequently willing to pay extra for higher-quality water. It is important to recognise the willingness to pay for superior quality extends beyond desalination plants and applies to all products in general (Vásquez, Raheem, Quiroga and Ochoa -Herrera, 2022). Developers of seawater desalination plant products need to carry out appropriate process investigations. This investigation should be based on selecting quality standards the community is willing to pay for. Without regulatory compliance standards or water quality to meet, there is no requirement for desalinated water quality, and thus no justification for an economic premium (Cooley et al., 2006).

c) Increase in water availability

Desalination plants not only produce additional water but also release the water available for economic activity. The desalination process is a supply-led approach to support the operation of closed industries due to the unavailability of water (Fragkou and Budds, 2020). This approach creates job stability and new opportunities for capital accumulation through producing the desalination plant's water (Fragkou and Budds, 2020). Desalination plants are an additional source of water used in times of crisis, providing additional water for critical industries. With the introduction of desalination plants, freshwater can be diverted for higher economic purposes and will not be used directly, but the release of freshwater will benefit resource allocation (Fragkou and Budds, 2020).

2.5. Social impacts and opportunities of RO desalination plants

Social sustainability refers to the process of conducting business fairly and beneficially to support labour, human capital, and the community at large. This emerges from the fact that business practices give back to society (Alhaddi, 2015). Good practices that businesses provide to their communities include fair wages, health insurance, and moral aspects. Failure of a company or system to fulfil its social responsibilities can affect its performance and sustainability. People can vote against any system that harms the community (Alhaddi, 2015).

An organisation's social performance centres on its interactions with the community, addressing matters such as local employment, equitable relationships, and fair wages (Alhaddi, 2015). The social impacts of desalination plants include their impact on households, health concerns, and consumer rejection. The social opportunities include access to quality water and accessible drinking water.

2.5.1. Social impacts of RO desalination plants

a) Impact on households

RO plant water is more expensive than dam water, and introducing RO plants will disadvantage the low-income group (Abazza, 2012). The cost of water produced by an RO desalination plant is roughly double that of dam water. Desalinated water costs R16 per kilolitre compared to R9 per kilolitre for dam water (Patel, 2018).

b) Health concerns

Potential health concerns associated with desalination plants have been identified. The water supplied to the desalination plant introduces biological contaminants, including biological and chemical contaminants that threaten human health, viruses, protozoa, unregulated chemicals, heterogeneous organisms, and algae toxins (World Health Organization, 2011).

Contaminants can be a serious problem if they are not removed in subsequent processing stages. RO can remove some chemicals, but some can pass through the RO plant and reach the final stage of the water treatment system (Cotruvo, 2005). Treatment steps can also introduce additional chemicals or new contaminants. An example is the combination of disinfectants such as chlorine and chloramines with high levels of bromide water. It can produce brominated organic by-products (Weinberg, Krasner, Richardson and Thruston, 2002) that are more likely to be carcinogenic or toxic than many chlorination by-products (Cotruvo, 2005) and this will pose a risk to humans.

c) Consumer rejection

The community's previous exposure to poor-quality water and the long-standing distrust of water suppliers and state services may cause the general populace to reject desalinated tap water (Dolnicar and Hurlimann, 2011).

2.5.2. Social opportunities of RO desalination plants

a) Accessible drinking water

Water Law 108 of 1997 (South African Government, 1997) states that one has the right to access safe drinking water. The introduction of desalination plants will bring water to areas where there is no drinking water supply. In areas with sufficient water, these plants supply water during arid areas or droughts (Ackermans, 2018). When there is excess water, these plants allow water to be used for economic activities such as construction. The resulting economic opportunities also offer opportunities for people who do not use plants (Fragkou and Budd, 2020).

b) Capital accumulation

Using desalination plants as additional water sources reveals capital accumulation and investment opportunities in these plants and strategies for supplying key industries. If there is additional water to drive economic activities, this water can be used for additional activities such as capital accumulation and job creation (Fragkou and Budd, 2020).

2.6. Water governance impacts and opportunities

Three SDG goals are crucial when discussing water-related issues: sustainable development, poverty reduction, and universal access to clean water and sanitation. There is a substantial worldwide difficulty in meeting these goals, with more than 1 billion people not having access to clean water and more than 2.4 billion people without access to basic sanitation (Batchelor, 2020). It is important to recognise that this water crisis is primarily a result of human factors and failures in water governance (United Nations Developmental Programme, 2015). The obstacles hindering the country's efforts to achieve universal access to clean water and sanitation are not solely attributable to natural water supply constraints, inadequate financing, or lacking appropriate technologies; they result from poor governance (Tortajada, 2010).

Water governance in this context refers to "the range of political, institutional, and administrative rules, practices, and processes (formal and informal) through which decisions are taken and implemented" (Tortajada, 2010; pg. 299). Moench, Dixit, Janakarajan, Rathore and Mudrakartha (2003) further simplified this definition to "water governance is a set of systems that controls decision-making regarding water resource development and management" (Moench, Dixit, Janakarajan, Rathore and Mudrakatha, 2003; pg. 15). Hence, water governance is much more about how decisions are made (by whom, how, and in what conditions) than the decisions themselves (Moench et al., 2003).

Failures in water governance can manifest in various ways, such as inadequate infrastructure development, ineffective water management policies, lack of stakeholder involvement, insufficient regulation and enforcement, and limited access to resources and decision-making processes (Batchelor, 2020). Addressing the water crisis requires comprehensive and effective water governance systems that prioritise sustainable water management, equitable distribution, and adequate infrastructure and services (Batchelor, 2020). The active involvement of governments, communities, civil society, and other stakeholders is necessary to formulate and enforce policies and strategies that guarantee fair access to clean water and sanitation (Batchelor, 2020).

In addition to improving water governance, addressing the water crisis also requires collaborative efforts to invest in appropriate technologies, ensure sustainable financing, promote water conservation and efficiency measures, and raise awareness about the importance of water resources and their sustainable management (Jiménez, Saikia, Giné, Avello, Leten, Lymer, Scheuder and Ward, 2020). By recognising the role of water governance failures in the water crisis, the country can work towards more effective and sustainable solutions that help achieve the SDG goals of universal access to clean water and sanitation, contributing to poverty reduction and sustainable development (United Nations, 2022).

The functionality of governance relies on stakeholders and decision-makers. Stakeholders voice their concerns, and decision-makers are held accountable for resource management (Tortajada, 2010). There are a few principles to consider for good water governance within this context: integrity and transparency, stakeholder engagement, and clear roles and responsibilities (OECD, 2022).

2.6.1. Principles to consider for good governance

a) Integrity

To enhance accountability and foster trust in decision-making processes, it is essential to ensure integrity and transparency throughout water policies, institutions, and governance frameworks (OECD, 2022 (b)). This may be accomplished by lobbying for legal and institutional frameworks that hold decision-makers and stakeholders responsible, such as the right to information, independent agencies to examine water-related issues, and strong enforcement of laws (OECD, 2022 (b)). These measures aim to safeguard the public interest and facilitate the identification of misconduct (OECD, 2022 (b)).

b) Stakeholder engagement

Effective stakeholder engagement is crucial for providing informed and results-driven input into the design and execution of water policies (OECD, 2022 (a)). This involves identifying and understanding the roles, interests, and interactions of diverse stakeholders — whether public, private, or non-profit — who have a stake in or may be impacted by water-related decisions. Meaningful engagement can be fostered by comprehensively mapping out these stakeholders and their responsibilities, core interests, and dynamics (OECD, 2022 (a)).

c) Roles and responsibilities

Roles and responsibilities for water policymaking (i.e., priority setting), policy implementation (i.e., financing and budgeting), operational management (i.e., service delivery, infrastructure operation), and regulation (standards) should be allocated and distinguished. A legal and institutional framework should be in place to aid in identifying gaps, overlaps, and conflicts of interest through effective coordination (OECD, 2022 (a)).

Effective water governance is required to ensure access to clean water and increase water supply (Woodhouse and Muller, 2017). The increase in the economy and societal changes put huge pressure on the water system. By 2030, it is projected that water demand in South Africa will exceed supply by 17% (CSIR, 2021). The available water resources are fully allocated; there is no additional supply available.

2.6.2. Water governance impacts

The impacts of water governance include economic, environmental, and political change, stakeholder participation, and poor governance.

a) Economic, environmental, and political change

Water governance faces the challenge of incorporating and adapting to the dynamic interplay of economic, political, and environmental factors (Cleaver, 2000). The fundamental issue lies in developing water governance systems that can effectively respond to and navigate these domains' uncertainties, unpredictability, and changes (Cleaver, 2000). Attempting to create strategies and plans that comprehensively address all water management issues, both present and future, is impractical.

Instead, the important aspect is to enhance the effectiveness of water governance capacity, enabling society to adequately address and adjust to different types of uncertainty, variability, and transformation (Cleaver, 2000). This entails developing robust information systems, establishing platforms for stakeholder engagement, implementing appropriate legal and regulatory mechanisms, enhancing executive capabilities, and establishing effective conflict resolution systems (Batchelor, 2020). By strengthening water governance capacity, the complexities of water management can be addressed and sustainable outcomes in the face of diverse and evolving challenges can be fostered (Batchelor, 2020).

b) Stakeholder participation

In water management, the parameters of consent are evolving due to heightened stakeholder involvement in decision-making across water use and water resource management, particularly at the river basin level (Wester, Merrey and Lange, 2003). A significant obstacle arises from the large population size within municipalities, which hinders the direct engagement of all stakeholders in decision-making processes (Wester et al., 2003). A fundamental concern consistently revolves around determining the representation of extensive stakeholder groups, which remains a deeply political issue.

c) Poor governance

There is insufficient awareness of how the water governance system affects residents' livelihoods, and there needs to be more effort to differentiate the outcomes of effective water governance from those resulting from inadequate governance (Batchelor, 2020). Pro-poor governance initiatives aim to address this gap by prioritising the needs of the impoverished (Batchelor, 2020). This includes ensuring that the requirements of the poor are adequately met, facilitating access to information for the less privileged, involving them in decision-making processes, and integrating gender and development concerns across all water sector activities (Batchelor, 2020). By implementing pro-poor governance practices, the country can strive towards more inclusive and equitable water management that benefits all segments of society (Batchelor, 2020).

2.7. Criteria to consider before using RO desalination to augmentation existing water supply sources

Water augmentation is securing additional water sources to increase water availability for an existing or prospective group of water users (Dawoud, 2005). In response to water scarcity, desalination plants have been increasingly established in water-stressed regions to augment existing water sources (Elimelech and Phillip, 2011). It is anticipated that the construction of desalination plants will continue to grow over time (Elimelech and Phillip, 2011). In South Africa, the implementation of RO desalination plants is considered to augment the available water supply sources (Masha, 2019; Department of Water and Sanitation, 2012).

This research will not concentrate on RO desalination plants as 'the' augmentation solution for water demand challenges. It will, however, identify criteria to consider before using RO technologies to augment existing water supply sources and thereby help inform decision-making around options for meeting water demand. Some of the key considerations are explained below.

2.7.1. The physical location of the desalination plants

Seawater desalination is suitable in coastal towns, and infrastructure is required to deliver water to high-demand areas (Patel, 2018). Due to their space utilisation, desalination plants are ideally placed in light industrial zones, ports, or harbours. Desalination plants must be located near bulk water distribution systems; otherwise, major civil works are necessary to connect the plants with the distribution pipeline (Patel, 2018).

2.7.2. Energy source

To meet their high energy requirements, desalination plants must be located near a source of adequate and affordable power (Patel, 2018). Because South Africa's electricity is dependent on coal, the energy intensity of desalination presents a difficult question from an environmental standpoint. If energy is not considered for RO desalination plants, the assessment of the desalination process is incomplete (Swartz, Plessis, Burger and Offringa, 2009).

2.7.3. Manufacturing specification and plant life

Desalination rollout is jeopardised by uncertainty about future rainfall. If adequate rain occurs in the future, the cost of producing water from the desalination plant will increase. The materials used in construction and equipment impact cost of maintenance costs and the functionality and accessibility of the plant. Building standards are required to prevent the plant's long-term failure (Swartz et al., 2009).

2.7.4. Fouling

The most serious problem in RO desalination processes is fouling. It is caused by accumulating undesirable deposits on the membrane's surface or within its pores (Malaeb and Ayoub, 2011). Fouling reduces the output water's volume and quality (Malaeb and Ayoub, 2011). The pre-treatment step in RO is designed to prevent fouling and extend membrane life (Malaeb and Ayoub, 2011).

2.7.5. Financial implication

When considering the augmentation of desalination plants, it is vital to evaluate the financial implications. This involves evaluating the capital investment needed for plant construction or expansion and the ongoing operational and maintenance costs (Fischer et al., 2019). Additionally, exploring various funding options and evaluating the financial viability and affordability of the augmented water supply for consumers is crucial. By conducting a detailed analysis of these factors, insight can be gained into the financial aspects of augmenting desalination plants and making informed decisions regarding funding, financial sustainability, and ensuring accessible water supply for consumers (Fischer et al., 2019).

2.7.6. Water quality

It is essential to ensure that the augmented desalination plant consistently produces high-quality freshwater that meets the required standards for different purposes, including drinking water, agriculture, or industrial applications (Swartz et al., 2009). This entails evaluating the effectiveness of the treatment processes and considering potential upgrades or additional treatment steps if necessary. By conducting a thorough assessment, a determination can be made regarding the adequacy of the treatment processes and informed decisions to maintain or enhance the quality of the freshwater output from the desalination plant to meet diverse user requirements (Swartz et al., 2009).

2.8. The underpinning theory: Resilience Theory

The underpinning theory for this research is resilience theory. For the purposes of this study, resilience is viewed as the "biological or biophysical" ability of a system to withstand or address risks, shocks, and stressors (climate change, social crises, economic shocks, catastrophic events) while maintaining specific functions and structures (Rodina, 2019).

Furthermore, related to the context of this research, it's worthwhile to consider resilience from this perspective too. Rodina (2019) defines water resilience as the ability to withstand various water shocks, such as drought and changes in water quality while maintaining essential functions and adaptability of the water system (Rodina, 2019). Resilience has been extended to include adaptability to more desirable conditions in the face of climate change and scarcity (Johannessen and Wamsler, 2017). Sustainability aims to improve the quality of life for current and future generations by considering environmental, social, and economic factors (Collier, Wang, Vogel, Tatham and Linkov, 2013). In contrast, resilience focuses on how various systems, including environmental, social, and economic, react to both acute shocks (National Research Council, 2012) and ongoing stressors (Folke and Gunderson, 2010). One notable difference between sustainability and resilience lies in their implementation timelines, with sustainability initiatives often spanning longer durations compared to resilience efforts (Folke and Gunderson, 2010).

The basic goal of sustainability is to provide favourable conditions for future generations. (Meacham, 2016). As a result, while sustainability measures may not have an immediate influence on the present generation, they may have far-reaching repercussions for future generations. In contrast, resilience is often associated with shorter timeframes (Lew, Ng, Ni and Wu, 2016). However, both sustainability and resilience are concerned with the long-term status of a system or feature, emphasising its capacity to continue under normal conditions and adapt to disruptions (Fiksel, Goodman and Hecht, 2014).

The literature provides extensive support for the notion that resilience is a crucial component of sustainability. Lebel et al. (2006) state that "Strengthening the capacity of societies to manage resilience is critical to effectively pursuing sustainable development" (Lebel, Anderies, Campbell, Folke, Hatfield-Dodds, Hughes and Wilson, 2006; pg. 2). They emphasise the importance of adaptive governance and management strategies in fostering resilience at various levels of society, from local communities to national governments (Lebel et al., 2006). Similarly, Arrow et al. (1995) conclude that "economic activities are sustainable only if the life-support ecosystem upon which they depend is resilient" (Arrow, Bolin, Costanza, Dasgupta, Folke, Holling, Jansson, Levin, Mäler, Perrings and Pimentel, 1995; pg. 93).

Their argument emphasises that sustainable economic practices rely inherently on the resilience of the ecosystem upon which they depend. This perspective highlights the importance of preserving ecosystem health for long-term economic sustainability (Arrow et al., 1995). Perrings (2006; pg. 418) argues that "a development strategy is not sustainable if it is not resilient". Perrings (2006) argument emphasises the inseparable link between resilience and sustainability in the context of development planning. By recognising the need for strategies that can withstand and adapt to changing conditions, Perrings (2006) highlights resilience as a prerequisite for achieving sustainable development outcomes. Finally, Ivanov (2020) argued that sustainability improves survival to external high-impact changes (social and environmental) and adds to resilience building.

Figure 1 shows how a system's resilience can impact its sustainability and explains how a system, once it has recovered from a disruption, can transition to sustainability by utilising the adaptive element of resilience. When a system experiences disruptions like drought or infrastructure damage, the system's resilience becomes important in mitigating the negative impacts on sustainability (Marchese, Reynolds, Bates, Morgan and Clark, 2018). If the system is resilient (as shown by the dotted line), it can absorb or adapt to these disturbances and minimise their effects on its overall functionality and sustainability. Through its adaptive component of resilience, the system can adjust its structure, processes, and functions to overcome challenges and maintain sustainable operations (Marchese et al., 2018). In a case where the system is not resilient (as shown by the bold line), the opposite happens. The disturbances will have a significant influence on sustainability, and the system will not recover its initial form (Marchese et al., 2018).

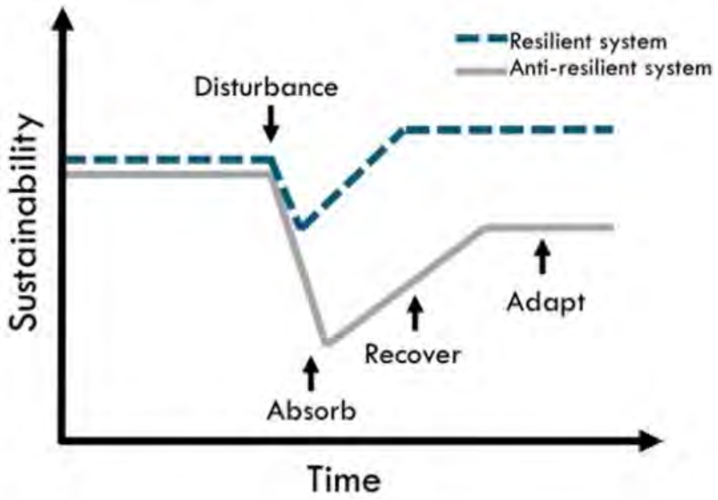

Figure 8: Resilience as a component of sustainability (Source: Marchese et al., 2018).

Resilience and sustainability have a part to play in directing the operations of the water sector globally (Johannessen and Wamsler, 2017). It is critical to consider resilience within the context of sustainability. According to Butler, Farmani, Ward, Diao and Astaraie-Imani (2014), the purpose of a sustainable system is to continue working for a long period while balancing the agreed-upon goals. Aside from basic operation, the water system must adapt to evolving operating conditions and environments and deal with internal and external disturbances to maintain the required level of performance. In summary, the system must be both sustainable and resilient, with resilience coming first before sustainability (Butler et al., 2014).

In this study life cycle assessment was used for environmental impact assessment. Only a few scholars in the literature have considered LCA with resilience design (Fiksel et al., 2014). LCA is important in resilience planning because it provides information about the environmental vulnerabilities and risks associated with goods, processes, and systems (De Luca Peña, Taelman, Preat, Boone, Van der Biest, Custodio, Hernandez, Evaraert andDewulf, 2022). By doing LCA, practitioners can identify hotspots of environmental impact and examine the potential implications, interruptions, or changes in the supply chain. This data can help to inform resilience measures such as minimising reliance on vital resources, diversifying the supply chain, and enhancing resource efficiency (Hinton, 2021).

Integrating LCA into resilience planning supports a more comprehensive approach to sustainability (Carissimi, Creazza and Colicchia, 2023). By addressing environmental consequences with resilience concerns, practitioners may build more robust and sustainable solutions that not only minimise environmental harm but also enhance the systems' ability to adapt and prosper in the face of uncertainty and change (Carissimi et al., 2023).

2.9. Conclusion

In conclusion, this chapter has provided a review of the literature surrounding Life Cycle Assessment (LCA) and its application to the Reverse Osmosis (RO) desalination plant. The life cycle of the RO plant has three distinct phases: Construction, Operation and Maintenance, and Disposal. Moreover, the concepts of Quadruple Bottom Line (QBL) sustainability were explored, which evaluates organisational performance across four critical pillars: environmental, social, economic, and governance. Each of these pillars has been examined in detail.

Furthermore, the resilience theory was examined, which is the underpinning theory for this study. Resilience theory offers insights into how systems, such as the water supply system, can adapt and thrive in the face of challenges and uncertainties. In the next chapter, the methodology of the research will be unpacked.

CHAPTER 3: Research Methodology

3. Introduction

This chapter describes the study plan and the procedures taken to aid the research process. It provides a full overview of the qualitative data-gathering procedures used, including the study paradigm and design. It also digs into the intricacies of participant selection, revealing both the number of people sampled and the criteria used to pick them. Furthermore, it discusses the many stages of the data collection process.

3.1. Research aims and objectives

This study aimed to investigate the sustainability (QBL) impacts and opportunities of RO desalination plants from a life cycle perspective. The specific objectives of the study were as follows:

1. To identify the sustainability (quadruple bottom line) impacts and opportunities associated with reverse osmosis desalination plants in the Eastern Cape from a life cycle perspective.
2. To investigate the key sustainability considerations relevant for RO desalination plants to potentially augment available water provision sources in the Eastern Cape.
3. To make recommendations on how RO desalination plants could potentially augment the available water provision sources, considering all four pillars of the quadruple bottom line.
4. To formulate recommendations on the QBL outcomes of the desalination plants (from a life cycle perspective) for better utilisation and management of these plants.

3.2. Research design

A qualitative case study was conducted to evaluate the desalination plant technology, and the impacts and opportunities associated with the plant on the economy, environment, governance, and society. Qualitative research involves exploring the essence of phenomena, encompassing their characteristics, various expressions, the settings in which they emerge, or the viewpoints from which they can be observed. However, it does not search into their extent, occurrence frequency, or position within an objectively determined cause-and-effect sequence (Philipsen and Vernooij-Dassen, 2007).

3.3. Research paradigm

The research adopted the post-positivism paradigm. Post-positivism is a form of pluralism that strikes a balance between positivist and interpretivist methods (Ryan, 2006). It centres on investigating issues within the context of incorporating the experiences of the majority and presenting results that align with the consensus of the majority (Ryan, 2006). Post-positivism brings together theory and practice, allowing the researchers encouragement and motivation (Ryan, 2006). In post-positivism, scholars concentrate on verifying and seeking credible and dependable evidence regarding current phenomena (Nel, 2020). Researchers working with the post-positivism paradigm adhere to a critical realist ontology, which implies that knowledge is flawed in some way (Nel, 2020).

