Water innovation and the circular economy in special economic zones in South Africa

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ABSTRACT

In light of the planned economic recovery identified by the South African government, the applicability of various mechanisms, principles and theories which enable economic development should be considered, particularly in the context of growing urbanisation and water scarcity challenges. The first mechanism considered in this study relates to the use of special economic zones to drive industrial growth and as a mechanism of attracting foreign direct investment. The second mechanism relates to the adoption of alternative economic models such as the circular economy (CE) which addresses both economic development and resource challenges. The third mechanism relates to expedition and exploration of technologies aligned to the current technological revolution which is information, communication and technology (ICT) based and is expected to result in a new social and economic paradigm or techno-economic paradigm (TEP). The final mechanism for economic development is related to the promotion of all types of innovation which historically have been linked to economic development. This research report explores these selected recovery mechanisms with a focus on ICT-led circular water innovation and its impact on economic development and developing a green economic paradigm.

There is a need to understand the meaning and impact of the CE on economic development in South Africa in light of the economic recovery considerations and the constraints related to water. CE innovation, in all categories, is important given the positive relationship innovation has with economic development and the opportunity to use all types of innovation and not just original innovation as a developing country. In addition, a better understanding of the current global technological revolution is required in order to determine its applicability for the South African context, particularly given its expected culmination into a green techno-economic paradigm which will have a beneficial societal and economic impact. The role of SEZs as a showcase on how circular economy innovation and water technologies have been adopted in an environmentally and economically beneficial manner will assist in providing practicality to the study.

Seven of the ten SEZs in South Africa were used as a sample with qualitative, semi-structured interviews conducted with SEZ representatives and water specialists. All interviewees were familiar with the topics of water, innovation and the circular economy in SEZs. Interviews were supplemented with document analyses of water innovation in industries in South Africa.

The major findings of this study are that water innovation in the circular economy has a positive environmental impact through the reduction of pollution and improved water security. The socio-economic impact primarily relates to job creation both in new industries that are emerging from offtakes and new service models and there is potential for green jobs.

There are many types of ICT enabled water innovation adopted within the SEZs with water monitors being the most prevalent. From a techno-economic paradigm perspective when measured against the TEP criteria of low cost, opportunities for entrepreneurship and organisational change, only the criterion of cost reduction has been observed in this study with entrepreneurship and organisational change lagging. However, the potential exists to create clusters of innovation which include water monitors, robotics and data analytics as a cluster or desalination, renewable energy (hydro and solar power) and low-cost membranes as another cluster. These clusters when coupled with government support through entrepreneurship incubation and policy incentives, have the potential to hasten the technological revolution through increased innovation, adoption and diffusion of technologies. This is however a collaborative effort wherein both the private and public sector need to work together to build an ICT enabled circular economy to create new green growth and economic development.

Key words

circular economy, water, techno-economic paradigm, special economic zones, innovation capabilities

DECLARATION

I, Kiara Bedessy, declare that this dissertation is my own unaided work. It is submitted in partial fulfilment of the requirements for the degree of Master of Management in Innovation Studies at the Wits Business School in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other University.

On this 31st day of March 2022

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Kiara Bedessy

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Chapter 1: Introduction

1.1 Purpose of the study

The South African economy plummeted in 2020 in light of the effects of the Covid-19 pandemic (Chitiga-Mabugu et al., 2021). A decline of 7% in GDP was observed in that year (World Bank, 2021). In response to this, the president of South Africa initiated an "Economic Recovery Plan" in October 2020 which included focused on, inter alia: 1-Investment in infrastructure, 2-localisation of industries enabled by special economic zones, 3-energy security, 4-tourism support, 5-inclusion and gender equality, 6-interventions for a green economy, 7-mass employment, 8-food security and 9-economic development through macro-economic initiatives (South African Government, 2020). From this plan it can be inferred that economic recovery in South Africa is a multi-layered challenge. This research report focuses on water and specifically the innovation required to drive economic development and aid South Africa's economic recovery. In so doing, three of the focus areas highlighted in the economic recovery plans are addressed. These elements are: infrastructure (focus area one) namely water infrastructure, localisation through SEZ's (focus area two) and the establishment of a green economy (focus area three). This research considers these focus areas in the context of the expected green techno-economic paradigm (Freeman, 1992) which will be enabled by ICT technologies and circular economy development (Mazzucato & Perez, 2015). The purpose of this study is to investigate possible pathways for contributing to South Africa's economic recovery through driving innovation within circular economy initiatives for SEZs.

1.2 Background

1.2.1 The state of water in South Africa

South Africa is considered a water scarce country which is a challenge because unlike other natural resources there are no substitutes for water and it therefore requires conservation (Nepfumbada & Seetal, 2020). In South Africa, there is an uneven distribution of rainfall (Matchaya et al., 2019). Of the rainfall received only 9% results in surface water which is predominantly used as the urban water supply which supports industrialisation (WWF-SA, 2016). The majority of water in South Africa is used to support industry (10.5%) and agriculture (60%) (Waterwise, 2005). For each unit of water that is used in industry, 100 times the value add is generated when compared to agriculture and 10 times the job creation (Manase, 2009). Furthermore, a study conducted in Norway in 2005 found that depending on the region in Africa, an investment of USD 1 in water supply can yield an economic benefit of USD 11 (SIWI, 2005). Water is a critical input into South Africa's industry, energy and agricultural sectors (WWF-SA, 2016) and their economic outputs and water shortages will have an impact on economic performance.

There are several threats to water security which include: invasive plant species which reduce water resource availability (WWF-SA, 2016), over abstraction of existing water sources, poor water quality, the destruction of freshwater habitats and increased urbanisation (WWF-SA, 2016). This urbanisation is expected to result in greater demand for water with water demand expected to exceed water supply by 2030. These threats impact water demand.

From a water supply perspective aging and limited water infrastructure systems have exacerbated water delivery and access through leakages. Currently, 37% of piped water in