3.4. Sampling

Four organisations and sixteen research participants were selected using convenience (Etikan et al., 2016) and purposive (Robison, 2014) sampling techniques, respectively. Out of the four organisations, only three (3) participated in the study, and out of the sixteen participants, only ten (10) participated. Stratton (2021) defines convenience sampling as a technique used to select clinical cases or participants that are around the location, internet site, or customer membership list (Stratton, 2021). These two plants were selected due to their proximity to the researcher. Purposive sampling involves deliberately choosing individuals as research participants due to their capacity to provide valuable insights into a particular theme, concept, or phenomenon (Robison, 2014). This method proves highly advantageous when seeking the expertise of individuals in a research investigation.

3.4.1. Research participants

The study consisted of a total of 10 participants, five (5) participants from Cerebos, four (4) participants from Amatola Water, and one (1) participant from the Ndlambe Municipality. In qualitative research, a sample size of six (6) is generally considered adequate for drawing reliable conclusions from the collected data (Braun and Clarke, 2012). Due to the specialist nature of RO desalination, only those with the appropriate understanding were required to participate.

Morse (2000) emphasised that the quality of data obtained from each participant influences the overall sample size requirement (Morse, 2000). In this context, the focus should be on maximising usable data rather than merely increasing participant numbers.

Morse (2000) additionally recommended considering elements such as the study's extent, the intricacy and ease of access to the subject matter, data reliability, and the study's structure. Table 3.1 lists the participants and their respective designations who actively contributed to the study. This approach ensures clarity and transparency in presenting the individuals involved in the research.

Table 1: Research participants

Name	**Professional background**	**Organisation's name**
Respondent 1 (R1)	Operations staff member	Cerebos S.A. (RO plant)
Respondent 2 (R2)	Operations staff member	
Respondent 3 (R3)	Environmental scientist	
Respondent 4 (R4)	Environmental scientist	
Respondent 5 (R5)	Company buyer	
Respondent 6 (R6)	Operations staff member	Amatola Water (RO plant)
Respondent 7 (R7)	Operations staff member	
Respondent 8 (R8)	Environmental scientist	
Respondent 9 (R9)	Company buyer	
Respondent 10 (R10)	Water service engineer	Ndlambe Municipality (local municipality where the Amatole Water plant is located)

3.5. Data collection

Conducting interviews stands as a fundamental data collection method in qualitative research (Jamshed, 2014). Interviews typically possess a certain degree of structure, with most qualitative research interviews falling into the categories of semi-structured, structured, or unstructured (Mason, 1994). In this study, data was gathered through semi-structured interviews and document analysis. Interviews are used to discover more about a person's opinions, motivation, and subjective experiences, rather than facts (Hak, 2007).

3.5.1. Semi-structured interviews and document analysis

Semi-structured interviews and document analysis were used for data collection. Semi-structured interviews provide a controlled and focused direction throughout the conversation (Ruslin, Mashuri, Sarib, Alhabsyi and Syam, 2022). Based on a paper by Bernard (1988, as cited in Cohen and Crabtree, 2006), semi-structured interviews are preferred when the chance of re-interviewing participants is unlikely. Semi-structured interviews were chosen because they offer reliable and comparable data (Cohen and Crabtree, 2006). The interviews primarily featured open-ended questions, as outlined in the interview guide provided in Appendix A and Appendix B. This approach aimed to encourage in-depth discussions and uncover fresh insights, aligning with Cohen and Crabtree's (2006) recommendation for effective data collection (Cohen and Crabtree, 2006).

The interviews took place via Zoom and Microsoft Teams for online sessions, and some were carried out face-to-face with recordings made using Otter.ai and a Huawei phone recorder. "Otter" is a voice-to-text transcription tool that utilises artificial intelligence. It detects speech in an audio feed, analyses it using an AI algorithm, and starts converting the spoken words into written text, which users can then read, highlight, and copy (Rabelo, 2023). The recorded interviews were then transcribed into text format using Otter.ai, and the researcher made the required amendments, mainly translating when information was provided in isiXhosa to ensure all data was captured in English. Subsequently, these transcriptions were transferred to Microsoft Excel and organised following a qualitative data structuring technique outlined by Ose (Ose, 2016). Following the initial round of interviews, additional follow-up interviews were conducted to address and fill any gaps in the data.

Document analysis is a systematic approach utilised to evaluate a range of documents, encompassing both physical and digital forms like printed materials and electronically conveyed content (Bowen, 2009). It involves a systematic examination and interpretation of data within documents to uncover insights and construct empirical knowledge (Corbin and Strauss, 2008). These documents encompass text and images that are captured without any direct involvement from the researcher (Bowen, 2009). The documents that were analysed in this research include process flow diagrams, financial statements, environmental impact Assessment reports, and integrated annual reports downloaded from the internet.

3.6. Data analysis

The analysis of the collected interview and document analysis data followed a deductive thematic approach (Nel, 2020). Deductive thematic analysis starts with established theories as a foundational framework (Boyatzis, 1988). These theories, as referenced by Boyatzis (1998), are drawn from existing literature and are represented as research propositions explained by Pearse (2019).

The researcher in the thematic analysis made use of the six-phase guide framework of Braun and Clarke (2012). The guide phase framework involves 6 phases (Braun and Clarke, 2012), See the figure below.

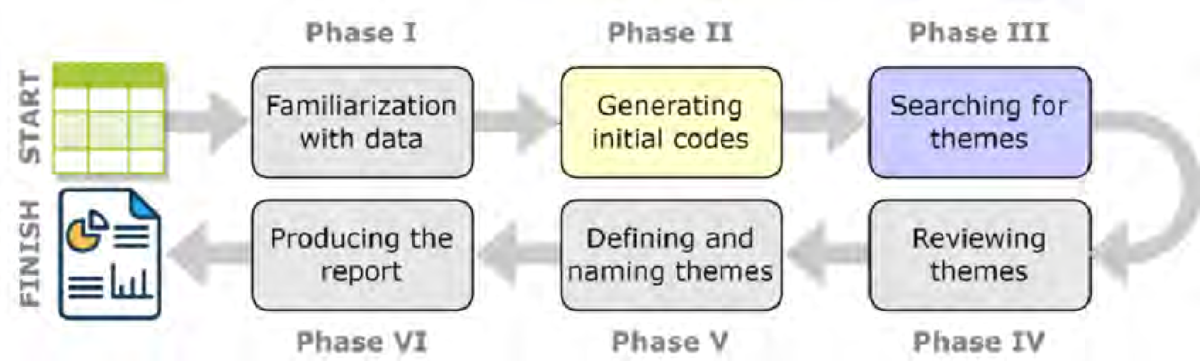

Figure 9: Six guide phase framework (Source: Braun and Clarke, 2012)

Phase 1: Familiarising yourself with your data

The researcher took careful steps to become well-acquainted with the data. The researcher extensively listened to the interview recordings, simultaneously reading the transcripts while ensuring the accuracy of the Otter.ai transcriptions. The researcher independently read the transcripts to thoroughly explore the data.

Phase 2: Generating initial codes

This step entails creating preliminary codes that highlight relevant aspects of the data. These codes are used to organise data into relevant grouping as part of the analysis process. The codes that were developed within this study based on the interview questions are in Appendix C.

Phase 3: Searching for themes

The researcher evaluated the codes and extracted the themes. Some initial codes develop into core themes (see Chapter 4).

Phase 4: Reviewing themes

Once the researcher developed the themes (see Chapter 4), these themes involved refining them, recognising possible concerns such as inadequate or diverse data, and assessing whether they are genuinely themes or need to be broken down into smaller ones.

Phase 5: Defining and naming themes

At this step, the researcher refined and displayed the themes in more detail, as shown in Chapter 4.

Phase 6: Producing a report.

3.7. Research credibility and trustworthiness

In qualitative research, the criteria for ensuring trustworthiness are credibility, transferability, and confirmability (Korstjen and Moser, 2018). Three strategies were used to ensure credibility data for this study. These were triangulation (Cohen, Manion and Morrison, 2000), where relevant (i.e. to support statements that did not relate to the interviewed experts' opinions, perceptions, and insights), interviewing a diverse set of experts from the three organisations, audio interview data were transcribed into text using Otter.ai, thereby ensuring that the respondents' direct words were captured, without interference by the researcher. In addition, the researcher did follow-up calls and follow-up interviews to confirm statements and insights provided by the interviewees that the researcher did not understand (Korstjen and Moser, 2018).

3.7.1. Research Bias

Bias is a process that occurs at any level of inference and produces results or conclusions that deviate systematically from the truth. It can contaminate the whole scope of the study, including its design, interpretation, and reporting (Yarborough, 2021). The researcher works within one of the organisations being studied and maintains regular interactions with the desalination plant workers to ensure water quality; there is a potential for favouring the organisation's interests by selectively focusing on supportive data rather than contradictory information. To mitigate bias, the researcher transparently disclosed her position, and the interviews were recorded to ensure accuracy and later transcribed using the Otter.ai software application.

3.8. Ethical compliance and consideration

The research proposal received approval from the Commerce Faculty Higher Degrees Committee at Rhodes University, and authorisation to conduct research involving human subjects was granted by the Rhodes Ethics Committee (Review reference: 2023-7163-7807). Before the interviews took place, participants were sent a consent letter (see Appendix B) that explained the study's particulars and the interview procedure. Additionally, all participants were given the choice to remain anonymous if they preferred.

3.9. Conclusion

In conclusion, this chapter provided an overview of the research plan, design, and methodologies employed within this study. Through qualitative case research, involving semi-structured interviews and document analysis, data was gathered from participants from the two organisations of study. The selection of the participants was guided by convenience and purposive sampling techniques, ensuring the inclusion of individuals with relevant expertise.

The research design was grounded in the post-positivism paradigm, emphasising the incorporation of diverse perspectives and the search for valid and reliable evidence within existing phenomena. The trustworthiness of the research findings was upheld through strategies such as triangulation, diverse participant selection, and audio interview transcription using Otter.ai while efforts were made to mitigate potential bias arising from the researcher's affiliation with one of the organisations.

Ethical considerations were prioritised throughout the research process, with approval obtained from relevant ethics committees and participants provided with informed consent.

CHAPTER 4: Results

4. Introduction

This chapter aims to present findings of the research on sustainability, sustainability (QBL) impacts, and opportunities of RO desalination plants from a life cycle perspective and key considerations for augmentation. Within this chapter, the findings will be presented as per the three objectives from the Ten (10) interviews that were conducted.

4.1. Sample respondents

Ten (10) research participants were interviewed within this study to understand the sustainability (QBL) impacts and opportunities of RO plants from a life cycle perspective and key considerations for augmentation. Table 3.1 (Chapter 3) has a summary of the participants together with their designations.

4.2. Understanding the concept of Sustainability

The perspectives of the respondents about the concept of sustainability were examined by unpacking their understanding of the definition; moreover, key themes were extracted from the respondents' responses. The themes were balance, limited resources, longevity, four pillars, and resource conservation.

The respondents from both RO plants were asked about their understanding of sustainability during separate interviews, and collectively, they demonstrated a coherent grasp of the concept. Respondent 8 defined sustainability as a combination of longevity and balance, emphasising, "*Sustainability is about ensuring that what we have today remains viable into the future. It involves maintaining an adequate quantity of resources for the future and achieving balanced socio-economic development*."

Respondent 9 defined sustainability as the ability to sustain oneself for an extended period while functioning effectively, Respondent 9's words were "*working with limited resources with the plan to make them last*". Respondent 4 mentioned that sustainability is the usage of specific resources in such a way that you can use enough for the current moment while being conservative and thinking about the future generation. Respondent 2 defined sustainability as the "*responsible management of resources, emphasising the avoidance of resource depletion to the point where nothing is left for future generations*".

The other respondents' definitions of sustainability were similar. The respondents' perspectives emphasised the significance of balancing the present requirements, conserving resources, and managing resources efficiently for long-term sustainability. This definition was also noted in the Amatola Water Integrated Report (Amatola Water, 2022/23).

4.2.1. Understanding the Quadruple Bottom Line (QBL)

The perspectives of the respondents about the concept of QBL were examined by unpacking their understanding of the definition; moreover, key themes were extracted from the respondents' responses, and these themes were four aspects and four pillars.

Only three respondents demonstrated an understanding of what QBL is. Some respondents did not explain what the QBL is; they simply mentioned that it is linked to sustainability. Respondent 4 recognised QBL as a sub-theme of sustainability and noted that "*QBL is examining four key aspects—social, economic, and governance—and ensuring their proper management and protection during the utilisation of specific resources*". Similarly, Respondent 5, when defining sustainability, emphasised evaluating the pillars or bottom lines, which include governance, environmental, social, and economic aspects. These responses collectively illustrate a prevalent association between QBL and sustainability. The documents analysed did not cover QBL.

4.3. LCA of the two RO desalination plants

To understand the impact of RO desalination plants, it is important to first unpack their life cycle and operational processes.

4.3.1. The life cycle of RO desalination plants

The respondents from Amatola Water and Cerebos shared the life cycle of their RO desalination plants. Respondents from both plants explained the process during the interviews and provided relevant documents outlining the plant's operational processes, see Figure 10 and Figure 11.

4.3.2. Amatola Water desalination plant life cycle

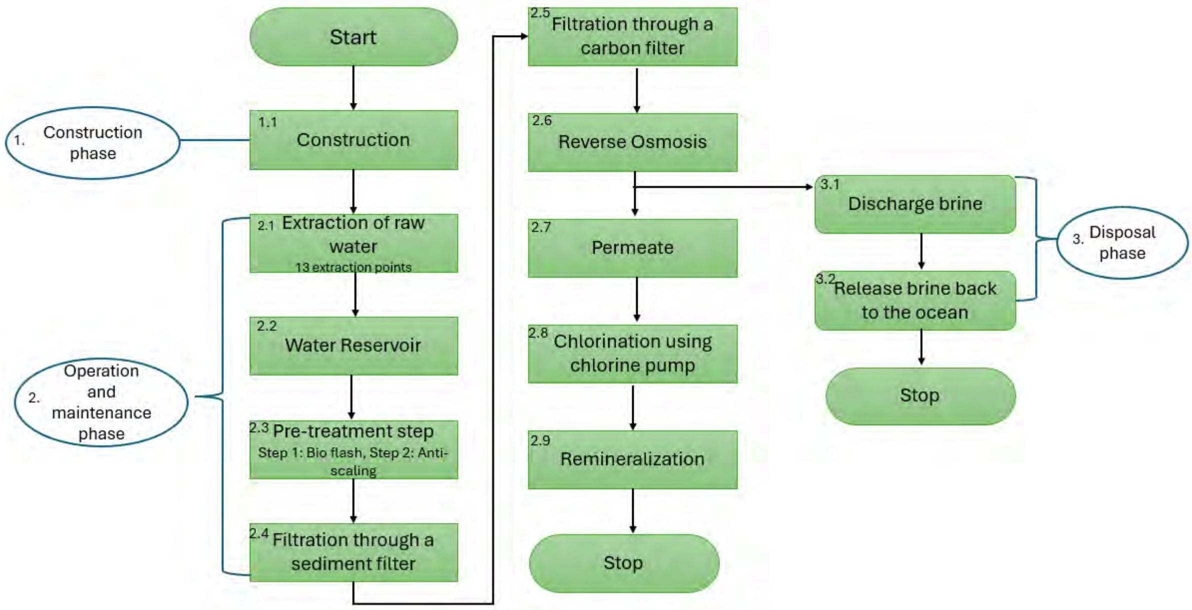

Figure 10: Summary of the life cycle of Amatola Water desalination plant (created by the researcher).

The respondents were asked about the life cycle of the RO desalination plant, which was also reviewed through the analysis of relevant documents. Respondent 6 highlighted that the plant is situated at the river mouth, where raw water (untreated water referred to as raw water) is extracted. The water is sourced from different points known as sea wells. This respondent (R6) emphasised that "*there are 13 points of extraction, and the sea wells are situated underground and contain a considerable amount of biological matter that eventually ends up in the water reservoir*" (see Figure 10, item 2.1). These points were also noted in the provided flow diagram (Amatola Water, 2015/16). The respondent further explained that "*to mitigate the impact of biological matter, a biocide is introduced during the water pumping process from the 1-megaliter reservoir*". Respondent 6 further highlighted that it's crucial to store the biocide in a separate tank to prevent any environmental risks associated with its discharge back into the ocean.

Respondent 8 mentioned that the pretreatment procedures commence with the application of bio-flash to prevent algae buildup on filters, followed by the utilisation of an anti-scaling chemical designed to break down calcium (refer to figure 10, item 2.4). The respondent explained that "*the rationale behind this is to address the potential issues caused by calcium under high pressure, such as silica formation or membrane surface blockage*". Respondent 8 further mentioned that after the anti-scaling phase, the Reverse Osmosis (RO) process is initiated (Figure 10, item 2.6). During this stage, water is forced through a semi-permeable membrane, and the resulting permeate becomes the final product (see Figure 10, item 2.7). Any water not passing through the membrane is designated as brine discharge, which is released back into the ocean. The discharge brine is released through the diffuser, and there are two discharge points (see Figure 10, items 3.1 to 3.2). The points above were also noted on the flow diagram provided by Amatola Water (Amatola Water, 2015/16). Respondent 6 mentioned that, upon obtaining the permeate, chlorine is introduced, utilising aquatic chlorine, sodium hypochlorite, or chlorine gas, depending on availability (see Figure 10, item 2.9). Respondent 8 highlighted the importance of remineralisation and noted that "*[i]t's essential to note that the RO process removes all minerals from the water*". Therefore, remineralisation is implemented (see Figure 10, item 2.9). The respondent explained that the remineralisation process involves the utilisation of natural methods, specifically drawing from various aquifers. These aquifers play an important role in remineralising the water. This approach ensures that the desalinated water meets both quality and safety standards, aligning with environmental considerations and the unique geological characteristics of the aquifers utilised in the process. These points were also noted in the provided flow diagram (Amatola Water, 2015/16).

4.3.3. Cerebos South Africa desalination plant life cycle

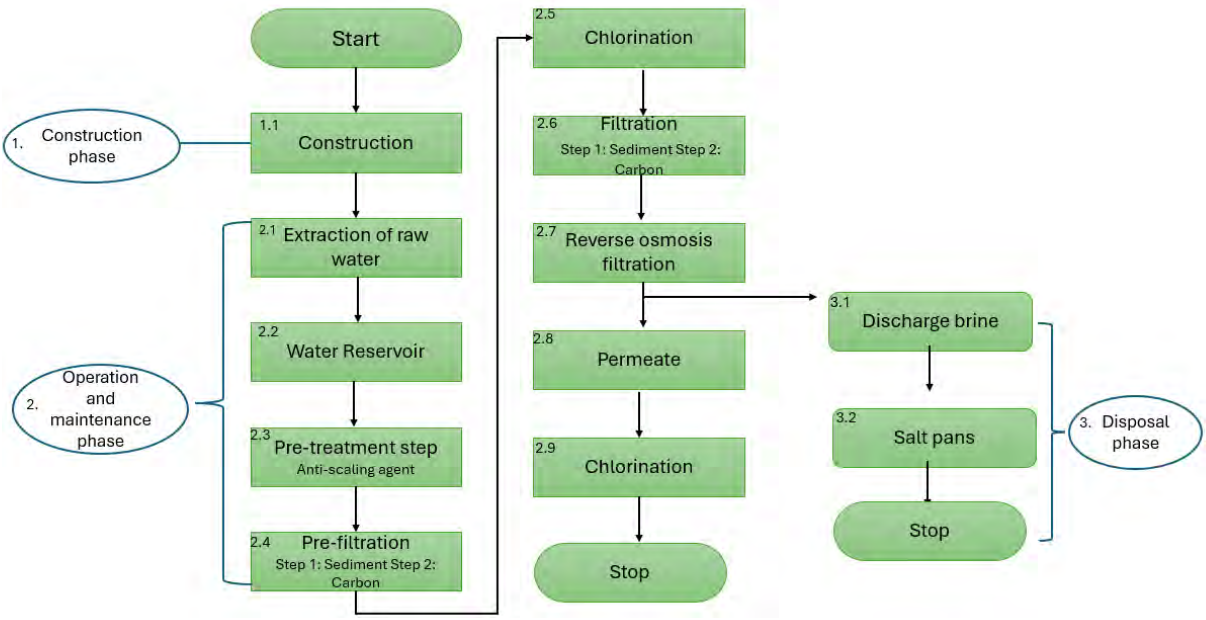

Figure 11: Summary of the life cycle of the Cerebos desalination plant (created by the researcher).

Respondent 2 highlighted that the RO process starts with the extraction of seawater from the sea (see Figure 11, item 2.1). The respondent's words were, "*Cerebos is a salt manufacturing company and has been using seawater for plant processing. The same pipes that are used for salt processing are used for the extraction of raw water. After extraction, the water undergoes treatment with sodium hypochlorite to eliminate microorganisms, preventing their entry into the membrane*". The respondent mentioned that the plant consists of two main sections: the pre-filtration section (Figure 11, item 2.3), where solids are removed from seawater, and sodium hypochlorite is dosed again to eliminate bacteria and organisms, and the subsequent filtration of particles before passing through activated carbon to remove unreacted chlorine (See Figure 11, item 2.6). Respondent 1 further explained that "*the treated water then proceeds to the RO plant, where it passes through membrane vessels, initiating osmosis under a pressure of around 14 bar, effectively separating molecules from seawater or salt tank content*" (Figure 11, item 2.7). These process steps were also noted in the Cerebos flow diagram (Cerebos, 2020).

Respondent 2 also highlighted that to enhance energy efficiency, the plant incorporates an innovative design, featuring an energy recovery pump. Within the membrane vessel, where a 40-bar pressure is maintained, not all the energy present in the water is utilised. The energy recovery pump retrieves the pressure in the vessel during the process, utilising it to run the pump. Consequently, the main pump in this design is four times smaller than those in older plants, ensuring optimal efficiency in line with current technological capabilities. This was also noted in the procedure for control and operation of the RO desalination plant (Cerebos, 2022). Respondent 2 further emphasised that "*while the RO plant does consume a significant amount of electricity, the implementation of the energy recovery pump mitigates energy loss*". Furthermore, the respondent highlighted that energy would be discarded without this specific pump on the waste side. Therefore, the plant ensures a more energy-efficient operation by recovering and reinvesting the energy into the system.

Additionally, Respondent 2 commented on the RO plant output, explaining that "*the final output of the RO process results in the separation of permeate, representing freshwater, and brine, signifying the waste side*" (Figure 11, item 2.7). The respondent further highlighted that the split is approximately 40% permeate and 60% raw water waste. Importantly, the waste is not discharged into the ocean but repurposed for the salt manufacturing process. (See Figure 11, items 3.1-3.2). These process steps were also noted in the Cerebos plant flow diagram

(Cerebos, 2020). The RO plants operate by filtering water under pressure, effectively segregating molecules, and producing two distinct products.

4.4. QBL impacts of RO desalination plants from a life cycle perspective

The respondents from both plants were asked questions about the sustainability impacts of RO desalination plants from a life cycle perspective. Key themes were extracted from the respondents' responses, and documents were analysed and presented alongside the applicable life cycle phases (see Table 2 below). From the respondents' feedback and documents reviewed, limited data emerged on social and governance issues during the process steps or phases; these were most evident post-plant processes.

Table 2: Themes for the QBL impacts from a life cycle perspective.

Life cycle phase	Environmental	Economic	Social	Governance
Construction phase	• Destruction of environment • Vegetation removal • Habitat destruction	• Construction cost • Equipment purchase • Specialised pumps	• Disturbances caused by construction vehicles	• None mentioned
Operation and maintenance phase	• Carbon footprint • Energy cost • Energy recovery system • High Electricity demand • Location of the plant • Spillages • Hydraulic and oil leaks • Noise pollution • Vibration • Temperature differences • Organism extraction • Disruption of wildlife • Leakage of chemicals • CIP chemicals • Incorrect disposal of CIP chemicals • Leakage of CIP chemicals • Pollution	• Electricity cost • Maintenance spares • Unavailability of maintenance spares • Infrastructure damage • Poor planning • Fixed contracts • Water quality • Plant efficiency • Inexpensive filters • Expensive membranes • CIP • Fouling	• Vandalism and theft • Technical challenges • Pipeline burst-damage roads	• None mentioned
Disposal phase	• Brine discharge • Diffuser • Temperature variation	• None mentioned	• None mentioned	• None mentioned

Post-plant operations	• None mentioned	• None mentioned	• Illegal connections • Lack of knowledge • Demand and supply • Social gap • Rejection by community • Affordability	• None mentioned

4.4.1. Environmental sustainability impacts of RO desalination plants from a life perspective

The respondents from both organisations were asked about the environmental sustainability impacts of RO desalination plants from a life cycle perspective. Sections 4.4.1.1 to 4.4.1.3 present the findings from the interviews and documents analysed, and these are presented and organised according to the life cycle phases outlined in Table 2.

4.4.1.1. Construction phase

a) Environmental impact of RO plant construction process

Respondent 3 expressed concern about the environmental disturbance caused during the construction of desalination plants. This includes clearing the construction area, introducing foreign structures, disturbing both plant and animal life, and installing pipes into the sea, which further impacts the ecosystem, causing problems for plant and animal life. The respondent said, "*the construction process involves clearing vegetation, potentially affecting endangered species, if proper search and rescue procedures are not followed*". The removal of shrubs and bushes also destroys habitats for wild animals and bird life residing in these areas. The respondent pointed out that such disturbances create a void in the animal community, altering their living space. Additionally, the soil itself is disrupted during the clearing process, interfering with natural environmental processes.

Respondent 8 echoed similar concerns, noting that plant construction and maintenance activities involve tearing down areas for plant placement and installing conveying pipes, both of which disrupt the habitats of organisms in the ecosystem. The respondent said, "*You will need to disturb your environment; you cannot have your terrestrial pipes outside that environment; the impact will be there, and you will manipulate the terrestrial component*". The construction process of desalination plants was not mentioned in the documents analysed.

The collective insights from the respondents show the significant environmental impact associated with the construction of desalination plants. The disturbance of natural habitats, both on land and in the sea, poses challenges to plant and animal life.

4.4.1.2. Operation and Maintenance phase

a) *Extraction of raw water: Impingement or entrainment*

Respondent 6 from Amatola Water mentioned that they upgraded their desalination water system in 2019. In their previous system, they had a pre-treatment step to eliminate organisms before entering the 1-megaliter reservoir. However, in the current system, there is no pre-filtration step. Organisms are extracted during processing and end up in the 1-megaliter reservoir. Respondent 6 noted that the extraction of these organisms is a part of the process, stating, "*We have tried several screens and shade cloth to prevent organisms from getting through. However, this has failed because the more stuff you put on the RO plant, the more you restrict the flow of water*."

Respondent 3 mentioned the extraction of organisms and said, "*When you pull the water out of the sea out to the plant. It does not take only sea water, in seawater we have organisms that are called zooplankton and phytoplankton, which are small, suspended animals and plants in the water where the other sea life feeds; so, the extraction process distracts the feeding cycle of the sea"*. The respondent further explained that this type of plant is different when it comes to blockages. The respondent said, "*Unlike normal stormwater drains where you find papers and plastics, the line from the sea may contain dead fish and molluscs, disrupting the flora and fauna cycle*".

Respondent 1 also touched on the extraction process, mentioning, "*When extracting seawater, we end up extracting living organisms*". There are filters in place, but the filters are not there to support marine flora. Respondent 4 said, "*affecting aquatic flora by essentially taking seawater and having an effect on the life cycle of marine organisms*". Respondent 2 had a contrary view as their organisation does not have a separate intake for the RO itself. The respondent stated, "*We have intake from the sea for our whole salt work area, and the organisms we extract end up proliferating in the salt pans*".

b) *CIP chemicals- causing pollution*

The recurring term highlighted by different respondents is the potential environmental impact of CIP (Cleaning In Place) chemicals. Respondent 8 expressed concern about these chemicals in the treatment process, stating, "*One of the things that you must be concerned about in the whole treatment process is the cleaning chemicals (CIP system).* Respondent 8 mentioned that there are occasional leakages that result in the release of CIP into the environment. Respondent 7 pointed out that the CIP chemicals cause pollution, and their plant is located in a sensitive area, which exacerbates the challenge. Respondent 3 highlighted that the use of chemicals in the purification process poses an environmental risk, especially in cases where these chemicals are not disposed of correctly. Respondent 8 and Respondent 9 mentioned that their process uses biocide, and the waste is collected by a waste company rather than disposed of conventionally; with the leakages they experience, there could be a possible leak of the biocide tank. The impact of CIP chemicals was not covered in the documents analysed.

c) Noise pollution

The respondents highlighted concerns about noise pollution from RO desalination plants. Respondent 3 noted that the RO plant generates significant noise and vibrations from large pumps, potentially disturbing wildlife, even though the plant is situated away from residential areas. Respondent 3 said, "*The RO desalination plants are very noisy, you also introduce vibration into the water as you have big pumps that are running and animal life around it*". Respondent 8 echoed these concerns, citing community sensitivity to noise, occasional lapses in door closure by operators, and ongoing efforts to soundproof the plant. Respondent 8 said, "*There is also the noise aspect, but that is being dealt with, with all the pumps, measures are in place to mitigate the impact as the community is very sensitive about the noise and they complain very quickly._But at the same time, our operators do things like leaving the doors open, which they shouldn't do*". Respondent 9 also acknowledged noise-related complaints from neighbours. Respondents 1-5 acknowledged the inherent noise in RO plants due to high-pressure equipment. They emphasised the importance of soundproofing, as their plant is insulated to comply with legal noise pollution requirements. The impact of noise pollution was not covered in the documents analysed.

d*) Carbon Footprint*

Respondents from both organisations emphasised the significant concern of carbon footprint associated with RO desalination plants, with variations noted between the Cerebos and Amatola Water plants. Respondent 1 expressed the shared sentiment that desalination operations demand substantial energy, leading to potential greenhouse gas emissions. The respondent said, *"A lot of desalination plants use a lot of energy. This energy can result in* *greenhouse gases being emitted, depending on how the process is done. So, with regard to greenhouse gases, let's look at climate change. You know we are having longer winters and shorter summers with a lot of wind*". The respondent highlighted the broader environmental impact, linking it to observed climate changes such as extended winters and shorter summers.

Respondent 2 outlined the plant's design strategy to address energy consumption. The respondent explained that the incorporation of an energy recovery pump allowed for reduced electricity usage, making their plant more efficient with a pump size four times smaller than conventional desalination pumps. This approach aligns with the latest technological advancements.

Conversely, Respondent 8 shed light on the challenges faced by Amatola Water, emphasising the high electricity demand and associated carbon footprint. The intricate water supply system, involving multiple pumping stages, contributes to elevated energy consumption. Respondent 9 further explained that the plant's dependency on coal as a source of electricity plays a significant role in the carbon footprint. This finding was also noted in the Amatola Water document, the document further explained how some environmental scientists are against the use of desalination plants due to the high energy consumption of the plant (Amatola Water, 2017/18).

The examination of RO desalination plants through the perspectives of respondents' from Cerebos and Amatola Water organisations and analysed documents revealed a shared concern for the carbon footprint associated with these operations. While Cerebos showcased a proactive approach to energy efficiency through the integration of an energy recovery pump to minimise the cost, Amatola Water faced challenges stemming from high electricity demands and complex water supply systems.

e) Oil spillages pose a threat to terrestrial and marine life

One of the respondents expressed concern about oil spillages, highlighting the potential for spills during maintenance activities involving lines and equipment, particularly with hydraulics and oil leaks. This respondent, Respondent 3, expressed the worry that such leaks could enter the sea environment, introducing foreign substances and posing a threat to marine space. The respondent said, "With *the equipment that is used during a breakdown, it happens that there are oil leaks and hydraulics. These hydraulic leaks and oil leaks may go into the sea environment and may affect the space and introduce foreign substances into the environment. The same applies to the terrestrial environment; you may have concrete spillages that then cut* *further in the environment*". This concern is equally applicable to terrestrial environments, where oil spillages could have detrimental effects. The oil spillage impact was not covered in the documents analysed.

f) Temperature differences affect marine life

Respondent 6 discussed the concept of temperature variation between the water and the discharge brine. The respondent noted instances where the brine's temperature was either lower or higher than that of the water. The respondent said, "*The temperature of the brine is usually higher because it is coming out of the treatment plant*". Respondent 6 explained that optimal efficiency is achieved when both temperatures are high. However, if the water's temperature is lower than that of the brine, it may potentially impact marine life due to the temperature difference "*When your temperature is higher, then the water temperature will be higher, and this will increase the efficiency of your trains. The higher the temperature, the more product you have, and you improve your operations because you do not have to work hard to increase the temperature of your water as it is already high*". This impact was not noted in the documents analysed.

g) The location of the plant affects the biodiversity of the pristine environment

Both plants are situated in sensitive areas, namely the Sundays River (The Sundays River Valley begins at Colchester, about 37km north of Gqeberha on the N2) and St Mark's area (Town in Chris Hani District Municipality in the Eastern Cape province of South Africa). Respondent 8 highlighted a challenge with the Amatola Water plant, expressing that its location in a sensitive area, particularly in the ecotourism hub of St Mark's, raises concerns about industrialisation in such pristine surroundings. The respondent explained that the plant's establishment was prompted by water scarcity in the settlement of the Bushmans, leading to the creation of Dias Cross (headland known as Kwaaihoek, close to the Boknes lagoon on the Sunshine Coast, Eastern Cape). When it became apparent that this water source was insufficient, they explored alternatives, eventually leading to the adoption of brackish water and the implementation of the RO desalination plant. Respondent 8 emphasised, "*It is not ideal to have a facility right in the middle of such a pristine environment*." The location of the plants was not covered in the documents that were analysed.

4.4.1.3. Disposal phase

a) *Brine discharge- affecting surface organism*

A common term among various respondents was the discharge of brine, with different practices and considerations outlined. Respondent 6 mentioned that their plant discharges brine back into the sea, utilising a diffuser at the sea bottom to distribute the flow evenly, minimising concentration in one area. Respondent 6 said, "*At the discharge point, there is a diffuser, that splits the flow, blending the highly concentrated brine with seawater*". Respondent 7 highlighted that while they utilise 50% of extracted seawater, the remaining 50% is discharged back to the sea, contributing to environmental impact, "*treating seawater, you have to use 50% of the seawater and the rest you need to discharge it to the sea*". Respondent 8 acknowledged the localised impact of brine discharge, expressing concerns about mixing highly concentrated brine with seawater, which could affect surface organisms. However, a diffuser is in place to mitigate this impact by blending the concentrated brine with normal seawater and avoiding bubble formation. The respondent's words were "*If you do not have proper mixing of the brine, you will have localised impact on any surface organism that are around there*". The impact of brine discharge was not covered in the documents analysed. Respondent 8 also mentioned community pressure to relocate brine discharge points from the estuary. However, the respondent's concern was finding new discharge points, potentially requiring drilling and habitat destruction for construction. Respondent 10 explained that, despite pumping 2 million litres, the impact on the ocean is minimal, and they are exploring better brine treatment methods. The respondent's words were "*Currently, we pump the discharge back to the sea. remember as much as we are treating 2 million litres, it is pinch in the ocean. If we were dealing with 50 megalitres a day, then maybe we would investigate it. It's things we still looking into, how best we can treat our brine*".

Respondents 1-5 highlighted their unique approach, utilising brine in their manufacturing process rather than discharging it into the ocean. The analysed Environmental Impact Assessment report did not mention the impact of brine discharge, as it is a by-product of another process (Cerebos, 2021). Respondent 1 emphasised their luck in minimising environmental wastage during the RO desalination process. Despite measures like diffusers to reduce environmental impact, it was evident among respondents that brine discharge remains a concern. However, there is a lack of comprehensive environmental assessments and research on the long-term effects of these practices. This indicates a need for further investigation and evaluation of the environmental implications of brine discharge from desalination plants.

In conclusion, the insights gathered from respondents from Cerebos, Ndlambe Municipality, and Amatola Water facilities provide an overview of various environmental concerns associated with RO desalination plants.

4.4.2. Economic sustainability impacts of RO desalination plants from a life cycle perspective

The respondents from both organisations were asked about the economic sustainability impacts of RO desalination plants from a life cycle perspective. Sections 4.4.2.1 to 4.4.2.3 present the findings from the interviews and documents analysed, and these are presented and organised according to the life cycle phases as outlined in Table 2.

4.4.2.1. Construction phase

a) Construction cost

Respondent 4 spoke about the initial construction cost, including the purchase of equipment and specialised pumps. Respondent 4 said, "*Building an RO desalination plant involves a fairly expensive initial investment*". Respondent 5 also commented on the startup of the plant and emphasised how expensive it is. The expensive construction cost was also noted in the Cerebos project startup document (Cerebos, 2019)

b) Poor Planning for future project costs

Within the responses provided by the interviewees, a recurrent code that emerged is inadequate planning and insufficient investigation. Organisations currently operating RO plants appear to have encountered challenges due to a lack of proper planning, especially concerning the long-term costs of the project.

Respondent 6 highlighted that when the plant started, it did not start as a desalination facility. Instead, it started with good points to supply the works. The respondent's words were "*Looking at the history that I've received from my predecessors. They never started with the RO here. They first started with the good points and the wells points they were using to supply the works and then from there, pump into the main reservoirs to the consumers. Then they realised these volumes are too little now too because the community was starting to grow*". Recognising that the volumes were insufficient as the community grew, they opted to drill sea wells and construct a small RO desalination plant. At the time, the impact was negligible because they were extracting from a reliable water source. However, as they attempted further expansion, the costs began to escalate. Unfortunately, by this point, it was late to explore alternative water sources. The planning for the future cost of the project was not covered in the documents analysed.

4.4.2.2. Operation and Maintenance phase

a) Expensive membranes

Respondent 6 noted that standard filters, like bag filters and carbon filters, are replaced weekly. While not excessively costly, they do come at a price. According to Respondent 6, sourcing these filters is not a major challenge. However, the most expensive filters they need to purchase are the RO membrane filters. The respondent's words were "*We have two pressure vessels for the filters, with each filter accommodating eight membranes, and each membrane costing R15,000. Therefore, for the RO membrane filters alone, the company incurs a cost of R240,000*". Under stable operating conditions, these filters last for years. However, if the water quality varies and is not of good quality, it may take a month or two to change the filters. In cases where the pretreatment process fails, even if the filters were changed recently, they might have to be replaced again. Unfortunately, there is no way to recover these filters; the only solution is to replace them. Respondent 7 also mentioned that "*The membranes cost them no less than three million within five years*". Respondent 1 also addressed the issue of downtime, stating that they must perform CIP to prevent fouling that could damage the membranes, and the membranes cost them approximately 3 million rands. The expensive membranes were also noted on the Cerebos fixed expenses (Cerebos, 2023 (a)).

b) Unavailability of maintenance spares- High import cost

Respondent 6 highlighted that South Africa lacks the most expensive spares, necessitating the need to import them. The respondent's words were "*Unfortunately, South Africa does not have spares for the RO plant therefore you need to import them. There are agencies, but even the agencies that you have, do not keep the material. They keep membranes and bag filters, but the serious things like the turbos need to be imported*". Respondent 9 also addressed the issue of maintenance spares, noting the unavailability of certain required components in South Africa. The respondent emphasised the challenges posed by the fluctuating rand-dollar exchange rate. The respondent's words were "*We diminish the rand dollar exchange, so if we buy filters from the USA, it might cost us R100 today, R200 tomorrow*". The price difference is due to exchange rate variation. An analysis of the approved supplier checklist revealed that the suppliers for the Reverse Osmosis (RO) components are predominantly international (Cerebos, 2023(b)).

c) Infrastructure damage

Respondent 8 highlighted situations where insufficient valves in a system fail to prevent water from flowing back. The respondent mentioned that "*during electricity restoration after load* *shedding, water pushes through the pipelines, causing a phenomenon known as water hammer*". This creates pressure against the pipes, especially in aging infrastructure, leading to potential weaknesses and bursts that may go unnoticed for a period. Additionally, the respondent noted that severe weather events like big storms and flooding can damage infrastructure. The absence of mechanisms to secure pipelines during water hammer exacerbates these issues, contributing to significant water losses, reaching up to 45% in certain areas. This loss is particularly impactful as the treated water, with chemicals used in the purification process, goes to waste. The infrastructure damage was not covered in the documents analysed.

d) Electricity cost

All the respondents from the different organisations mentioned that electricity cost is one of the major contributors to overall expenses. This cost is intertwined with the quality of water as well. If your water quality is good, then you will use less electricity. However, overall, the cost of electricity for the plant is very high. The electricity cost is one of the major costs for RO desalination and this was noted in the analysed Amatola Water document. The document highlighted that "*One of the primary reasons for the high cost of these plants is the substantial amount of energy required to push water through the membrane* (Amatola Water, 2017/18). Additionally, the document highlighted that the main challenge in operating a desalination plant is the production cost, particularly during winter months when electricity tariffs tend to be higher (Amatola Water, 2017/18).

e) Overall operating costs

Overall, running the plant is very expensive, as indicated by the information provided by the respondents. Respondent 9 mentioned that "*we are operating the plant at a loss; the cost versus the benefits is not breaking even*". For example, they spend R2 million and get R1 million in returns for a month. Additionally, one of the factors that could be recognised as a major contributor is that the business absorbs most of the costs. The electricity cost, RO membranes, and the spares are the major contributors to the costly plant. Respondent 9 said, "*We are spending more on the plant, making a loss, and the biggest challenge we are facing is the municipality not paying the bills*." The overall operating cost was also mentioned in the documents analysed, the document highlighted that with maintenance costs higher than anticipated, desalination remains twice as expensive as treating rainwater or wastewater (Amatola, 2017/18).

4.4.2.3. Post-plant operations

a) *Fixed contracts- undercharging resulting in financial loss*

Respondent 8 identified another significant factor, namely the undercharging of the municipality and the absorption of costs by the business. The respondent mentioned that the contracts established between Amatola Water and the municipality were formulated a long time ago. Initially, the municipality operated under a misconception regarding the actual cost of producing desalinated water. However, as the municipality embarked on various projects over the years, they gradually realised the substantial expenses associated with running the desalination plant.

Confronted with financial losses from the desalination plant's operation, the organisation resorted to utilising profits from other segments of its business to offset the deficits. This strategic move was essential to maintain the plant's functioning despite operating at a loss. Respondent 6 echoed similar sentiments regarding pricing issues. The respondent expressed that the municipality had adopted a broad approach when negotiating deals with the organisation, failing to distinguish between different production processes. Consequently, the organisation found itself running the facility at a financial loss.

The low prices of water supplied to the municipality, approximately R12 per liter, combined with free transportation of the water to the municipality, exemplify the inadequacies in the existing pricing structure and show the challenges within the system. Respondent 9's words were "W*e are running the facility at a loss"*. The fixed contracts impact was not covered in the documents analysed.

4.4.3. Social sustainability impacts of RO desalination plants from a life cycle perspective

The respondents from both organisations were asked about the social sustainability impacts of RO desalination plants from a life cycle perspective. Sections 4.4.3.1 to 4.4.3.2 present the findings from the interviews and documents analysed, and these are presented and organised according to the phases as outlined in Table 2.

4.4.3.1. Construction phase

a) *Disturbances caused by construction vehicles*

Respondent 8 emphasised that during the construction phase, a significant number of construction vehicles were frequently traveling to and from the site. Given the plant's location in a small town with narrow roads, there was considerable traffic congestion at the time. The respondent noted, "*Specifically regarding this issue, from a social perspective, the plant's location presents several challenges. It is situated in a small town with limited road infrastructure, causing social impacts due to the increased construction vehicle traffic"*. Additionally, the site is located in an environmentally sensitive area, which poses substantial difficulties from a construction standpoint.

4.4.3.2. Operation and Maintenance phase

a) Vandalism and theft

Respondent 8 highlighted the significant issue of theft at Dias Cross, emphasising the severity of the situation due to the absence of surveillance. People engage in stealing cables, and the company incurs substantial costs for cable replacement. The respondent's words were "People *do not care about the cost to the community and organisation as this cost is enormous. It costs the organisation thousands of Rand to replace cables, this is exclusive of the labour cost"* The process involves hiring personnel, acquiring equipment, and conducting activities like digging trenches to access the cables. This results in significant disruptions, including downtime. The respondent further mentioned that thieves appear to overlook the broader impact of their actions on both the community and the organisation. Respondent 6 also mentioned that one of the things they struggle with is the theft of pipes, and during the repair thereof, the terrestrial environment or marine environment could be disturbed. The impact of theft and vandalism was not covered in the documents analysed.

b) Technical challenges (Knowledge of technicians)

Respondent 7 pointed out that "*the RO desalination plant has been recently introduced in South Africa*". As a result, there is a shortage of adequate data, and the mastery of their operation is still in its early stages. There is a lack of skilled labour, and the learning curve for the operation and maintenance of these facilities is ongoing. Respondent 7 further highlighted that the technical challenges experienced within the facilities, particularly regarding operational efficiency and water supply capabilities, are not solely attributed to unskilled labour but also to a deficiency in knowledge and expertise. Technical challenges were not covered in the documents analysed.

4.4.3.3. Disposal phase

There are no social impacts associated with the disposal phase of the RO desalination plant. The respondents did not consider these impacts, and they were also not noted in the documents reviewed.

4.4.3.4. Post-plant Operations

a) Lack of knowledge

Respondent 8 pointed out that while the source of the water is free, operating the desalination plant is a costly endeavour. The respondent's words were "*People often underestimate the difficulty and expenses associated with running an RO desalination plant, leading to instances where individuals use desalinated water casually, such as for watering their gardens*". The respondent highlighted that this reflects a knowledge gap within our communities. Lack of knowledge was not covered in the documents analysed.

b) Illegal connection

Respondent 8 highlighted instances where they discovered illegal connections, and water was used for irrigating plants without proper authorisation. The respondent's words were "*The connections were unauthorised, and the individual responsible was not paying for the water. The quantity of water being utilised in such cases remains unknown, and as a result, the person is not charged; essentially, they are getting water for free".* The respondent further explained that the lack of accountability in tracking water usage impacts the planning process, making it challenging to estimate production needs due to the uncertainty about the amount of water that is unaccounted for. This creates an unfair situation within the community, as some individuals deplete reservoirs for irrigation purposes while others require water for drinking.

Respondent 9 added another factor to the issue, stating that "*the municipality is not adequately tracking water usage".* The respondent cited good practices in the Western Cape, where exceeding a certain percentage of water usage requires individuals to account for it to the municipality. Furthermore, the respondent explained that in other areas of the country, this level of oversight is lacking, allowing people to construct mansions without paying for water. The illegal connection was not covered in the documents analysed.

c) Demand and Supply

Respondent 8 mentioned that during certain seasons of the year, especially around Christmas and New Year, there is usually a significant influx of holiday-makers into the area. The respondent's words were "*The population during that time triples, and the increase in water demand is phenomenal*". The respondent mentioned that the plant cannot be designed to produce more for that period of the year because the population of Kenton-on-Sea (located in Port Alfred) is not that big. Demand and supply were not covered in the documents analysed.

d) Social gap

Another common concern raised by the interviewees is the social gap. Respondent 8 pointed out that the government should provide tanks to indigenous people to enable them to catch rainwater. Respondent 9 highlighted affordability as a significant challenge, stating that, "many *people cannot afford the required amount of water*". The respondent explained that there is a certain initial allocation of free water, after which the municipality begins billing the residents. Respondent 2 suggested that to address the social gap, the government should subsidise water so that it becomes affordable for everyone. The respondent's words were "*So the only way I can think about it is the municipality or the government needs to find a way if they go that route for a RO plant or a desalination plant somehow subsidise the water with another method or find the money somewhere else as they do with it with a fuel levy. The fuel levy goes to the road accident fund, and everybody can then suddenly benefit from that*". The respondent emphasised the essential nature of water, a resource indispensable for everyone's life. The social gap impact was not covered in the documents analysed.

e) Rejection by community

Respondent 3 highlighted that some communities stereotyped sea water as drinking water. This occurred during the period when Cerebos distributed water during the dry season. The predominant sentiment comes from individuals of black descent who express reluctance to drink seawater due to the various associations linked to the sea. Some believe that the sea is connected to a multitude of elements, while others express concerns about the potential disposal of contaminants into the sea. Rejection by the community was not covered in the documents analysed.

f) Affordability

Respondent 3, Respondent 4, and Respondent 5 highlighted the affordability of water from the RO desalination plant, expressing concerns that most people may struggle to afford it. They noted that even in urban areas, some households might find the water unaffordable, as it is not as economical as the current tap water system. Interestingly, individuals from privileged backgrounds are currently shifting away from tap water for drinking purposes, opting to purchase bottled water instead. This transition has the advantage of alleviating pressure on the existing water supply systems. Affordability was not covered in the documents analysed.

4.5. QBL opportunities of RO desalination plants from a life cycle perspective

The respondents from both plants were asked questions about the sustainability opportunities of RO desalination plants from a life cycle perspective. Key themes were extracted from the respondents' responses and documents analysed and these were presented alongside the applicable life cycle phases (see Table 3 below). From the respondents' feedback and documents analysed, most opportunities of RO desalination occur post-plant, rather than within the life cycle phases.

Table 3: Themes for the QBL opportunities within the RO life cycle

Life cycle phase	Environmental	Economic	Social	Governance
Construction	• None mentioned	• Job creation	• Job creation	• Community involvement
Operation and maintenance	• Reduce surface water use-pressure alleviation • Water availability	• Economic and social development	• Water services ongoing employment	• Community involvement • Public participation
Disposal	• None mentioned	• Salt production	• Job creation	• None mentioned
Post-plant operations	• Reliable water source • Environmentally safe option • Dependable water supply • Sustainable water supply • Superior water quality • Consistently high-quality water • Burden off the municipal supply	• Economic and social development • Dependency on water for running business • Clean water • Improves health care • Consistent water supply	• Water availability • Job creation • Reliable water source • Safer water	• Community involvement • Good relationships • Community engagement • Transparency • Availability of information

4.5.1. Environmental sustainability opportunities of RO desalination plants from a life cycle perspective

The respondents from both organisations were asked about the environmental sustainability opportunities of RO desalination plants from a life cycle perspective. Sections 4.5.1.1 to 4.5.1.4 present the findings from the interviews and documents analysed, and these are presented and organised according to the phases as outlined in Table 3.

4.5.1.1. Construction phase

No opportunities were noted, and the interviewees mentioned that there are no opportunities associated with the construction phase of RO desalination on the environment.

4.5.1.2. Operation and Maintenance phase

a) Pressure alleviation

Respondent 3 highlighted that the availability of this type of water would alleviate pressure on the municipality. Respondent 4 echoed this sentiment, emphasising that utilising this sustainable water supply ensures a continuous water source for dams without depleting them to a level where the ecosystem cannot survive water extraction.

Furthermore, Respondent 4 outlined a dual advantage for Cerebos. Firstly, the use of the RO plant enhances salt production efficiency by increasing brine concentration. Secondly, as a business, Cerebos is not reliant on the municipal water line. This reduces the burden on the municipality, allowing the municipality to allocate the water to other businesses in the industrial area. The entire Cerebos plant exclusively employs RO water for its water supply, without relying on other sources. The alleviation of pressure from the local water supply was not covered in the documents analysed.

4.5.1.3. Disposal phase

No opportunities were noted, and the interviewees mentioned that there are no opportunities associated with the disposal phase of RO desalination on the environment.

4.5.1.4. Post-plant operations

a) Convenient water source

The keywords highlighted by the respondents revolved around water availability and dependence on a reliable water source. Respondent 8 emphasised that the Kenton-on-Sea area relies solely on the RO desalination plant as there is no alternative water source. The respondent's words were "*While there were initial considerations about constructing a dam at the Bushman River mouth, these ideas were abandoned due to careful evaluation*". The respondent further explained that concerns included the potential disaster for the Bushman River (a Town in Ndlambe Local Municipality in the Eastern Cape province of South Africa). if the dam had been opened, this would have led to the closure of the river mouth. After thorough consideration, considering water quality and various factors, the RO desalination plant was deemed the best option for the Kenton-on-Sea area. Respondent 7 added that despite

Kenton being along the coast, there are no available water resources for them to utilise. These points were also noted in the Amatola Water report (Amatola Water, 2022/23).

b) Consistent reliable source of water

Two respondents highlighted a key advantage of the RO desalination plant, emphasising the critical factor of water availability. Respondent 3 explained, " *It's widely known that we face challenges with leaks and water mix-ups. Our dam levels remain consistently low, even after brief periods of rain"*. The respondent further mentioned that *"this poses a serious problem for our freshwater storage reservoirs and the overall water supply to the city. In such a scenario, having a reliable source like an RO plant, drawing water from the sea, ensures a sustainable and dependable water supply for the municipality. This holds whether the system is privately owned or procured by the local authority from a company with RO desalination plants. The primary advantage lies in achieving a consistent and reliable water supply*." Respondent 7 echoed similar sentiments, noting, "*The benefit lies in obtaining drinking water from the sea, especially considering that seawater is more abundant compared to other water sources.*" This was not covered in the documents analysed.

c) Better Quality

Respondent 3 also emphasised the significance of water quality. According to the respondent's response, the municipality's current water supply, as widely reported in the media, is contaminated. In contrast, the RO desalination plant produces water of superior quality. Respondent 3 explained, "*The water quality that residents receive from the RO desalination plant is notably higher than the standards set by the local authority. The availability of superior-quality water not only alleviates pressure on the local authority but also ensures residents have access to reliable, sustainable, and consistently high-quality water*." These points were noted in the Amatola Water integrated report highlighting the improved provision of safe and reliable water service (Amatola Water, 2022/23).

4.5.2. <u>Economic sustainability opportunities of RO desalination plants from a life cycle perspective</u>

The respondents from both organisations were asked about the economic sustainability opportunities of RO desalination plants from a life cycle perspective. Sections 4.5.2.1 to 4.5.2.4 presents the findings from the interviews and documents analysed, and these findings are presented according to the life cycle phases and operational process steps as outlined in Table 3.

4.5.2.1. Construction phase

a) Job creation

Respondent 9 explained that in their procurement process, they typically engage local individuals, companies owned by women, and businesses owned by youth. Additionally, the respondent noted that a significant portion of the workforce at the Amatola Water Ndlambe plant is comprised of residents, with a focus on hiring individuals from the surrounding neighbourhood. The respondent's words were "*Most employees who work at the plant reside in the local community, there is no definite assurance that they are from the local community, but chances are high*". Job creation was also noted in the Amatola Water integrated report (Amatola Water, 2022/23).

4.5.2.2. Operation and Maintenance phase

a) Social and economic development

Respondent 8 highlighted the advantage of having water, emphasising its crucial role in running businesses such as bed and breakfast establishments. The respondent's words were "*The advantage is, you can run your businesses. These include your bed and breakfast*" In South Africa, almost every business, whether for product processing or drinking purposes, relies on water. It is a fundamental necessity, and ensuring its availability requires basic planning. Long-term strategies are essential to prevent situations where water scarcity becomes a challenge in the future.

Respondent 1 further explained the dependence on water for day-to-day operations and the broader business landscape, "*I have seen that not having water affects a lot of business. We depend on water for our day-to-day operations*". According to the respondent's responses, without a reliable and consistent water supply, the economy is at risk. This emphasises the critical importance of strategic water management to sustain business activities and ensure the overall economic stability of the region. This is also noted in the Amatola Water integrated report, the report highlights that the organisation aims to ensure socio-economic development, particularly in rural areas, through the provision of essential services (Amatola Water, 2022/23). The exact words that are used within the report are "*To contribute to the socio-economic development of the Eastern Cape through the provision of safe and reliable water services*" (Amatola Water, 2022/23).

4.5.2.3. Disposal phase

a) Salt production

Respondents 1 through to 5 highlighted that the disposal of brine increases their salt production. The concentrated brine accelerates their evaporation process, resulting in increased productivity and more products available for sale. Respondent 1 stated, "*By disposing of the brine in our salt pans, we increase the productivity of our salt manufacturing process, which means our output will be higher*." Respondent 8 mentioned that they were also approached by a salt manufacturing company interested in the brine. However, the respondent expressed concerns about the process output, noting that she does not think the volumes they produce will suffice.

4.5.2.4. Post-plant operations

a) Improved health care

Respondent 3 emphasised that the water quality from the RO desalination plant surpasses that of municipal water, especially in locations like Gqeberha. The respondent *said, "Having clean water results in fewer health issues among the population*". The respondent further explained that this translates to the allocation of resources to other critical areas. In instances of health problems, human resources are diverted towards addressing and managing the health issues, incurring significant costs to the state, regardless of the administrative level.

The respondent mentioned that having an RO plant acts as a buffer in the system, mitigating these health-related challenges. With people in good health, communities become more productive, contributing positively to overall productivity. The respondent explained that, in this scenario, city residents can engage in work activities rather than being confined to hospitals and clinics. This positive state of health allows them to make meaningful contributions to the city's overall performance and economic well-being. This was also noted in the Amatola Water integrated report which highlights the importance of improved health, dignity, and well-being for the people of the Eastern Cape through Amatola Water's provision of safe and reliable water services (Amatola Water, 2022/2023).

4.5.3. <u>Social sustainability opportunities of RO desalination plants from a life cycle perspective</u>

The respondents from both organisations were asked about the social sustainability opportunities of RO desalination plants from a life cycle perspective. Sections 4.5.3.1 to 4.5.3.3

presents the findings from the interviews and documents analysed and, these findings are presented and organised according to the life cycle phases as outlined in Table 3.

4.5.3.1. Construction phase

a) Job creation

The respondents highlighted that employment opportunities are created during the construction phase of the RO desalination plant. This is discussed in detail in section 4.5.2.1.

4.5.3.2. Operation and Maintenance phase

a) Water availability

Respondent 6 mentioned that "*In the Kenton region, there are no alternative water sources available, without RO desalination Kenton will have no water*". Respondent 7 also emphasised the limited water availability within the Kenton region due to the absence of alternative water supplies. Respondent 2 mentioned that since "*the Cerebos facility no longer relies on municipal water, they are relieving the municipality of the pressure associated with ensuring water availability*". This shift allows the municipality to redirect its resources to meet the water needs of other individuals who genuinely require this essential resource. This was also noted in the Amatola Water integrated report, the report further emphasised that desalination plants ensure water availability, especially in the Kenton region, as there are no other sources of water (Amatola Water, 2022/2023).

4.5.3.3. Post-plant operation

a) Safe water

Respondent 3 emphasised that the implementation of a desalination plant could liberate people from poor-quality water, water shortages, and the need for makeshift laboratories. With a more reliable water source, the risk associated with water quality issues can be shifted from the community to the water supply itself. Respondent 1 expressed hesitation with tap water, stating, "*I, for one, do not drink tap water*." The respondent highlighted the opportunities of the RO desalination process, describing it as an enclosed system that minimally introduces external contaminants, ensuring the safety and reduced risk of drinking water. Respondent 4 also commented on the current water quality, describing it as the worst and mentioning the constant chlorine taste. The respondent argued that replacing the existing water system with desalinated water from a plant could alleviate the community's current water-related challenges.

4.5.4. <u>Governance opportunities of RO desalination plants from a life cycle perspective</u>

The respondents from both organisations were asked about the governance opportunities of RO desalination plants from a life cycle perspective. Sections 4.5.4.1 to 4.5.4.3 present the findings from individual responses and documents analysed, and these are presented and organised according to the life cycle phases outlined in Table 3. However, the concept of governance was difficult to understand and collect opinions on owing to the lack of awareness of what defines water governance and its relation to current water system concerns.

4.5.4.1. Construction phase

a) *Community involvement*

Respondents from both plants discussed community involvement in their processes. Respondent's 6 words were, "*We even reach out to our community to inform them about our challenges, not only operational issues but also other difficulties such as theft of our electrical cables. We request their assistance in monitoring and reporting any such incidents*." Respondent 1 also highlighted the existence of a community task team, primarily composed of community members, and emphasised an open-door policy between the community and the team. This finding was also noted in the document analysed, the document highlighted that "*Amatola Water takes full responsibility for their actions and strives to exceed expectations. The entity aims to make the right decisions always to honour its commitment*." (Amatola Water, 2022/2023).

4.5.4.2. Operation and Maintenance phase

a) *Public participation*

Respondent 8 mentioned that there is an Environmental Impact Assessment (EIA) process that they are busy doing for upgrades that will allow for public participation. The organisation, especially on the environmental side, is more sensitive, and they consider community input. The respondent's words were "*The community has not raised anything that we have not raised*". The respondent also mentioned that they have a good relationship with St Mark's where their extraction points are located and further said, "*Before they dig, they need to ask permission, and the Addo group will visit the area to inspect it and then once they are satisfied, they will give the go-ahead to dig*". The St Mark's side is Amatola Water's major stakeholder in terms of the environmental impact. Respondent 9 also mentioned that they have weekly engagements and regular information sessions with the community and the community is very active. The documents analysed highlighted that "*Amatola Water recognises that stakeholders* *have an interest in the work it does and always strives to satisfy its stakeholders. Amatola Water is committed to listening and responding positively to their needs*." (Amatola Water, 2022/2023).

4.5.4.3. Post-plant operations

a) Transparency

Respondent 8 mentioned that being a public entity, their financial records are open for public scrutiny. They have a technical task team available for individuals interested in corresponding with them. When community members wish to communicate with the organisation, the technical task team ensures they receive a response. Occasionally, community members seek information, and the organisation is responsive in providing the required details. The organisation is transparent about its challenges, sharing them with the community as these challenges, directly and indirectly, affect the community.

In cases of water shedding, the community raises questions, and the organisation feels obligated to inform them. When the organisation decides to temporarily switch off the water to allow the reservoir to replenish, they inform the local community in advance so that they can prepare accordingly.

Respondent 3 explained that their stakeholders are well-informed about the organisation's activities, and the organisation actively engages in positive initiatives. Respondent 1 added that Cerebos is highly transparent, allowing anyone interested to audit their processes. This transparency extends to quality testing and water results, where they openly communicate with the customers. This trust has resulted in loyal customers, as the organisation delivers what it promises. The Amatola Water integrated report also noted transparency, the report highlighted that Amatola Water strives to be honest in its dealing with one another and stakeholders. It prides itself on ethical conduct and acts with openness and respect (Amatola Water, 2022/2023).

4.6. Water problems caused by water management and/or water scarcity

Most individuals interviewed in this study possess the knowledge and skills relevant to the subject. They were asked about the underlying causes of water issues. It is essential to improve our systems and undertake various activities to ensure water availability. However, it is equally crucial to understand the root cause of water scarcity and the factors contributing to it. Each interviewee was asked about their perspective on the possible cause, whether it be water scarcity itself or mismanagement of the resource, and they shared their insights.

Respondent 8 mentioned that "*the current water problems result from a combination of water scarcity and mismanagement*". The respondent emphasised that the water infrastructure is not managed effectively, and insufficient attention is paid to water availability. The situation has gradually evolved, leading to dams frequently being empty due to inadequate monitoring of dam levels. Another significant issue is the considerable water losses once treated water enters the bulk system. Respondent 8 indicated that "*their organisation's water losses currently stand at approximately 15%, which, in comparison to other places, is relatively better*". The respondent clarified that the losses encompass vandalism, infrastructure damage, and the ripple effects of load shedding.

Respondent 4 echoed Respondent 8 sentiments, attributing the problems to mismanagement. The respondent highlighted instances in the Nelson Mandela municipality where a pipe bursts and leaks in municipal lines are widespread, often with delayed responses from the municipality in addressing reported issues. Respondent 4 also emphasised vandalism as a contributing factor.

Respondent 5 expressed a strong belief that both water scarcity and mismanagement contributed to the issues, with water scarcity being the more significant factor. Respondent 2 concurred, asserting that both aspects play a role, and the respondent reiterated points made by Respondent 8.

4.7. Augmentation considerations

This section presents the insights provided by a water service engineer from the municipality regarding the key sustainability considerations relevant to RO desalination plants to potentially augment available water provision.

4.7.1. Water Source overview

Respondent 10 explained that the municipality has a mixed water source, their sources are surface water, groundwater, and desalination plants. Each of these different sources supplies them with a certain amount of water. Overall, the Ndlambe Municipality gets 7.3 million litres of water from these different sources and the demand only for Port Alfred (a small town located in the Eastern Cape on the banks and at the mouth of the Kowie River, precisely halfway between Port Elizabeth (Gqeberha) and East London), side during peak season is 8 million, meaning they have a shortfall. Despite these shortfalls, the Ndlambe Municipality still not considering getting another RO desalination because it is expensive.

4.7.2. Themes emerging from data

The perspective of the respondent on key sustainability considerations relevant to RO desalination plants to potentially augment available water provision sources was examined by unpacking the respondent's responses to the key consideration question. Based on the respondent's responses and the documents analysed key themes were extracted, these were cost, water quality, procurement, learning from past experience, membrane selection, partnership, infrastructure, affordability, and social aspects,

a) Cost

Respondent 10 pointed out the challenges associated with desalination, noting its high cost. The respondent mentioned that RO is considered when other water sources, like surface water and groundwater, are insufficient because it is very expensive. The respondent's words were "*Reverse osmosis type of treatment is an advanced treatment which one considers when there are no other sources of water other than seawater*". The respondent highlighted that the Ndlambe Municipality uses the guide for South African municipal engineers (Swartz et al., 2009). The cost was also noted in the desalination guide for South African municipal engineers.

b) Water Quality Challenges

Respondent 10 highlighted that water quality is another critical factor, particularly the presence of dissolved salts, the quality of water that you have, the quality of water directs one towards the process to use either a conventional process or an advanced process. The total dissolved solids are the major determining factor of the technology that you use. The respondent said, "*Before considering the technology, you also need to consider the quality of the water that you have, which will direct you towards the process to use, either a conventional process or an advanced process. When you look at our raw water quality sources even on the rivers that we take our water from, you find that there are dissolved salts. The dissolved makes the water salty, the dissolved salt is the crux that makes one decide which technology one can use, besides desalination we have other technologies that you can use such as distillation, and electrodialysis*". These points were also noted in the research guide for South African municipal engineers (Swartz et al., 2009).

c) Procurement

Respondent 10 highlighted the difficulties in finding experienced players for desalination projects due to a lack of established professionals in the field. The open tender process might lead to inexperienced contractors, emphasising the need to prioritise experienced consultants. The respondent said, "*Our experience has been good and bad, we had a situation where we had a service provider that we appointed, at the time of the appointment we followed the procurement procedure and unfortunately, we could only pick up later that they struggled previously with a desalination plant, however in the reports that gave us, they did not mention that they once struggled*". These points were also noted in the desalination guide for South African municipal engineers (Swartz et al., 2009).

d) Learning from Past Experiences

Reflecting on past experiences, Respondent 10 discussed a project where a service provider struggled with desalination, leading to project under-scoping and non-completion. The lesson learned was to separate roles, have an independent consultant, and carefully choose contractors. This was not covered in the document reviewed.

e) Membrane Selection and Technology Types

Choosing the right membranes for desalination plants is crucial and depends on salinity levels. The salinity refers to the salt levels. The respondent said, "*If you choose incorrect membrane height, you will not be able to acquire the quality of water you are looking for*" The respondent emphasised the unpredictability of seawater quality compared to river water, highlighting that the seawater requires constant monitoring and when one decides to buy the membranes, they must buy membranes that cover a broader spectrum so that when the quality changes to require a higher demand of the membrane, the membrane can take the water. This was also noted in the desalination guide for South African Municipal engineers (Swartz et al., 2019).

f) Partnerships and Alternatives

Respondent 10 suggested two alternatives for setting up desalination plants: partnering with service providers or seeking collaborations with countries experienced in desalination. Partnering with the service entails allowing the service provider to station their plant, signing an agreement with them to buy the water as the municipality, and distributing the water. The respondent's words were "*allow the service provider to station their plant, sign an agreement with the service provider, and buy your water from your service provider with a certain amount. So basically, setting up an RO desalination plant using service providers*", With collaboration with other countries with experience in desalination, the respondent mentioned that it will involve learning from best practices through consultation, asking advice from them, and visiting these countries to see the desalination plant, the respondent said, "*There are a lot of countries that have been doing this desalination process, one of the best things you can do, obviously using the political structures*". This was not covered in the document analysed.

g) Infrastructure Considerations

Respondent 10 mentioned that the infrastructure in terms of the pipelines is not the most expensive, the daily operations and the building process based on the respondent statements are the most expensive aspects of the RO desalination plant. The respondent mentioned that there are ways that one can reduce the daily operational cost which is through blending. Blending the water from the sea and other sources to reduce salinity and then running that water through the RO desalination process reduces the energy cost. This was not covered in the documents analysed

h) Community Affordability and Social Aspects

Respondent 10 emphasised the importance of considering the community's ability to afford desalinated water. The respondent mentioned that there are areas where you cannot apply a desalination plant unless you are willing to take the financial loss and there are no other options available to supply water due to the financial strain associated with the desalination plant water. This was not covered in the documents analysed.

4.8. Conclusion

In conclusion, Chapter 4 offered valuable insights into the sustainability impacts and opportunities of RO desalination plants from the Life Cycle perspective. While the respondents demonstrated a clear understanding of sustainability, the concept of QBL was less familiar to many. This chapter detailed the life cycle of RO plants, highlighting similarities and differences in pre-treatment, energy efficiency measures, and brine disposal methods. Furthermore, the respondents unpacked QBL impacts and opportunities within the RO life cycle. Environmental concerns included habitat disruption and pollution, while economic sustainability concerns included planning issues and high costs. Social impacts ranged from technical skill shortages to affordability concerns. Despite these impacts, the respondents also highlighted the RO plant's QBL opportunities, including environmental sustainability through reliable water sources and superior water quality, economic opportunities such as supporting development and healthcare, and social advantages like job creation and safe water provision. Governance opportunities, although less clear, included community involvement and transparency. The section on augmentation consideration for the RO desalination plants, as provided by Respondent 10, also highlighted several key themes. Firstly, cost is a significant factor, with RO desalination being considered only when other water sources are insufficient due to its high expense. Water quality is another critical consideration, especially regarding the presence of dissolved salts, which determines the suitability of different treatment processes. Procurement impacts include finding experienced contractors and necessitating careful selection to avoid project setbacks. Learning from past experiences underscores the importance of separating roles, employing independent consultants, and choosing contractors wisely.

Chapter 5: Research Discussion

5. Introduction

This chapter discusses the findings on the sustainability impacts and opportunities of RO desalination plants from a life cycle perspective. These findings were derived from the data of the interviews for this study in Chapter 4 and these were compared and contrasted to the literature, and based on the available data, conclusions were made.

5.1. Sustainability

The respondents from both plants demonstrated a coherent understanding of sustainability, employing two distinct categories of definition: intensional and extensional. Intensional definitions aimed to interpret the concept, while extensional definitions utilised practical examples to illustrate sustainability (Meadowcroft, 2024).

5.2. Quadruple bottom line

There was a notable degree of confusion among respondents regarding the distinction between QBL and sustainability (see Section 4.3.3). This confusion is a common and expected response when individuals encounter new concepts or information, as discussed by Lodge and Kennedy (2016).

Lodge and Kennedy (2016) highlight that confusion is a natural emotion that often accompanies the process of learning and understanding new ideas (Lodge and Kennedy, 2016). It serves as a catalyst for the development of knowledge and understanding. Therefore, the confusion expressed by some participants regarding the definition of QBL sustainability can be viewed as a normal and necessary aspect of their cognitive engagement with the topic.

This confusion is particularly understandable given that the concept of QBL sustainability represents an extension of the traditional triple bottom line (TBL) approach, incorporating an additional dimension focused on governance.

5.3. QBL impacts of RO desalination plants from a life cycle perspective

5.3.1. <u>Comparing the Amatola Water and Cerebos desalination plant life cycle</u>

The life cycles of both RO desalination plants were compared to identify any significant differences. The comparison was important because the responses from the different respondents were going to be presented in phases; therefore, it was important for the researcher to know the difference between the life cycles of the RO desalination plant. Based on the information in the above sections, it can be summarised that the life cycle of the two desalination plants is largely similar. The main difference lies in the pre-treatment process, electricity cost, and discharge brine. In the Amatola Water desalination plant, a dedicated pre-treatment step is absent. The process involves direct extraction of seawater from the sea, which then proceeds directly to the water reservoir. Unlike the Cerebos desalination plant, Amatola Water omits a specific pre-treatment phase before introducing seawater into the system.

The Cerebos plant has the energy recovery pump to save energy cost and the Amatola Water uses the normal pumps. Additionally, the discharge point for Amatola Water is the sea. Once the desalination process is complete, any brine generated is released back into the ocean, representing a standard disposal method for the byproduct.

The findings of the study showed that the two organisations employ different approaches to the life cycle, the cradle-to-cradle approach (Cerebos) and the cradle-to-grave approach (Amatola Water). In the water sector, there has been a move towards the cradle-to-cradle approach with systems like closed-loop water systems, green infrastructure, and water-efficient technologies (Pearlmutter, Pucher, Calheiros, Hoffman, Aicher, Pinho, Stracqualuris, Korolova, Pobric, Galvão, Tokuç, Bas, Theochari, Milosevic, Giancola, Bertino, Catellar, Flaszynska, Onur, Mateo, Andreucci, Milousi, Fonseca, Lornado, Gezik, Pitha and Nehls, 2021). Compared to other countries, South Africa has made strides in promoting a circular economy however still faces challenges related to resource constraints, infrastructure gaps, and socio-economic disparities (Godfrey, 2021).

In the RO desalination plant industry, there is no documented success story of the C2C approach. An international example of the C2C approach is in the Murray region in Australia. However, with the ponds in Murray, there are concerns about the environmental integrity, especially those that lack liners which pose risks to the ecosystems (Ahmed, Shayya, Hoey, Mahendran, Morris and Al-Handaly, 2000). Additionally, large-scale adoption of C2C practices faces logistical and infrastructural challenges, particularly in regions with different climates or regulatory environments. It's noteworthy that while evaporation ponds, like those used in the Cerebos desalination plant, are suitable for small-scale operations and areas with dry, warm climates, their large-scale adoption is limited (Omerspahic, Al-Jabri, Siddiqui and Saadaoui, 2022). There are not a lot of industries that use brine and salt is an essential commodity; you cannot want more of salt or less of salt.

The private sector is witnessing a trend toward embracing the C2C approach to achieve sustainability goals, increase productivity, drive innovation, and create long-term value for both business and society (Severis and Rech, 2019). For example, Cerebos is a private sector that must ensure its capability of keeping up with its business competition and is largely profit-driven whereas, Amatola Water is a State-owned Entity (SoE) whose focus is service delivery (Jurisch, Ikas, Wolf and Krcmar, 2013).

5.3.2. Environmental sustainability impacts of RO desalination plant from a life cycle perspective

As outlined in section 4.1.1, all stages of the life cycle assessment were considered. The study findings show that the operational and maintenance phase incurs more significant environmental impacts compared to the construction and disposal phases. This observation is consistent with existing literature on Life Cycle Assessment within the water sector (Buckley, Friedrich and Blottnitz, 2011). Below is a discussion of all the findings regarding environmental impacts throughout the life cycle. The impacts identified in RO desalination plants strongly correspond with the literature, and no new impacts were identified in this study

5.3.2.1. Construction phase

The respondents' perspectives on construction phase impacts align with the literature. For example, a study by Nasruddin-Roshidi, Mansor, Ismail, Ngadi, Izzat-Husna, Husin, Mohd-Taib, Illias and Nor, 2021, observed a decline in bird species during habitat disturbance caused by a dam project in Peninsular Malaysia, with signs of recovery noted during the transition to the operational phase (Nasruddin-Roshidi et al., 2021). Though this is a case, there was a slight contradiction regarding the disturbance caused by the installation of the pipeline with the respondents' view being that the pipeline results in loss of habitat. However, the Anchor Environmental Consultant report contradicts this, suggesting that the installation of pipes does not result in the loss of sandy habitat, as benthic organisms can still dig sediment above the pipeline once it is constructed (Laird, Wright, Massie and Clark, 2017).

5.3.2.2. Operation and Maintenance phase

The respondents' perspectives on maintenance and operation phase impacts i.e. extraction of raw water, carbon footprint, noise pollution, temperature variation, oil spillage, CIP chemicals, and location of the plant align with the literature. The respondents from Cerebos highlighted that their desalination plant is designed with an energy recovery pump to mitigate energy consumption. There is not a lot of literature on energy recovery pumps. However, Mansour et al. (2020) did research focused on adopting an Energy Recovery System (ERS) to increase the performance of a small RO plant in remote locations with a capacity of 2.4 m3/day (Mansour, Ismail, Ramzy, and Abd El-Salam, 2020).

In his study, Mansour modelled the ERS to validate its effectiveness (Mansour et al., 2020). The ERS demonstrated significant power savings, reducing consumption by 80% due to the recovery ratio (Mansour et al., 2020). Based on their analysis within their study, there was a notable decrease in total cost when utilising ERS (Mansour et al., 2020). A CSIR (2018) research team highlighted in the environmental impact assessment that long-term desalination using fossil fuels is no longer consistent with sustainable development because fossil fuels are infinite, and they require maintenance for critical purposes, while the demand for desalinated water continues to rise (CSIR, 2018).

The location of the plant is another perspective that the respondents highlighted, both plants being in sensitive locations, which are areas characterised by unique environmental features necessitating preservation and special attention to protect habitats and safeguard surface and groundwater (Planokc, 2024). Moreover, these locations are popular tourist destinations. Literature indicates that constructing complexes and associated infrastructure can permanently alter the visual aesthetics of buildings and consequently affect their appeal to tourists (Consortium of Consultants, 2004). In urban contexts, desalination facilities may diminish the value of surrounding properties (Consortium of Consultants, 2004).

5.3.2.3. Disposal phase

The respondents' perspectives on brine discharge impacts align with the literature. The organisations use two types of brine discharge, evaporative ponds, and diffusers. There are some examples in literature on the use of diffusers, in Spain, they conducted a study to determine whether the diffuser works with the use of Echinoderms. Echinoderms are organisms that are highly sensitive to high salinity, in the absence of the diffuser the organisms disappeared, and in the presence of the diffuser, the organisms were recovered (Fernandez and Gonzalez, 2010).

5.3.3. Economic sustainability impacts of RO desalination plant from a life cycle perspective

The LCA has significant limitations regarding the economic impact, as it does not comprehensively address the economic impacts or challenges of the process or product (Buckley et al., 2011). Nonetheless, it was utilised in this study to provide insight. This becomes apparent in the study, as most of the economic impacts and opportunities arise post-plant operation.

5.3.3.1. Construction phase.

The respondents' perspectives on the construction cost and planning phase associated with RO desalination align with the literature. For instance, the expansion of the Amatola Water plant mirrors the trend seen in other parts of South Africa where desalination plants evolve to meet increasing water demand (Blersch, 2014). However, the decision-making process concerning expansion sometimes lacks comprehensive consideration of future financial implications (Blersch, 2014). For example, desalination plants built in rural areas may result in population growth, while those in urban areas could alter the character of the surroundings.

Most desalination plants found in the literature were constructed by municipalities, with the Mossel Bay desalination plant being a notable exception, as it was built through a contract between the municipality and a private sector entity (Blersch, 2014).

Information on desalination plant construction and fixed contracts is limited in the literature. The Amatola Water plant appears to be the only plant with a fixed contract issue with the municipality. According to Panigrahi (2021), fixed contracts in any project are generally not advisable (Panigrahi, 2021). This is because fixed contracts offer buyers greater certainty regarding future expenses than sellers. When prices fluctuate, sellers may be required to absorb additional costs, leading to potential financial challenges (Panigrahi, 2021).

5.3.3.2. Operation and Maintenance phase

The respondents' perspectives on maintenance and operation phase impact i.e. expensive membranes, availability of maintenance spares, infrastructure damage, raw water quality, and electricity cost align with the literature. For example, expensive membranes are a significant cost factor in desalination technology, as noted by Patel (2018), with water quality directly impacting membrane longevity (Xu et al., 2015). In their study, Xu et al., 2015 highlighted that if the quality of the water is not good, membrane fouling might occur, which decreases membrane efficiency and increases expenses due to the need for higher pump pressure to maintain water output (Xu, Cath, Robertson, Reinhard, Leckie and Drewes, 2013; Chong, Fane, Loo and Krant, 2015).

Similarly, the lack of availability of maintenance spares locally, leading to costly imports and suboptimal plant performance, mirrors challenges faced in other regions such as Algeria (Sadi and Kehal, 2003). In Algeria, an RO desalination plant experienced suboptimal performance due to a lack of maintenance spares and other challenges such as a shortage of skilled labour (Sadi and Kehal, 2003). The underdeveloped local market for desalination plants exacerbates this issue, with foreign entities dominating activities and the Rand-dollar exchange rate impacting spare parts procurement costs (South African Government, 2021).

Infrastructure damage, often stemming from inadequate maintenance, poses significant financial burdens, in line with observations by Othman et al. (2022), where it was noted that high rates of water losses are prevalent in developing countries. Of the estimated water losses, 50% are attributed to leakages, often stemming from either inadequate maintenance or failure to replace aging systems (Othman, Alias, Fuzil, Marpani, Shahruddin, Chew, David, Lau, David, Lau and Ismail, 2022). Moreover, raw water quality, particularly salinity levels, significantly affects production efficiency as highlighted by Ahmadi et al. (2020), with desalination plants operating more efficiently with lower salinity levels (Ahmadi et al., 2020).

The high energy costs linked to seawater desalination in South Africa have hindered the widespread implementation of desalination plants (Patel, 2018). For instance, the Mossel Bay desalination plant in South Africa was halted due to the high cost of water production, with desalinated water priced at approximately double the cost of water from dams: R16 per kilolitre compared to R9 per kilolitre (Patel, 2018; Cloete, 2018). Furthermore, in South Africa, the energy intensity of desalination facilities represents a concern, considering the country's substantial reliance on coal for electricity generation (Patel, 2018). Internationally, the volatility of energy costs also impacts the operation of RO desalination plants, exemplified by the Ashkelon desalination plant where the cost of produced water increased by 17% due to higher-than-anticipated fuel costs (Herber, 2024 (b)).

5.3.4. Social sustainability impacts of RO desalination plant from a life cycle perspective.

The LCA has significant limitations concerning the social impacts as it does not fully address the social impacts or challenges of the process or product (Buckley et al., 2011). However, it was utilised within this study to provide insight. This is evident in the study, as most of the social impacts and opportunities arise after distribution. There were no social impacts associated with the disposal of brine noted in the literature, nor did the respondents identify any social impacts related to brine disposal.

5.3.4.1. Construction phase

The respondents' perspectives on construction phase impacts i.e. disturbances caused by construction vehicles align with the literature. According to Celik and Budayan (2016) in general construction processes are known to cause a nuisance to the neighbouring communities (Celik and Budayan, 2016), the same was highlighted by the respondents' in this study

5.3.4.2. Operation and Maintenance phase

The respondents' perspectives on operation and maintenance phase impacts i.e. vandalism, theft, technical challenges, and pipeline bursts damaging local roads align with the literature. The problem of theft and cable theft in South Africa poses significant challenges for public entities in the country. This issue extends beyond desalination plants, affecting various sectors. In South Africa, cable theft and vandalism of infrastructure cost entities like Telkom, Eskom, Prasa, and Transnet approximately R7 billion annually in direct losses. However, the broader economic impact is much larger, estimated at around R187 billion per year (Ebnet, 2022). An international example related to theft in the context of desalination is a community in Greece that vandalised solar stills connected to desalination plants that were donated (Kharraz, Richard and Schafer, 2017).

Another aspect that respondents highlighted is technical challenges. Operating desalination plants requires skilled personnel with adequate knowledge. Failures in desalination plant operations, such as those observed in Abu Dhabi where plants operated below their designed availability, can be attributed to insufficient staff training (South African Government, 2021). Consortium of Consultants (2004) highlights the problem of limited training for staff working at desalination plants, with low investment in training compared to the total infrastructure investment (Consortium of Consultants, 2004). Affordability also emerges as a critical concern, particularly regarding the unequal distribution of resources and the financial constraints faced by marginalised communities (Walsh, Shai and Mbangata, 2019).

5.3.4.3. Post-plant Operation

The respondents' perspectives on the social impacts of RO desalination i.e. lack of knowledge, illegal connection, demand and supply, rejection by the community, technical challenges, and affordability align with the literature. In terms of lack of knowledge, the study highlighted that there are communities that misuse desalination water. This finding can be likened to the tragedy of the commons, wherein individuals, who have access to a shared resource, tend to exploit it for their benefit, ultimately depleting the resource (Harvard Business School, 2021). This pattern may be seen in Lanzarote, Morocco, where the adoption of desalination technology was driven by reducing supply prices and improved water availability, rather than a growth in water demand (Meerganz von Medeazza, 2004).

Similarly, issues such as illegal connection, demand-supply imbalances, vandalism, and theft highlight systemic impacts that extend beyond desalination plants, reflecting broader issues in water resource management (Zhuwakinyu and Research Unit at Creamer Media, 2012; Ebnet, 2022). In South Africa, illegal irrigation is a significant issue (Zhuwakinyu and Research Unit at Creamer Media, 2012). For example, millions of litres are unlawfully used by farmers in the Vaal catchment area annually, with potential implications for the country. The theft of water from the Vaal system exacerbates South Africa's water loss due to infrastructure leakages (Zhuwakinyu and Research Unit at Creamer Media, 2012).

Social acceptance is crucial for the success or failure of desalination projects. An example of a failure in social acceptability can be observed in Australia, where a desalination project faced opposition and was halted due to insufficient community involvement during the planning process and widespread perception of reverse osmosis (RO) as environmentally unsustainable and energy-intensive (Ahmadi et al., 2020).

5.3.4. Governance impacts of RO desalination plant from a life cycle perspective

The participants did not indicate any governance impacts of RO desalination plants from a life cycle perspective. The concept of the QBL, which extends the TBL by adding governance, is still emerging in sustainability and is not yet fully understood. Organisations are generally more familiar with the TBL (Correia, 2019). This was evident in the study, as respondents provided detailed answers about the TBL pillars but struggled to respond when asked about governance.

5.4. QBL opportunities of RO desalination plants from a Life cycle perspective

The identified opportunities of RO desalination plants from a life cycle perspective strongly align with the existing literature; no new opportunities were identified in this study.

5.4.1. Environmental Sustainability opportunities of RO desalination plants from a life cycle perspective

In terms of the construction phase and the disposal phase, no opportunities were identified in this study or the literature.

5.4.1.1. Operation and Maintenance phase and post-plant operation

The respondents' perspectives on the environmental opportunities of the RO desalination plant i.e. convenient water source, consistent reliable source of water, improved quality of water, and pressure off the local supply align with the literature. Desalination plant water being a convenient water source is exemplified by the RO desalination plant in Spain, which was constructed during a severe drought and has maintained a consistent volume of water supply since its inception (Symons, 2023). The desalination plant being a consistent reliable source of water is exemplified by Singapore and Israel desalination plants, in both these countries the desalination plant water use has ensured a dependable water source, reducing reliance on imported water due to their geopolitical factors (Ahmadi et al., 2020). According to Ahmadi et al. (2020), desalination provides a secure and consistent water supply to meet these water demands (Ahmadi et al. 2020). The respondents of this study also expressed confidence in the quality of water supplied by desalination plants compared to the local sources and the ability of these plants to reduce pressure off the local municipal supply.

5.4.2. Economic sustainability opportunities of RO desalination plant from a life cycle perspective

The economic opportunities identified for RO desalination plants strongly align with the existing literature; no new opportunities were identified in this study.

5.4.2.1. Construction phase

According to the ISI Water (2017) report, desalination technology can do more than only providing drinking water in Africa. Investing in desalinated saltwater has the potential to boost employment, generate cash, and improve social sustainability in African communities (ISI Water, 2017). More detail on job creation is explained in 5.4.3.

5.4.2.2. Operations and Maintenance phase

The respondents' perspectives on the economic opportunities of the operation and maintenance phase of the RO desalination plant i.e. economic and social development align with the literature. To support the economic growth facilitated by RO desalination plants, over 150 countries worldwide utilise desalination technologies, representing approximately 1% of the global population. Particularly in the Middle East, most countries rely on desalination technologies for their daily operations (Ahmadi et al., 2020).

5.4.2.3. Disposal phase

As previously mentioned above, there is only one documented success story of using brine from desalination technology to increase the productivity of the salt production process. This is mentioned in section 5.3.1.

5.4.2.4. Post-plant process

The respondents' perspectives on the economic opportunities of RO desalination plants i.e. reliable water sources align with the literature. A local example, exemplifying the reliability of desalination plants is the Mossel Bay desalination plant, which was built in response to a severe drought. The drought, which is expected to occur about every 130 years, caused dam levels to plummet and severe water restrictions to be imposed throughout the region (Blersch and du Plessis, 2017).

The respondents' perspectives on the quality of water from desalination plants exceeding that of municipality water contradict the literature claims. While desalinated water is of good quality, there are serious worries about the introduction of biological and chemical pollutants that might endanger human health (Cooley et al., 2006). For instance, boron, which is typically found in low quantities in conventional water sources, is present at elevated levels in seawater (Cooley et al., 2006).

5.4.3. <u>Social sustainability opportunities of RO desalination plants from a life cycle perspective</u>

The social opportunities identified for RO desalination plants strongly align with the existing literature; no new opportunities were identified in this study.

5.4.3.1. Construction phase, Operations and Maintenance phase, and Post plant operation

The respondents' perspectives on the social sustainability opportunities of RO desalination plants i.e. water availability, job creation, and safer water, align well with the literature. For example, the desalination plant commissioned in Ghana in 2015 serves the water needs of 500,000 residents in Accra while also creating 400 job opportunities (ISI Water, 2017). This highlights how desalination technology may alleviate water scarcity and spur the growth of a new business focused on addressing local and regional water demands. Another example is the Mossel Bay desalination facility in the Western Cape, which helps provide water to a nearby refinery (ISI Water, 2017).

5.4.4. Governance opportunities of RO desalination plant from a life cycle perspective

5.4.4.1. Construction phase, Operation and Maintenance phase, post-plant operation

The respondents' perspectives on the governance opportunities of RO desalination plants i.e. public participation, community involvement, and transparency align with the literature. The respondents' highlighted public participation. Public involvement plays an important role, as projects can be cancelled if the public expresses dissatisfaction (Laird et al., 2017). For instance, in La Mercy, residents opposed the construction of an RO desalination plant at Umgeni in Kwazulu Natal due to concerns about its environmental impact (CSIR, 2018). Their dissatisfaction stemmed from insufficient awareness about the proposed project and its location in an environmentally sensitive area, potentially affecting indigenous forests (CSIR, 2018). Existing policies and legislation, including the 1996 Constitution, the Water Services Act of 1997, and the Municipal Systems Act of 2000, aim to facilitate citizen participation in service delivery (Masiya, Davids and Mazenda, 2019).

Community involvement encompasses practices that enable residents to influence municipal affairs through the exchange of information, consultation, and mobilisation, aimed at informing and influencing municipal policies (Shannon and O'Leary, 2020). According to Andriani et al., 2017, community engagement plays a crucial role in water management, requiring deliberate efforts and collaborative planning to foster meaningful participation (Andriani, Zagloel, Koestoer and Suparmoko, 2017). An illustrative example is seen in Australia, where a desalination plant project was opposed and ultimately halted due to community engagement during the planning phase and widespread perception of RO technology as environmentally unsustainable and energy-intensive (Ahmadi et al., 2020).

5.5. Water mismanagement and water scarcity

The respondents' views on the causes of the water crisis in South Africa align with the literature, as highlighted by Stoll (2024), who asserts that water experts in the region agree that the country's water challenges stem from both economic factors, such as insufficient investment, and physical constraints, such as limited rainfall (Stoll, 2024).

The situation is exacerbated by the prolonged absence of substantial rainfall in recent years. Furthermore, there has been a significant growth in water demand across many sectors, including residential, commercial, and industrial. This increase, coupled with the evident deterioration of infrastructure leading to significant water leaks, results in the alarming loss of approximately 25-30% of the available water supply (Stoll, 2024).

An example illustrating the mismanagement of resources is that of Cape Town. In 2018, the city faced a severe water crisis, marking it as the first large city to nearly exhaust its drinking water supply (Lia, 2022). This crisis stemmed from a combination of factors including prolonged drought, inadequate management of resources, and excessive consumption (Lia, 2022). In essence, the water crisis in South Africa is multifaceted, involving a complex interplay of environmental, infrastructural, and managerial issues, which necessitates comprehensive and coordinated efforts to address them effectively.

5.6. Augmentation consideration

The respondent's perspective on augmentation consideration i.e. cost, raw water quality, procurement, learning from past experiences, membrane selection, partnership alternatives, infrastructure consideration, community affordability, and social aspects align with the literature.

5.6.1. Cost

The cost of an RO plant typically includes construction, maintenance, and operational expenses. Construction costs for municipalities are generally one-time expenditures, as exemplified by Cape Town's plan to construct an R1.8 billion desalination plant (Marvin, 2020), while operational costs are influenced by various factors. The provided table outlines a typical breakdown of operational costs for a RO desalination plant. Table 4 below shows different desalination technologies, with RO (Reverse Osmosis) technology being the first one listed. The table indicates that the operational cost of RO desalination is constituted as follows: electrical energy (31.6%), membranes (3.9%), chemicals (9.2%), and other parameters (3.9%) (Marvin, 2020).

Table 4: Breakdown of operational costs for a RO desalination plant (Marvin, 2020),

Technology	Total Cost USD/m^3	Amortised Capital (%)	Electrical Energy (%)	Thermal Energy (%)	Membranes (%)	Labor (%)	Chemicals (%)	Miscellaneous (%)
RO	0.6–2.86	38.2	31.6	-	3.9	13.2	9.2	3.9
MED	1.12–1.5	34.9	7.2	37.3	-	9.6	9.6	1.2
MSF	1.02–1.74	39.3	18.7	29	-	7.5	4.7	0.9

As mentioned earlier, the table shows the breakdown of operational costs, with parameters such as plant size, feed water characteristics (salinity, temperature, and biofouling elements), energy requirements, and desired water quality (municipal, industrial, or agricultural). Many desalination facilities in South Africa were constructed as emergency responses to crises, leading to a significant increase in operational costs over time. Hence, water planners must consider future water demand when establishing desalination facilities.

5.6.2. Raw water quality

In cases of low salinity, RO plants offer a more economical option compared to thermal desalination systems due to energy efficiency and reduced energy requirements (Ahmadi et al., 2020). An RO seawater desalination plant in the Red Sea, with an average salinity of Total Dissolved Solids (TDS); total dissolved solids include inorganic salts such as calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates, along with minor amounts of organic matter dissolved in water 44ppt, consumes 30% more energy than plants processing seawater from the Pacific or Atlantic Oceans, with an average salinity of TDS 46ppt, under similar conditions (World Bank, 2019). Feed-water quality and temperature variation influences the efficiency of RO plants because the performance of the membrane is susceptible to these factors throughout the desalination process.

According to research conducted by Voutchkov (2018), RO plants in the Persian Gulf need 16% more capital and 14% more recurrent expenditures than those in the Mediterranean area due to variations in water supply. This is largely due to the greater salinity and increased biofouling potential of saltwater in the Persian Gulf, which requires more expensive pretreatment and intake systems, as well as more regular membrane maintenance or replacement (Ahmadi et al., 2020).

5.6.3. Procurement

In government departments, an open tender procedure is used to facilitate competitive procurement, however, in the desalination industry, this is a major challenge, primarily because the industry is dominated by large foreign firms, and there is a lack of local expertise and technical know-how to construct and commission desalination facilities domestically (South African Government, 2021). Therefore, in cases like this, the municipality should conduct a thorough local and project-specific assessment to identify segments of the value chain that can be localised. Construction, operations, and maintenance (O&M) offer the most significant opportunities in this regard. Investors may leverage their influence to enhance the skills of the local workforce (Patel, 2018). The procurement process for remineralisation phases holds significant potential for local content incorporation. Minerals such as calcium carbonate are readily available locally, making them more accessible for procurement by local businesses (Global Water Intelligence, 2019).

5.6.4. Learning from experience

Learning from experience entails reviewing the company's successes and failures (Blersch, 2014). There have been several blunders and failures in desalination technology, and any company or governmental agency considering RO desalination should learn from the mistakes of others. Most of South Africa's desalination facilities were established in reaction to disasters (Blersch, 2014). There was no strategy in place for the future or expansion of these facilities within the current water supply. An example of this is the R210 million investment in Mossel Bay, which is now underused, and the stakeholders of this desalination plant view it as an asset for guaranteeing drought resilience, system flexibility, and ability to deal with future population and economic expansion (News24, 2013).

5.6.5. Membrane selection

The type of membrane utilised in the reverse osmosis (RO) desalination process significantly influences its performance and efficiency (Carewater Tech and Solutions, 2024). Moreover, the material composition of the membrane can profoundly affect its properties, including hydrophobicity and surface characteristics, thereby influencing the membrane's separation capabilities (Othman et al., 2022). Different raw water sources, such as groundwater, surface water, salt water, and rainfall, contain various pollutants (Othman et al., 2022). For instance, extracting groundwater from large underground aquifers requires the construction of deep wells, and any standard membrane can suffice. However, the scenario differs in RO desalination, where the membrane must effectively reduce the total dissolved solids (TDS) from 35,000ppm to 200-500ppm TDS (Ahunbay, 2019).

5.6.6. Partnership alternatives

An example of collaboration in South Africa is between the Mossel Bay desalination plant and PetroSA. The rationale for collaboration is that desalination technologies are expensive, and the initial cost is one of the most significant expenses (News24, 2013).

Another example of collaboration in South Africa is the Amatola Water RO plant, which supplies water to the Ndlambe municipality at an agreed-upon price. Another form of collaboration involves forging relationships with nations experienced in desalination facilities, allowing for knowledge transfer and learning from best practices. For instance, Middle Eastern countries have been relying on desalination technology for years and possess considerable expertise in this field. South Africa can learn from such countries; for example, Saudi Arabia boasts the world's largest daily production capacity of 117 million cubic meters, with 27 desalination facilities scattered across the country (Sawe, 2017).

5.6.7. Infrastructure consideration (approaches for cutting cost)

One of the highlights from Respondent 10 response is that there are ongoing methods in place to reduce operational costs, one of which is through blending. As per Voutchkov (2013), the energy needed for salt separation in RO membrane desalination systems correlates with the salinity of the source water (Voutchkov, 2013). Lower salinity for source water requires less energy production for freshwater (Watson, Morin and Henthorne, 2003). Blending, a process of mixing seawater with another water source, is a technique for decreasing salinity levels. While not widely adopted presently, this strategy holds significant potential benefits given the right conditions (Watson et al., 2003).

5.6.8. Community affordability and social aspects

The respondent emphasised the necessity of considering the community's ability to afford desalinated water. The selling and buying costs for these plants must be balanced. As mentioned earlier in the preceding section, desalination plant water is pricier than conventional water sources due to factors such as associated energy costs, membrane expenses, and labour.

5.7. Conclusion

The primary cause of water scarcity in South Africa is a combination of water mismanagement and prolonged periods of low rainfall. While desalination plants present a potential solution to these water scarcity problems, it is crucial to understand their opportunities and impacts from a life cycle perspective. This knowledge provides valuable insights for decision-makers, guiding them in assessing the potential success and failure of desalination projects. Furthermore, key factors for augmentation were detailed with some industry examples, key factors such as cost, raw water quality, procurement processes, and the importance of learning from past experiences.

Chapter 6: Conclusion

6.1. Introduction

This chapter offers a conclusion of the study. It provides a summary of the study, suggests sustainability and augmentation recommendations for improvements, presents research limitations, contributions of the study, recommendations for future research, and concludes the research.

6.2. Summary of findings and alignment with literature objectives

As a reminder, the study's objectives were:

1. To identify the sustainability (quadruple bottom line) impacts and opportunities associated with RO desalination plants in the Eastern Cape, from a life cycle perspective.
2. To investigate the key sustainability considerations relevant for RO desalination plants to potentially augment available water provision sources in the Eastern Cape.
3. To make recommendations on how RO desalination plants could potentially augment the available water provision sources, considering all four pillars of the quadruple bottom line.
4. To formulate recommendations on the QBL outcomes of the desalination plants (from a life cycle perspective) for better utilisation and management of these plants.

Objective 1 and Objective 2 were met through interviews and document analysis. These methods of data collection entailed gathering insights from the diverse set of experts from the three organisations and reviewing relevant documents. The last two objectives were met by analysing the data from the study and reviewing the literature.

To highlight the findings from the study the respondents unpacked QBL impacts and opportunities within the RO life cycle. Environmental concerns included habitat disruption and pollution, while economic sustainability concerns included planning issues and high costs. Social impacts ranged from technical skill shortages to affordability concerns. Despite these impacts, the respondents also highlighted the RO plant's QBL opportunities, including environmental sustainability through reliable water sources and better water quality, economic opportunities such as supporting development and healthcare, and social advantages like job creation and safe water provision. Governance opportunities, although less clear, included community involvement and transparency. Identified augmentation considerations within this study included cost, water quality, procurement, and learning from experience. The cost is a significant factor, with RO desalination being considered only when other water sources are insufficient due to its high expense. Water quality is another critical consideration, especially regarding the presence of dissolved salts, which determines the suitability of different treatment processes. Procurement impacts include finding experienced contractors and necessitating careful selection to avoid project setbacks. Learning from past experiences emphasises the importance of separating roles, employing independent consultants, and choosing contractors wisely.

6.3. Recommendations

To address the final research objective, the study aims to provide recommendations on the quadruple bottom line (QBL) outcomes of desalination plants and on how reverse osmosis (RO) desalination plants could potentially augment the available water provision sources. These recommendations consider all four pillars of QBL.

6.3.1. Construction phase

6.3.1.1. Environmental sustainability

Most desalination plants discussed in the literature, including the one at Amatola Water, were constructed as emergency responses to water scarcity. Consequently, proper environmental impact assessments were often not conducted. It is essential to perform thorough environmental impact assessments before constructing desalination plants (CSIR, 2007). This practice will help mitigate disturbances to animal and plant life and ensure that these plants are not built in environmentally sensitive areas.

6.3.1.2. Economic sustainability

Feasibility studies and proper planning will need to be done for future desalination, which will assist in understanding the initial and long-term costs (Bridges, 2023). This feasibility study should detail the potential water sources, future demand projections, and future operational costs. Models can be used to project incremental capacity as demand grows (Güçlü, Ekinci, Korkmaz, Başaran, Karaaslan, Aldemir, Türkoğlu, Serindağ, Colino, Ar, Ülgen, Dikmen and Pakdemirli, 2021).

6.3.1.3. Social sustainability and governance

The lack of community involvement and widespread perceptions of reverse osmosis (RO) as environmentally unsustainable and energy-intensive (Ahmadi et al., 2020) have previously led to the halting of desalination projects. To prevent such issues, there should be regular community meetings before construction begins to explain the desalination technology and its implications. Additionally, the project team should ensure that the local community benefits from the project through employment opportunities.

6.3.2. Maintenance and operation phase

6.3.2.1. Environmental sustainability

Insulation of the in-plant housing should be incorporated within the first plant design to reduce the noise levels (CSIR, 2016). Given the high energy consumption of RO desalination plants (Herber, 2024 (c)), transitioning to renewable energy sources or incorporating Energy Recovery Systems (ERS) in plant design is essential to reduce GHG emissions.

6.3.2.2. Economic sustainability

Plant managers need to develop an inventory management system for essential spare parts to minimise lead times and reduce costs associated with emergency imports (Zhang, Huang and Yuan, 2021). In addition, organisations that own desalination plants need to establish strong relationships with local suppliers and explore opportunities to localise key components to enhance reliability and efficiency. Given that energy costs constitute a significant portion of desalination expenses (Patel, 2018) and the instability in electricity supply for countries like South Africa (Patel, 2018), organisations need to transition from non-renewable to renewable energy sources, like solar or wind energy to reduce the cost of operations. Additionally, implement Energy Recovery Systems (ERS) to capture and reuse energy within the plant, further optimising operational efficiency and reducing environmental impact.

6.3.2.3. Social sustainability and governance

Form training relationships with technical institutions and universities to develop a competent workforce capable of maintaining and managing RO desalination plants. This initiative should include on-the-job training, internships, and apprenticeships (Herber, 2024 (c)) to ensure practical skill development. Organisations need to implement educational campaigns to inform the public about the cost, benefits, and impacts of RO desalination. Highlighting the importance of using desalinated water responsibly and the impact of illegal connections on the community.

6.3.3. Disposal phase

6.3.3.1. Environmental sustainability

The impact of brine has not been studied, and as a result, there is no confirmed environmental impact of brine. A thorough environmental impact assessment should be conducted on the disposal of the brine into the environment.

6.3.4. Augmentation recommendations.

6.3.4.1. Cost

Implement cost-effective measures such as using the energy recovery pump (Mansour et al., 2020) and making sure that before implementing RO desalination plants, funding and partnership options are considered to mitigate high initial capital costs (Blersch, 2014).

6.3.4.2. Procurement challenges

Improve the procurement process by conducting due diligence on potential contractors and service providers. Establish a criterion that prioritises experience and track record in successful desalination projects to avoid project delays and cost overruns (Australian Government, 2023).

6.3.4.3. Membrane selection and technology type

Invest in research and development for membrane technologies that are adaptive and energy efficient. Foster partnerships with technology providers to ensure access to the latest advancements in membrane technology (Osman, Chen, Elgarahy, Farghali, Mohamed, Priya, Hawash and Yap, 2024).

6.3.4.4. Community affordability

Conduct a thorough socio-economic assessment to understand the local community's affordability and willingness to pay for desalinated water (Herber, 2024). Develop inclusive pricing models or subsidies where necessary to ensure equitable access to water while considering the financial strain on vulnerable communities (Herber, 2024).

6.3.5. QBL and LCA

Stakeholders of desalination plants need to raise awareness and build capacity to help people understand QBL throughout the life cycle of RO desalination plants. By building awareness, stakeholders will ensure that all aspects of desalination projects are considered, leading to more informed and balanced decision-making. Awareness-building initiatives could include educational campaigns, workshops, and public consultations.

6.4. Research limitations

The research focused only on two desalination plants, so the findings cannot be generalised to all desalination plants worldwide. Additionally, not all the sites that were supposed to be sampled were sampled. Only one municipal engineer participated in the study, meaning a broader perspective from the municipality was not covered. Another critical issue was the governance component, it was difficult to collect opinions on the concept due to the lack of awareness of what defines water governance and its relation to current water system concerns. However, it is worth noting that the findings from the study fill a gap in the literature from the QBL and LCA perspectives.

6.5. Recommendation for future research

1) Future research could include a larger number of desalination plants in diverse geographic and environmental settings to validate the findings and ensure they are broadly applicable, and this could help identify region-specific challenges.
2) Conduct a more in-depth Life Cycle Sustainability Assessment (LCSA)
3) Assess the resilience of desalination plants to climate change, including the impacts of sea level rise, changing water temperatures, and increased frequency of extreme weather events.

6.6. Contributions of the study

6.6.1. Knowledge gap

The study addressed previously unexplored areas by examining desalination plant technology from QBL and LCA perspectives. Furthermore, it contributed towards effective and sustainable augmentation of existing water supply sources using RO desalination. This study provided valuable insights that can be used to enhance water availability and promote progress towards achieving SDG 6

6.6.2. Methodological contribution

The study provided a high-level approach for integrating the QBL framework into the life cycle of RO desalination plants. This methodology emphasises a holistic view of sustainability, addressing environmental, economic, social, and governance aspects at each stage of a desalination plant life cycle- from construction, maintenance, and operation to disposal. By using this approach, stakeholders can evaluate and mitigate the negative impacts of these plants while enhancing the positive outcomes. This methodological contribution offers a road map for future studies and projects to ensure sustainability is included in core planning and operational processes.

6.6.3. Policy

The outcomes of this study provide valuable insights for organisation and sector policies. The recommendations that are derived from this research can inform strategic approaches to improving sustainability in RO desalination plants, influencing policies related to environmental regulation, resource management, and technological innovation.

The outcomes of this study offer robust policy recommendations that can guide organisational and sector-wide strategies for improving the sustainability of RO desalination plants. Key recommendations include implementing environmental impact assessment before construction to ensure ecological preservation (CSIR, 2018), encouraging the adoption of renewable energy (Patel, 2018) and promoting policies that support local supply chain and inventory management to enhance economic resilience and operational efficiency (Zhang, Huang and Yuan, 2021).

6.6.4. Educational value

The study enriches academic literature by expanding knowledge of sustainability practices in desalination technologies. By documenting methodologies, empirical findings, and policy implications, the study serves as a reference for future research and educational initiatives aimed at advancing sustainable practices in water treatment.

6.6.5. Industry impact

The research has the potential to influence industry practices and approaches towards sustainability. By highlighting best practices, identifying challenges, and proposing actionable recommendations, the findings can guide the decision-making process within the desalination industry. This impact extends to technology developers, operators, and policymakers seeking to integrate sustainable practices into operational strategies.

6.7. Conclusion

As the global demand for freshwater continues to rise, RO desalination presents a viable solution to enhance water security, particularly in water-stressed regions. However, a balanced approach that considers economic, social, environmental, and governance factors is essential to realise its full potential. By adopting the recommendations outlined in this study and pursuing further research, stakeholders can ensure that RO desalination addresses current water scarcity impacts and contributes to a sustainable and resilient water future.

References

Abazza, H., 2012.Economic considerations for supplying water through desalination in South Mediterranean countries. [online] Available at < https://www.swim-sm.eu/files/Economic_Considerations_on_Desalination_Final.pdf> [Accessed on 21.09.2022].

Ackerman, A., 2018. Advantages and disadvantages of desalination plants. [Online] Available at https://sciencing.com/advantages-disadvantages-desalination-plants-8580206.html> [Accessed on 25.05.2022].

Ahmadi, E., McLellan, B., Mohammadi-Ivatloo, B., Tezuka, T., 2020. The role of renewable energy resources in the sustainability of water desalination as a potential fresh-water source: an updated review. *Sustainability*, 12, pp. 5233.

Ahmed, M., Shayya, W.H., Hoey, D., Mahendran, A., Morris, R., Al-Handaly, J., 2000. Use of evaporation ponds for brine disposal in desalination plants. *Desalination*, 130, pp. 155-168.

Ahunbay, M.G., 2019. Achieving high water recovery at low pressure in reverse osmosis processes for seawater desalination. *Desalination,* 465, pp. 58-68.

Alhaddi, H., 2015. Triple bottom line and sustainability: a literature review. *Journal of Business Management Studies,*1 (2), pp. 11-15.

Alibašić, H., 2017. Measuring the sustainability impact in local governments using the quadruple bottom line. *The International Journal of Sustainability Policy and Practice,* 13, pp. 37-45.

Amalfitano, A.,Lam, K., 2005. Power to seawater RO in China. *World Water and Environmental Engineering,* 28, pp. 16-17.

Amatola Water, 2015/16. Flow diagram of RO desalination process. Internal report. Unpublished.

Amatola Water, 2017/18. Desalination is an alternative solution to SA's water supply challenges. [online] available at < https://amatolawater.co.za/talking-water/details/desalination-an-alternative-solution-to-sas-water-supply-challenges> [accessed on 25.04.2024].

Amatola Water, 2021/22. Amatola Water integrated annual report. [online] available at < https://www.amatolawater.co.za/media-centre/publications?cat=1> [accessed on 25.04.2024].

Amatola Water, 2022/23. Amatola Water integrated annual report. [online] available at < https://www.amatolawater.co.za/media-centre/publications?cat=1> [accessed on 25.04.2024].

Andriani, Y., Zagloel, Y., Koestoer, R.H., Suparmoko, M., 2017. Public participation in water resources management: restructuring model of upstream Musi watershed. Presented at the AIP Conference Proceedings, p. 100014.

APA Engineering, 2024. Understanding the essence of Life Cycle Assessment. [online] available at < https://apaengineering.com/compliance-blog/understanding-the-essence-of-life-cycle-assessment> [accessed on 04.03.2024].

Aras, G., Crowther, D., 2008. Corporate sustainability reporting: A study in disingenuity. *Journal of Business Ethics,* 87, pp.279-288.

Arrow, K., Bolin, B., Costanza, R., Dasgupta, P., Folke, C., Holling, C.S., Jansson, B.-O., Levin, S., Mäler, K.-G., Perrings, C., Pimentel, D., 1995. Economic growth, carrying capacity, and the environment. *Ecological Economics*, 15, pp. 91-95.

Australian Government, 2023. Due diligence in procurement. [online] available at < https://www.finance.gov.au/sites/default/files/2023-11/Due-Diligence-in-Procurement.pdf> [accessed on 27.06.2024].

Aziz, N.I.H.A., Hanafiah, M.M., 2021. Application of life cycle assessment for desalination: Progress, challenges, and future directions. *Environmental Pollution,* 268, pp. 115948.

Batchelor, C., 2020. Water governance literature assessment: report contributing to the scoping exercise managed by IIED to help develop a DFID research program on water ecosystem and poverty reduction under climate change. Blersch, C.L., 2014. Planning for seawater desalination in the context of the Western Cape water supply system.

Blersch, C.L., du Plessis, J.A., 2017. Planning for desalination in the context of the Western Cape water supply system. *Journal of the South African Institution of Civil Engineering,* 59, pp. 11-21.

Bowen, G.A., 2009. Document analysis as a qualitative research method. *Qualitative Research Journal,* 9, pp. 27-40.

Boyatzis, R., 1998. Transforming qualitative information*:* thematic analysis and code development. Thousand Oaks: SAGE Publications.

Braun, V., Clarke, V., 2012. *Thematic Analysis*. In H. Cooper, P. M. Camic, D. L. Long, A. T. Panter, D. Rindskopf, & K. J. Sher, eds. APA Handbook of Research Methods in Psychology, Vol. 2: Research Designs: Quantitative, Qualitative, Neuropsychological, and Biological. pp. 57-71. Washington DC: American Psychological Association.

Bridges, J., 2023. What is a feasibility study? How to conduct one for your project. [online] available at < https://www.projectmanager.com/training/how-to-conduct-a-feasibility-study> [accessed on 12.06.2024].

Brundtland, G., 1987. Our common future: The World Commission on Environment and Development. Oxford, England: Oxford University Press.

Buckley, C., Friedrich, E., Blottnitz, Von, H., , 2011. Life-cycle assessments in the South African water sector: a review and future challenges. *Water SA*, 37, pp. 719-726.

Butler, D., Farmani, R., Fu, G., Ward, S., Diao, K., Astaraie-Imani, M., 2014. A New approach to urban water management: safe and sure. Procedia Engineering, 16th Water Distribution System Analysis Conference, 89, pp. 347-354.

Carewater Tech and Solutions, 2024. The role of membranes in reverse osmosis. [online] available at < https://carewater.solutions/en/the-role-of-membranes-in-reverse-osmosis/> [accessed on 05.02.2024].

Carissimi, M.C., Creazza, A., Colicchia, C., 2023. Crossing the chasm: investigating the relationship between sustainability and resilience in supply chain management. *Cleaner Logistics and Supply Chain,* 7, pp. 100098.

Celik, T., Budayan, C., 2016. How the Residents Are Affected from Construction Operations Conducted in Residential Areas. *Procedia Engineering,* 161, pp. 394-398

Cerebos, 2019. Project start-up. Internal document. Unpublished.

Cerebos, 2020. Flow diagram of RO desalination water. Internal document. Unpublished.

Cerebos, 2021. Environmental Impact Assessment Report (EIA). Internal document. Unpublished.

Cerebos, 2022. Control and operation of RO desalination plant. Internal Document. Unpublished.

Cerebos, 2023 (a). Fixed expenses. Internal Document. Unpublished.

Cerebos, 2023 (b). Approved supplier List. Internal Document. Unpublished.

Chaudhry, S., 2006. Unit cost of desalination. California desalination task force, California Energy Commission. [online] available at < https://static1.squarespace.com/static/5eb18d627d53aa0e85b60c65/t/5edf516d8c1e0f59aa350072/1591693682402/UnitCostDesalination.pdf> [accessed on 01.06.2023].

Cherif, H., Belhadj, J., 2018. Chapter 15 - Environmental life cycle analysis of water desalination processes, in: Gude, V.G. (Ed.), sustainable desalination handbook. Butterworth-Heinemann, pp. 527-559.

Chong, T.H., Loo, S.L., Fane, A.G., Krantz, W., 2015. Energy-efficient reverse osmosis desalination: effect of retentate recycle and pump and energy recovery device efficiencies. *Desalination*, 366.

Cleaver, F., 2000. Moral ecological rationality, institutions, and management of the common property. *Development and change,* 31, pp. 361-383.

Cloete, K., 2018. Capetonians applauded for driving down water use. [online] available at < https://www.engineeringnews.co.za/article/capetonians-applauded-for-driving-down-water-use-2018-06-01> [accessed on 01.02.2024].

Cohen, D,Crabtree, B., 2006. Semi-structured interviews: qualitative research guidelines project. *Robert Wood Johnson Foundation*. [online] Available at: <http://www.qualres.org/HomeSemi-3629.html> [Accessed 14.01.2024].

Cohen, L., Manion, L.Morrison, K., 2000. Research methods in education. 5th edition, Routledge Falmer, London.

Collier, Z., Wang, D., Vogel, J.T., Tatham, E.K., Linkov, I., 2013. Sustainable roofing technology under multiple constraints: a decision analytic approach. *Environment, Systems, Decisions*,33, pp. 261-271.

Conflict Environment Observatory, 2021. Oil spills from Libya's Derna power and desalination plant. [online] available at < https://ceobs.org/oil-spills-from-libyas-derna-power-and-desalination-plant/> [accessed on 31.01.2024].

Consortium of Consultants (DHV Water BV, Amersfoort, The Netherlands, and BRL Ingenierie, nimes, France), 2004. Seawater and brackish water desalination in the Middle East, North Africa, and Central Asia. [online] available at < https://documents1.worldbank.org/curated/en/890811468002102369/pdf/335150v10Seawater0mainreport1Final2.pdf> [accessed on 02.02.2024].

Cooley, H., Gleick, P.H., Wolff, G.H., 2006. Desalination, with a grain of salt: a California perspective. Pacific Institute for Studies in Development, Environment, and Security, Oakland, California.

Corbin, J ., Strauss, A., 2008. Basics of qualitative research: techniques and procedures for developing grounded theory (3rd ed.). Thousand Oaks, CA: Sage.

Cornejo, P.K., Santana, M.V.E., Hokanson, D.R., Mihelcic, J.R., Zhang, Q., 2014. The carbon footprint of water reuse and desalination: a review of greenhouse gas emissions and estimation tools. *Journal of Water Reuse and Desalination,* 4, pp. 238-252.

Correia, M.S., 2019. Sustainability: An overview of the triple bottom line and sustainability implementation. *International Journal of Strategic Engineering*, 2(1), pp.29-38.

Cotruvo, J.A., 2005. Water desalination processes and associated health and environmental issues. *Water Conditioning and Purification,* 4, pp. 13-17.

CSIR, 2007. Ben Schoeman dock berth deepening project: Integrated Marine Impact Assessment Study. Report number CSIR/NRE/ECO/ER/2007/0014/C prepared by the CSIR. 153 pp.

CSIR, 2016. Environmental Impact Assessment (EIA) for the proposed construction, operation, and decommissioning of seawater reverse osmosis plant and associated Infrastructure proposed at Lovu on the KwaZulu-Natal South Coast: chapter 11: Noise facts. [online] available at <https://www.csir.co.za/sites/default/files/Documents/FEIAR_UW_Chap_11_Noise_Lovu_240316.pdf> [accessed on 02.02.2024].

CSIR, 2018. Environmental Impact Assessment (EIA); updated final Environmental Impact Assessment Report for the proposed construction, operation, and decommissioning of seawater reverse osmosis plant and associated Infrastructure in Tongaat, Kwazulu-Natal. [online] available at < https://www.csir.co.za/sites/default/files/Documents/FEIAR_UW_APP_E_Public%20Participation_Tongaat_200618_Part%20II.pdf> [accessed on 02.02.2024].

CSIR, 2021. Decoupling South Africa’s development from water demand through circular economy. [online] Available at < https://www.circulareconomy.co.za/wp-content/uploads/2021/11/8.-Water_CE-Briefing-Note.pdf> [accessed on 05.02.2024]

Danoun, R.,Jones, I.S.F., 2007. Desalination plants: potential impacts of brine discharge on marine life. The Ocean Technology Group, Australia.

Dawoud, M., 2005. The role of desalination in augmentation of water supply in GCC countries. *Desalination,* 186, 187-198.

Dawoud, M., Mulla, M.M., 2012. Environmental Impacts of seawater desalination: Arabian Gulf Case Study. *International Journal of Environmental Sustainability*, 1, pp. 22-37.

De Luca Peña, L.V., Taelman, S.E., Préat, N., Boone, L., Van der Biest, K., Custódio, M., Hernandez Lucas, S., Everaert, G., Dewulf, J., 2022. Towards a comprehensive sustainability methodology to assess anthropogenic impacts on ecosystems: Review of the integration of Life Cycle Assessment, environmental risk Assessment, and ecosystem services assessment. *Science of The Total Environment,* 808, pp.152125.

Department of Environmental Affairs and Tourism, 2004. Life cycle assessment- integrated environmental information series. [online] available at < https://www.dffe.gov.za/sites/default/files/docs/series9_lifecycle_assessment.pdf> [accessed 04.03.2024].

Department of Water and Sanitation (DWS), 20120. Annual report. [online] Available at < https://www.gov.za/documents/department-water-and-sanitation-annual-report-20192020-10-mar-2021-0000> [accessed 20.06.2023].

Diemen, E., 2022. An effective roll-out of renewable energy could have prevented 2021 load shedding and saved billions – report. [Online] available at https://www.dailymaverick.co.za/article/2022-06-20-an-effective-roll-out-of-renewable-energy-could-have-prevented-2021-load-shedding-and-saved-billions-report/ [Accessed on 25.06.2022].

Dolnicar, S., Hurlimann, A., 2011. Water alternatives—who and what influences public acceptance? Journal of Public Affairs, 11, pp. 49-59.

Ebnet, 2022. Cable Theft and vandalism threaten South Africa's economic recovery. [Online] available at https://www.ebnet.co.za/cable-theft-and-vandalism-threatens-south-africas-economic-recovery/ [accessed on 02.02.2024].

Elimelech, M., Phillip, W.A., 2011. The Future of seawater desalination: energy, technology, and the environment. *Science,* 333(6043), pp. 712-717.

Elkington, J., 1997. Cannibals with forks: the Triple Bottom Line of 21st-century business. Capstone, Oxford.

Etikan, I., Musa, S.B., Alkassim, R.S., 2016. Comparison of convenience sampling and purposive sampling. *American Journal of Theoretical and Applied Statistics*, 5, pp. 14.

Fastercapital, 2024. Lifecycle analysis: A holistic view of whole life cost. [online] available at < https://fastercapital.com/content/Lifecycle-analysis--A-Holistic-View-of-Whole-Life-Cost.html> [accessed on 20.02.2024].

Feo-García, J., Pulido-Alonso, A., Florido-Betancor, A., Florido-Suárez, N.R., 2024. Cost Studies of Reverse Osmosis Desalination Plants in the Range of 23,000–33,000 m3/day. Water, 16, pp. 910.

Fernandez, R., Gonzalez, R. P., 2010. Green roofs as a habitat for birds: a review. *Journal of Animal and Veterinary Advances,* 9(15), pp. 2041-2052.

Fiksel, J., Goodman, I., Hecht, A., 2014. Resilience: navigating toward a sustainable future. *Solutions Journal,* 5, pp.38-47.

Fischer, T., Kühl, J., Govender, M., 2019. Framing Desalination Within the Water-Energy-Climate Nexus 115.

Folke, C., Gunderson, L., 2010. Resilience and Global Sustainability. *Ecology and Society*,15 (4), pp. 43.

Fragkou, M.C., Budds, J., 2020. Desalination and the disarticulation of water resources: stabilising the neoliberal model in Chile. *Transactions of the Institute of British Geographers,* 45, pp. 448-468

Fthenakis, V., Atia, A.A., Morin, O., Bkayrat, R., Sinha, P., 2016. New prospects for PV powered water desalination plants: case studies in Saudi Arabia: new prospects for PV powered water desalination plants. *Progress in Photovoltaics: Research and application,* 24, pp. 543-550.

Global Water Intelligence, 2019. Brine concentration redux. [online] available at < https://www.globalwaterintel.com/global-water-intelligence-magazine/20/6/from-cto/brine-concentration-redux> [accessed on 04.02.2024].

Godfrey, L., 2021. The circular economy as development opportunity. CSIR: Pretoria.

Goel, P., 2010. Triple bottom line reporting: An analytical approach for corporate sustainability. *Journal of Finance, Accounting, and Management*, 1(1), pp. 27-42.

Güçlü, M., Ekinci, B., Korkmaz,A., Başaran, Y., Karaaslan, Y., Aldemir, S., Türkoğlu, A., Serindağ, A., Colino, J., Ar, K., Ülgen, B., Dikmen, B., Pakdemirli, B., 2021. The Feasibility Study to Improve the Efficiency of Municipal Water Supply. *Turkish Journal of Water Science and Management,* 5, pp. 2–39.

Gude, V.G., 2016. Desalination and sustainability – An appraisal and current perspective. *Water Research,* 89, pp. 87-106.

Hak, T., 2007. Waarnemingsmethoden in kwalitatief onderzoek: Methodologie van kwalitatief onderzoek. *HUWE,* 47, pp. 205-212.

Harvard Business School, 2021. The tragedy of the commons: What is it and 5 examples. [online] available at < online.hbs.edu/blog/post/tragedy-of-the-commons-impact-on-sustainability-issues> [accessed on 04.02.2024].

Harvey, F., 2023. Global water demand will outstrip supply by 40% by 2030. [online] Available at < https://www.theguardian.com/environment/2023/mar/17/global-fresh-water-demand-outstrip-supply-by-2030#:~:text=1%20month%20old-> [accessed on 17.05.2023].

Herber, G., 2024 (a). Plant Prices: The costs of constructing a desalination plant and facility: How much does it cost to build a desalination plant? [online] available at < https://medium.com/@desalter/plant-prices-the-costs-of-constructing-a-desalination-facility-2c31f7fcb690> [accessed on 08.06.2024].

Herber, G., 2024 (b). Price of desalination: Factors and solution for making clean water more affordable. [online] available at https://medium.com/@desalter/price-of-desalination-factors-and-solutions-for-making-clean-water-more-affordable-1a4957803570 [accessed 20.02.2024].

Herber, G., 2024 (c). How to operate a commercial seawater desalination plant. [online] available at < https://medium.com/@desalter/how-to-operate-a-commercial-seawater-desalination-plant-8ac591f6b1e4> [accessed on 12.06.2024].

Hinton, S., 2021. Why life cycle assessment is crucial for sustainable product and technology development. [online] available at < https://www.ricardo.com/en/news-and-insights/insights/why-life-cycle-assessment-is-crucial-for-sustainable-product-and-technology-development> [accessed 04.03.2024].

Huxley, D. E., Bellamy, W. D., Sathyanarayan, P., Ridens, M., 2009. Greenhouse gas emission inventory and management strategy guidelines for water utilities. report of the Water Research Foundation. Water Research Foundation, Denver, CO.

Intergovernmental Panel on Climate Change (IPCC), 2008. 2006 IPCC guidelines for national greenhouse gas inventories – A primer, prepared by the national greenhouse gas inventories programme, Eggleston H.S., Miwa K., Srivastava N. and Tanabe K. (eds). Published: IGES, Japan.

International Desalination Association, 2016. Data Shows the Third Year of Continued Growth in Desalination and Increased Adoption of Water Reuse. [online] Available at < https://idadesal.org/wp-content/uploads/2018/11/State-of-Desalination-Press-Release-IDA-and-GWI.pdf> [Accessed on 20.09.2022].

ISI Water, 2017. Desalination and the road to development in Africa. [online] available at < https://isi-water.com/desalination-and-development-in-africa/> [accessed on 05.02.2024].

Ivanov, D., 2020. Viable supply chain model: Integrating agility, resilience and sustainability perspectives—lessons from and thinking beyond the COVID-19 pandemic. Annals of Operations Research.

Jamshed, S., 2014. Qualitative research method-interviewing and observation. *Journal of Basic and Clinical Pharmacy,* 5, pp. 87-88.

Jiménez, A., Saikia, P., Giné, R., Avello, P., Leten, J., Liss Lymer, B., Schneider, K., Ward, R., 2020. Unpacking Water Governance: A Framework for Practitioners. *Water*,12, pp. 827.

Johannessen, Å. and Wamsler, C., 2017. What does resilience mean for urban water services? *Ecology and Society*, 22(1), pp.1-5.

Jørgensen, A., Le Bocq, A., Nazarkina, L., Hauschild M., 2008. Methodologies for social life cycle assessment. *International Journal of Life Cycle Assessment,* 13 (2), pp. 96–103.

Jurisch, M., Ikas, C., Wolf, P., Krcmar, H., 2013. Key differences of private and public sector business process change. *e-Service Journal*, 9, pp. 3–27.

Kearney, A., 2009. Green winners: The performance of sustainability-focused organizations during the financial crisis. [online] Available at < https://www.business-humanrights.org/en/latest-news/pdf-green-winners-the-performance-of-sustainability-focused-companies-during-the-financial-crisis/> [Accessed 30.06.2022].

Kharraz, J., Richard, B., Schafer, A., 2017. Chapter 3: autonomous solar-powered desalination plant for remote communities. A technical, Socioeconomic and Environmental Approach, Elsevier: Amsterdam, the Netherlands.

Korstjens, I., Moser, A., 2017. Series: Practical guidance to qualitative research. Part 4: Trustworthiness and publishing. *European Journal of General Practice*, *24*(1), pp. 120-124.

KPMG, 2024. Life cycle assessment guide- undertaking an LCA is becoming a fundamental part of how companies are working towards net zero. [online] available at < https://kpmg.com/xx/en/home/insights/2023/10/life-cycle-assessment-guide.html> [accessed on 04.02.2024].

Kumar, V., Ladha, J.K., 2011. Chapter six - direct seeding of rice: Recent developments and future research needs, in Sparks, D.L. (Ed.), Advances in Agronomy. Academic Press, pp. 297–413.

Laird, M., Wright, A., Massie, V., Clark, B., 2017. Marine environmental impact assessment for the proposed desalination plants around the Cape Peninsula, South Africa. assessment framework for the management of effluent from land-based sources discharged to the marine environment. [online] available at <https://sahris.sahra.org.za/sites/default/files/heritagereports/Marine%20Environmental%20Impact%20Assessment%20-%20CoCT%20Desalination%20Plants%20-%20Draft%203%20copy.pdf> [accessed on 07.02.2024].

Lebel, L., Anderies, J., Campbell, B., Folke, C., Hatfield-Dodds, S., Hughes, T., Wilson, J., 2006. Governance and the capacity to manage resilience in regional social-ecological systems. *Ecology and Society,* 11, pp. 12-32.

Lee, K., Jepson, W., 2021. Environmental impact of desalination: A systematic review of Life Cycle Assessment. *Desalination,* 509, pp. 115066.

Lew, A., Ng, P., Ni, C., Wu, T.-C., 2016. Community sustainability and resilience: similarities, differences, and indicators. *Tourism Geographies*,18, pp. 18–27.

Lia, O., 2022. Water shortage: causes and effects. [online] available at < https://earth.org/causes-and-effects-of-water-shortage/> [accessed on 09.02.2024].

Lodge, J.M., Kennedy, G., 2016. *Confused? Don't worry because that can be a good thing*. [online] Available at: <http://theconversation.com/confused-dont-worry-because-that-can-be-a-good-thing-64421> [Accessed 03.04.2024].

Malaeb, L. and Ayoub, G.M., 2011. Reverse Osmosis technology for water treatment: State of the Art review. *Desalination,* 267, pp. 1-8.

Mansour, T.M., Ismail, T.M., Ramzy, K., Abd El-Salam, M., 2020. Energy recovery system in small reverse osmosis desalination plant: Experimental and theoretical investigations. *Alexandria Engineering Journal*, 59, pp. 3741-3753.

Marchese, D., Reynolds, E., Bates, M., Morgan, H., Clark, S., 2018. Resilience and sustainability: Similarities and differences in environmental management applications. *Science of The Total Environment*, 613, pp. 1275-1283.

Marvin, C., 2020. The city of Cape Town planning to build an R1.8bn desalination plant. [online] available at < https://www.iol.co.za/capeargus/news/city-of-cape-town-planning-to-build-r18bn-desalination-plant-94faeba8-5df9-4865-b84b-77d21488debf> [accessible 15.01.2024].

Masha, S., 2019. Energy saving environmentally friendly desalination technology, remix water. [Online] available at < https://www.imesa.org.za/wp-content/uploads/2019/10/paper-15-energy-saving-and-environmentally-friendly-desalination-technology.pdf> [Accessed on 20.11.2022].

Masiya, T., Davids, Y.D., Mazenda, A., 2019. Effective public participation in municipal service delivery: the case of Nyanga township. *Administratio Publica*, 37(3), pp. 27-47.

Mason, J., 1994. Linking qualitative and quantitative data analysis, in analyzing qualitative data.1st Edition, Bryman, J., Burgess, R.S, Routledge, London and New York.

Meacham, B.J., 2016. Sustainability and resiliency objectives in performance building regulations. *Building Research and Information,* 44, pp. 474-489.

Meadowcroft, J., 2024. Sustainability. [online] available at https://www.britannica.com/science/sustainability [accessed 02.02.2024].

Meerganz von Medeazza, G., 2004. Water desalination as a long-term sustainable solution to alleviate global freshwater scarcity? A North-South approach. *Desalination*,169, pp. 287-301.

Mezher, T., Fath, H., Abbas, Z., Khaled, A., 2011. Techno-economic assessment and environmental impacts of desalination technologies. *Desalination*, 266, pp. 263-273.

Miller, J. E., 2003. Review of water resources and desalination technologies, Sandia National Laboratories, Albuquerque, New Mexico 87185 and Livermore, California 94550.

Moench, M., Dixit, A., Janakarajan, M., Rathore, S., Mudrakartha, S., 2003. The fluid mosaic, water governance in the context of variability, uncertainty, and change. Nepal Water Conservation Foundation, Kathmandu, and the Institute for Social and Environmental Transition, Boulder, Colorado, USA.

Morse, J.M., 2000. Determining sample size. *Qualitative Health Research*, 10(1), pp. 3-5.

Nasruddin-Roshidi, A., Mansor, M.S., Ismail, N.A., Ngadi, E., Izzat-Husna, M., Husin, S.M., Mohd-Taib, F.S., Illias, R., Nor S.M., 2021. Recovery of bird communities following the construction of a large-scale hydroelectric dam. *Ecological Processes,* 10, pp. 30.

National Research Council, 2012. Disaster resilience: A national Imperative. National Academies Press, Washington, D.C.

Nel, H., 2020. Research methods for Ph.D. and master's degree studies: post-positivism. [Online] available at https://www.intgrty.co.za/tag/post-positivism/ [Accessed on 20 September 2022].

Neugebauer, S., Forin, S., Finkbeiner, M., 2016. From life cycle costing to economic life cycle assessment—Introducing an economic impact pathway. *Sustainability*, 8, pp. 428.

News24, 2013. Top desalination plant virtually untapped. [online] available < https://www.news24.com/news24/top-desalination-plant-virtually-untapped-20150430> [accessed on 09.02.2024].

OECD, 2020. G20/OECD Principles of corporate governance. [online] available at < https://www.oecd.org/daf/ca/Corporate-Governance-Principles-ENG.pdf> [accessed on 04.03.2024].

OECD, 2022 (a). How to assess water governance: A methodology based on the OECD principles on water governance. [online] available at https://www.oecd.org/cfe/cities/HowToAssessWaterGovernance.pdf [Accessed on 12.01.2023].

OECD, 2022 (b). The OECD Principles on water governance. [online] available at < https://www.oecd.org/governance/oecd-principles-on-water-governance.htm> [accessed on 15.01.2024].

Ogunbiyi, O., Al-Rewaily, R., Saththasivam, J., Lawler, J., Liu, Z., 2023. Oil spill management to prevent desalination plant shutdown from the perspectives of offshore cleanup, seawater intake, and onshore pretreatment. *Desalination*, 564, pp.116780.

Omerspahic, M., Al-Jabri, H., Siddiqui, S.A., Saadaoui, I., 2022. Characteristics of desalination brine and its impacts on marine chemistry and health, with emphasis on the Persian/Arabian Gulf: A Review. *Frontiers in Marine Science*, 9.

Ose, S.O., 2016. Using Excel and Word to Structure Qualitative Data. *Journal of Applied Social Science*, 10(2), pp.147-162.

Osman, A.I., Chen, Z., Elgarahy, A,M., Farghali, M., Mohamed, I, M., Priya, A.K., Hawash, H.B., Yap, P., 2024. Membrane Technology for Energy Saving: Principles, Techniques, Applications, Challenges, and Prospects. *Advanced Energy and Sustainability Research*, 5(5), pp.1-29.

Othman, N.H., Alias, N.H., Fuzil, N.S., Marpani, F., Shahruddin, M.Z., Chew, C.M., David Ng, K.M., Lau, W.J., Ismail, A.F., 2022. A Review on the Use of Membrane Technology Systems in Developing Countries. *Membranes,* 12, pp. 30.

Panigrahi, S., 2021. Advantages and disadvantages of fixed-price contracts. [online] available at https://blog.ipleaders.in/advantages-and-disadvantages-of-fixed-price-contracts/ [accessed on 04.02.2024].

Patel, M.,2018. Desalination in South Africa: Panacea or Peril for Industrial Development? [online] available at < https://tips.org.za/research-archive/sustainable-growth/item/3500-desalination-in-south-africa-panacea-or-peril-for-industrial-development> [accessed 19.11.2022].

Pazouki, P., Lu, H.R., El Hanandeh, A., Biswas, W., Bertone, E., Helfer, F., Stewart, R.A., 2021. Comparative environmental life cycle assessment of alternative osmotic and mixing dilution desalination system configurations. *Desalinatio,* 504, pp. 114963.

Pearlmutter, D., Pucher, B., Calheiros, C.S.C., Hoffmann, K.A., Aicher, A., Pinho, P., Stracqualursi, A., Korolova, A., Pobric, A., Galvão, A., Tokuç, A., Bas, B., Theochari, D., Milosevic, D., Giancola, E., Bertino, G., Castellar, J.A.C., Flaszynska, J., Onur, M., Mateo, M.C.G., Andreucci, M.B., Milousi, M., Fonseca, M., Lonardo, S.D., Gezik, V., Pitha, U., Nehls, T., 2021. Closing Water Cycles in the Built Environment through Nature-Based Solutions: The Contribution of Vertical Greening Systems and Green Roofs. *Water,* 13, pp. 2165.

Pearse, N., 2019. An Illustration of a deductive pattern matching procedure in qualitative leadership research. *The Electronic Journal of Business Research Methods*, 17(3), pp.143-154.

Perrings, C., 2006. Resilience and sustainable development. *Environmental Development Economics,* 11, pp. 417-427.

Philipsen, H., and Vernooij-Dassen, M., 2007. Qualitative research: useful, indispensable, and challenging. In: Qualitative research: Practical methods for medical practice (pp. 5–12).

Pinto, F.S., Marques, R.C., 2017. Desalination projects economic feasibility: A standardization of cost determinants. *Renewable and Sustainable Energy Reviews,* 78, pp. 904-915.

Planokc, 2024. Environmentally sensitive areas. [online] available at <https://planokc.org/development-guide/land-use-plan/environmentally-sensitive-areas/> [accessed on 05.02.2024].

Rabelo, M., 2023. What is Otter.ai? transcribe meetings and take voice notes with Otter. [online] available at < https://zapier.com/blog/otter-ai/> [accessed 20.01.2024].

Robinson, O., 2014. Sampling in interview-based qualitative research: A Theoretical and practical guide. *Qualitative Research in Psychology,* 11.

Rodina, L., 2019. Water resilience lessons from Cape Town's water crisis. WIREs Water 6, e1376.

Ruslin, R., Mashuri, S., Sarib, M., Alhabsyi, F., Syam, H., 2022. Semi-structured Interview: A Methodological Reflection on the Development of a Qualitative Research Instrument in Educational Studies. *Journal of Research and Method in Education*, 12 (1), pp. 22-29.

Ryan, A, N., 2006. Post-positivism approaches research. In: researching and writing your thesis: a guide for postgraduate students. MACE: Maynooth Adult and Community Education, pp. 12-26.

Sadhwani, J., Veza, J.M and Santana, C., 2005. Case studies on the environmental impact of seawater desalination. *Desalination,* 185, pp. 1-8.

Sadi, A., Kehal, S., 2003. Retrospectives and potential use of saline water desalination in Algeria. *Desalination,* 152, pp. 51-56.

Sawe, B.E., 2017. Countries that rely on desalination. [online] available at < https://www.worldatlas.com/articles/countries-who-rely-on-desalination.html> [09.02.2024].

Severis, R.M., Rech, J.P.P.B., 2019. Cradle to Cradle: An Eco-effective Model, in Leal Filho, W., Azul, A.M., Brandli, L., Özuyar, P.G., Wall, T. (Eds.), Responsible consumption and production, Encyclopedia of the UN sustainable development goals. Springer International Publishing, Cham, pp. 1-9.

Shannon, L., O'Leary, F., 2020. Local government: Engaging and empowering local communities. Local Government Research Series (No.4). Institute of Public Administration. [online] available at <https://www.ipa.ie/_fileUpload/Documents/LocalGov_EngagingandEmpoweringLocalComm.pdf> [accessed on 01.02.2024].

Sharma, P., 2019. A study on life cycle assessment. *International Journal of Engineering and Advanced Technology,* 6, pp. 24-25

Sherratt, A., 2013. Cradle to Cradle, in Idowu, S.O., Capaldi, N., Zu, L., Gupta, A.D. (Eds.), Encyclopedia of corporate social responsibility. Springer, Berlin, Heidelberg, pp. 630-638

Shokri, A., Sanavi Fard, M., 2022. A sustainable approach in water desalination with the integration of renewable energy sources. *Environmental Advances,* 9, pp. 100281.

Slaper, T., Hall, T., 2011. The triple bottom line: What is it and how does it work? [online] available at < http://www.ibrc.indiana.edu/ibr/2011/spring/article2.html> [Accessed on 25.05.2022].

South African Government, 1997. Water Services Act 1997 (Act No. 108 of 1997). [online] Available at < https://www.gov.za/sites/default/files/gcis_document/201409/a108-97.pdf> [Accessed on 25.05.2022]

South African Government, 2021. Water Research Commission on importance and cost water desalination: with Deputy Minister; Committee report. [online] available at < https://pmg.org.za/committee-meeting/32475/> [accessed on 05.02.2024].

South African Government, 2023. Municipalities of South Africa, 2023. Eastern Cape Municipalities. [online] available at < https://municipalities.co.za/provinces/view/1/eastern-cape> [accessed on 27.02.2024].

Spangenberg, J., 2005. Economic sustainability of the economy: concepts and indicators. *International Journal of Sustainable Development*, 8(1-2), pp. 47-64.

Stoll, D., 2024. Water crisis in South Africa: Causes, effects, and solutions. [online] Available at < https://earth.org/water-crisis-in-south-africa/> [accessed on 10.02.2024].

Stratton, S.J., 2021. Population Research: Convenience Sampling Strategies. Prehospital and Disaster Medicine, 36, pp. 373–374.

Swartz, C., Du Plessis, J., Burger, A., Offringa, G., 2009. A desalination guide for South African municipal engineers. *African Journal Online*, 32(6), pp. 641-647.

Symons, 2023. Barcelona is leaning on Europe's largest desalination plant as drought squeezes water supplies.[Online] Available at < https://www.euronews.com/green/2023/06/05/can-desalination-help-combat-europes-water-crisis-drought-struck-barcelona-is-banking-on-i> [accessed on 02.20.2024].

Tortajada, C., 2010. Water governance: Some Critical Issues. *International Journal of Water Resources Development,* 26, pp. 297-307.

United Arab Emirates (UAE), 2001. Municipality's oil spill report chronicles a string of shortcomings. [online] available at <https://gulfnews.com/uae/municipalitys-oil-spill-report-chronicles-string-of-shortcomings-1.417870 > [accessed on 01.02.2024].

United Nations, 2015. The 17 goals. [online] Available at < https://sdgs.un.org/goals> [accessed on 20.06.2023]

United Nations, 2022. Ensure access to water and sanitation for all. [online] available at < https://www.un.org/sustainabledevelopment/water-and-sanitation/> [accessed 20.06.2023].

United Nations Developmental Programme (UNDP), 2015. Water governance for poverty reduction. [online] available at https://www.undp.org/publications/water-governance-poverty-reduction [Accessed 20.06.2023].

Van Erkom Schurink, C., Griffiths, C.L., 1993. Factors affecting relative rates of growth in four South African mussel species. *Aquaculture,* 109, pp. 257-273.

Vásquez, W., Raheem, N., Quiroga, D., Ochoa-Herrera, V., 2022. Valuing improved water services and negative environmental externalities from seawater desalination technology: A choice experiment from the Galápagos. *Journal of Environmental Management,* 304, pp. 114204.

Voutchkov, N., 2013. Seawater Desalination-Costs and Technology Trends. In the book: Encyclopedia of Membrane Science and Technology

Voutchkov, N., 2018. Desalination project cost estimating and management. CRC Press: Baco Raton, FL, USA.

Walsh, K., Shai, L., Mbangata, T., 2019. Assessing the affordability of water services for residential consumers in South African municipalities. Report to the Research Commission.

Watson, I.C., Morin, O. J., Henthorne, L., 2003. Desalting handbook for planners, Third Edition. (No. PB2004104408). Rostek Services, Inc., Fort Myers, FL.; Bureau of Reclamation, Denver, CO.; DSS Engineers, Inc., Fort Lauderdale, FL.

Weinberg, H.S., S.W. Krasner, S.D. Richardson., A.D. Thruston, J.R., 2002. The Occurrence of disinfection By-Products (DBPs) of Health Concern in drinking water: Results of a nationwide DBP occurrence study. U.S. Environmental Protection Agency, Washington, DC. Wester, P., Merrey, D.J and De Lange, M., 2003. Boundaries of consent; stakeholder representation. *World Development,* 31, pp. 797-812.

Woodhouse, P., Muller, M., 2017. Water Governance—An Historical Perspective on Current Debates. *World Development*, 92, pp. 225-241.

World Bank, 2019. The Role of Desalination in an Increasingly Water-Scarce World. [online] Available at < https://openknowledge.worldbank.org/entities/publication/214476a0-e59d-55f2-a6cd-872cacc30c55> [accessed on 05.02.2024]

World Health Organization (WHO), 2011. Safe drinking water from Desalination. [online] available at < https://iris.who.int/rest/bitstreams/66882/retrieve> [Accessed on the 20.02.2024].

Xu, P., Cath, T., Robertson, A., Reinhard, M., Leckie, J., Drewes, J., 2013. A critical review of desalination concentrates on management, treatment, and beneficial use. *Environmental Engineering Science,* 30, pp. 502–514.

Yarborough, M., 2021. Moving towards less biased research. *British Medical Journal Open Science,* 5, pp. 100116.

York, R. and M. Foster., 2005. Issues and environmental impacts associated with once-through cooling at California's Coastal power plants. California Energy Commission. Sacramento, California.

Zain, Q and Fath, H., 2012. Application of carbon nanomaterials in desalination processes. *Desalination and water treatment,* 1 (10), pp. 1944-3994.

Zhang, S., Huang, K., Yuan, Y., 2021. Spare parts inventory management: A literature review. *Sustainability*, 13(5), pp. 2460

Zhuwakinyu, M., Research Unit at Creamer Media (pty) Ltd, 2012. Water 2012: A review of South Africa water sector. [online] available at < https://static.pmg.org.za/120904review.pdf> [accessed on 05.02.2024].

Appendix A: RO Plants Interview Questions

Hello,

Thank you for agreeing to participate in this research study. My name is Cwayita Mfihlo, and I will be conducting an interview with you about your experience with Reverse Osmosis (RO) plants.

As mentioned in our previous communication, your participation in this study is voluntary. Before we proceed with the interview, I would like to give you a consent form to sign. If you have any questions or concerns about the study or the consent form, please feel free to ask me now.

I want to emphasise that any information you provide during the interview will be kept confidential, and your participation in the study will not affect your work in any way. The data obtained from the study will be stored securely during and after the study with only the supervisor and student having access to the data. I would like to give you a background as to why the study is important, Water is a natural resource that is valuable for humans and the ecosystem. One of the most serious issues we face is water scarcity, the recent water crisis in the Eastern Cape, exacerbated by climate change, resulted in drought and mismanagement of municipal water. This shows water supply sources and the environment are not resistant to change caused by increased urbanisation, pressure, and governance impacts.

This research will look at desalination plants as an additional water source that can make coastal municipalities more resilient to the water crisis. The findings from this study will help to inform future efforts to improve water management practices and contribute to ensuring that communities have access to clean and safe water.

The interview will take approximately 30 minutes, and I will be recording our conversation with the use of Otter, a transcription software, to ensure that I accurately capture your responses. After the completion of the study, I will send you the outcome of the research.

Once again, thank you for participating in this study, and I appreciate your willingness to share your experiences with me.

Before we begin the interview, I would like to provide you with some background information on the terms used so that you can better understand the questions and respond to them accordingly.

When we talk about environmental sustainability, we are referring to the impact of desalination plants on the environment. In other words, we will examine the stages of the life cycle and determine the impacts or opportunities of desalination plants on the environment.

Economic sustainability is about using the economy to withstand impacts and evolve to provide for future generations. In this context, we will consider the economic opportunities and impacts of desalination.

Social sustainability involves conducting business reasonably and beneficially to support human capital, labour, and the community at large. We will examine the impacts and opportunities of desalination plants on the community and human capital.

Governance in this context refers to the range of political, institutional, and administrative rules, practices, and processes (both formal and informal) through which decisions are taken and implemented. We will consider principles of good governance such as transparency and accountability.

Questions

1. Please introduce yourself
2. What is your understanding of sustainability?
3. What is your understanding of QBL?
4. Please take me through the life cycle of your RO desalination plant.

The life cycle of the RO desalination plant consists of three main phases: Construction, Operation and maintenance, and Disposal. Construction includes infrastructure and facilities, and operation and maintenance cover everything from seawater extraction to distribution and disposal. with these stages of the life cycle in mind, answer the following questions.

5. **Social Sustainability.**
    1. What are the social impacts associated with the construction phase of RO desalination?
    2. What are the social impacts associated with the operations and maintenance of RO desalination plants?
    3. What are the social impacts associated with the disposal phase of RO desalination plants?
    4. What are the social opportunities associated with the construction phase of RO desalination plants?
    5. What are the social opportunities associated with the operations and maintenance of RO desalination plants?
    6. What are the social opportunities associated with the disposal phase of RO desalination plants?
6. **Environmental Sustainability.**
    1. What are the environmental impacts associated with the construction phase of RO desalination plants?
    2. What are the environmental impacts associated with the operations and maintenance of RO desalination plants?
    3. What are the environmental impacts associated with the disposal phase of RO desalination plants?
    4. What are the environmental opportunities associated with the construction phase of RO desalination plants?
    5. What are the environmental opportunities associated with the operations and maintenance of RO desalination plants?
    6. What are the environmental opportunities associated with the disposal phase of RO desalination plants?
7. **Economic sustainability**
    1. What are the economic impacts associated with the construction phase of RO desalination plants?
    2. What are the economic impacts associated with the operations and maintenance of RO desalination plants?
    3. What are the economic impacts associated with the disposal phase of RO desalination plants?
    4. What are the economic opportunities associated with the construction phase of RO

desalination plants?

5. What are the economic opportunities associated with the construction phase of RO desalination plants?
6. What are the economic opportunities associated with the disposal phase of RO desalination plants?

8. **Governance**
    1. What are the governance opportunities associated with RO desalination plants?
    2. What are the governance impacts associated with RO desalination plants
9. What are the most critical sustainability considerations that should be considered when implementing RO desalination plants to augment available water provision sources in the Eastern Cape?
10. How can these considerations be addressed to ensure the long-term viability and effectiveness of the plants?
11. Do you think the water problems we have are due to the scarcity of resources or mismanagement?

Appendix B- Municipality Interview Questions

Hello,

Thank you for agreeing to participate in this research study. My name is Cwayita Mfihlo, and I will be conducting an interview with you about your experience with Reverse Osmosis (RO) plants.

As mentioned in our previous communication, your participation in this study is voluntary. Before we proceed with the interview, I would like to give you a consent form to sign. If you have any questions or concerns about the study or the consent form, please feel free to ask me now.

I want to emphasise that any information you provide during the interview will be kept confidential, and your participation in the study will not affect your work in any way. The data obtained from the study will be stored securely during and after the study with only the supervisor and student having access to the data. I would like to give you a background as to why the study is important, Water is a natural resource that is valuable for humans and the ecosystem. One of the most serious issues we face is water scarcity, the recent water crisis in the Eastern Cape, exacerbated by climate change, resulted in drought and mismanagement of municipal water. This shows water supply sources and the environment are not resistant to change caused by increased urbanisation, pressure, and governance challenges.

Water augmentation is securing additional water sources to increase water availability for an existing or prospective group of water users (SEHGAL, 2022). Several desalination plants have been built in water-stressed areas to augment available water sources (Elimelech and Phillip, 2011). The number of constructed desalination plants is expected to increase with time (Elimelech and Phillip, 2011). RO desalination plants have been considered in South Africa to augment the available water supply sources (Masha, 2019; Department of Water Affairs and Forestry, 2019). This research will not concentrate on RO desalination plants as 'the' augmentation solution for water demand challenges. It will, however, identify criteria to consider before using RO technologies to augment existing water supply sources and thereby help inform decision-making around options for meeting water demand.

The interview will take approximately 30 minutes, and I will be recording our conversation with the use of Otter, a transcription software, to ensure that I accurately capture your responses. After the completion of the study, I will send you the outcome of the research.

Questions

1. What is your current availability of water in the municipality?
2. What is the current and estimated long-term demand of water?
3. What is the potential of RO desalination plants being used to augment the available water provision sources?
4. What are the legal and regulatory requirements that need to be considered if were to use an RO plant to augment the available water provision sources?
5. What are the key factors to consider for RO plants to augment the available water provision sources?
6. Comparing RO desalination plants to other water provision sources, which one would do you think is sustainable long term?

Appendix C: Example of Informed Consent letter sent to participants

PARTICIPANT INFORMED CONSENT DECLARATION

(To be signed by research participant/s)

Project Title: The sustainability impacts and opportunities of Reverse Osmosis (RO) plants using/on the Quadruple Bottom Line perspectives: a case of the Eastern Cape Province, South Africa.

Cwayita Mfihlo from the Rhodes Business School, Rhodes University has requested my permission to participate in the above-mentioned research project.

The nature and the purpose of the research project and of this informed consent declaration have been explained to me in a language that I understand.

I am aware that:

1. The purpose of the research project is to
   a. To identify the sustainability (quadruple bottom line) impacts and opportunities associated with reverse osmosis desalination plants in the Eastern Cape.
   b. To investigate the key sustainability considerations relevant for RO desalination plants to potentially augment available water provision sources in the Eastern Cape.
   c. To make recommendations on how RO desalination plants could potentially augment the available water provision sources, considering all four pillars of the quadruple bottom line.
   d. To formulate recommendations on the QBL outcomes of the desalination plants for better utilisation and management of these plants.

2. Rhodes University has given ethical clearance to this research project *(7163)* and I have seen/may request to see the clearance certificate by contacting the Ethics Coordinator (ethics-committee@ru.ac.za)

3. By participating in this research project I will be contributing to a better understanding of RO desalination plants and how these can be used to augment the available water provision to ensure system resilience.

4. I will participate in the project by participating in the interviews and answering the questions.

5. My participation is entirely voluntary and should I at any stage wish to withdraw from participating further, I may do so without any negative consequences.

6. I will not be compensated for participating in the research, but my out-of-pocket expenses will be reimbursed.

7. The following risks are associated with my participation: Participating in a research study may necessitate a significant amount of time and effort from participants, which may interfere with their daily lives or work schedules

8. The Researcher intends to publish the research results in the form of a Mini thesis. However, confidentiality and anonymity of records will be maintained and my name and identity will not be revealed to anyone who has not been involved in the conducting of the research ***unless I indicate to the contrary/recognize that as a public figure, my identity will inevitably be/become known, in which case I agree to accept the loss of anonymity.***

9. In terms of the Protection of Personal Information Act (No. 4 of 2013) it remains my right to request the Researcher to provide me with a detailed explanation of exactly how confidentiality and anonymity of the data I provide will be achieved. I may also request to know exactly how my personal information will be stored securely, and for how long it will be stored.

10. If any data collected from me for this research project is to be used by the Researcher for any further study, I am to be informed in writing and my written consent is requested again. I need not give consent for the new research if it is incompatible with the initial purpose of the present study (POPIA, s15(3)). Equally, I can simply reject the request. In such cases, a formal request needs to be made to me by the researcher via the Ethics Coordinator (ethics-committee@ru.ac.za).

11. In terms of the POPI Act, I possess the right to receive feedback about this research. This will take the form of written feedback, The participant will receive feedback in writing with the research findings and conclusion of the research.

12. Any further questions that I might have regarding the nature of the research and/or my participation in it will be answered by Cwayita Mfihlo, g21m1520

13. By signing this informed consent declaration, I am not waiving any legal claims, rights, or remedies. A copy of this informed consent declaration will be given to me, and the original will be kept on record by the Researcher.

14. I ***agree*** to the Researcher's use of voice recording of my comments and opinions during interviews, the purpose of which is to ensure the accurate recording of my views/responses. Furthermore, I have the right to request a copy of the interview transcriptions to confirm that my opinions are accurately recorded.

15. I understand that it may be challenging to provide anonymity within this study due to the nature of the study as expert advice will be given. I hereby grant consent to (tick one):

- ☐ Allow the researcher to use my name and designation.
- ☐ Allow the researcher to use only my designation
- ☐ Full anonymity (referred to respondent 1, 2 or 3)

I, ………………………………………………………………………., have read the above information / confirm that the above information has been explained to me in a language that I understand and I am aware of this document's contents. I have asked all questions that I wished to ask, and these have been answered to my satisfaction. I fully understand what is expected of me during the research.

I have not been pressurised in any way and I voluntarily agree to participate in the above-mentioned project.

…………………………………… ………………………… ………………………….

Participants signature **Witness** **Date**

Appendix D: Codes generated from the raw data

1. QBL impacts of RO desalination plant from a life cycle perspective

Environmental	Economic	Social	Governance
• Destruction of environment • Vegetation removal • Habitat destruction	• Construction cost • Equipment purchase • Specialised pumps	• Disturbances caused by construction vehicles	• None mentioned
• Carbon footprint • Energy cost • Energy recovery system • High Electricity demand • Location of the plant • Spillages • Hydraulic and oil leaks • Noise pollution • Vibration • Temperature differences • Organism extraction • Disruption of wildlife • Leakage of chemicals • CIP chemicals • Incorrect disposal of CIP chemicals • Leakage of CIP chemicals • Pollution	• Electricity cost • Maintenance spares • Unavailability of maintenance spares • Infrastructure damage • Poor planning • Fixed contracts • Water quality • Plant efficiency • Inexpensive filters • Expensive membranes • CIP • Fouling	• Vandalism and theft • Technical challenges • Pipeline burst- damage roads	• None mentioned
• Brine discharge • Diffuser • Temperature variation	• None mentioned	• None mentioned	• None mentioned
• None mentioned	• None mentioned	• Illegal connections • Lack of knowledge • Demand and supply • Social gap • Rejection by community • Affordability	• None mentioned

2. QBL opportunities of RO desalination plant from a life cycle perspective

Environmental	Economic	Social	Governance
• None mentioned	• Job creation	• Job creation	• Community involvement
• Reduce surface water use-pressure alleviation • Water availability	• Economic and social development	• Water services ongoing employment	• Community involvement • Public participation
• None mentioned	• Salt production	• Job creation	• None mentioned
• Reliable water source • Environmentally safe option • Dependable water supply • Sustainable water supply • Superior water quality • Consistently high-quality water • Burden off the municipal supply	• Economic and social development • Dependency on water for running business • Clean water • Improves health care • Consistent water supply	• Water availability • Job creation • Reliable water source • Safer water	• Community involvement • Good relationships • Community engagement • Transparency • Availability of information

3. Augmentation consideration
    a. Cost
    b. Procurement
    c. Past experiences
    d. Membrane selection
    e. Technology type
    f. Partnership
    g. Collaboration
4. Causes of water problems

    Scarcity

    Mismanagement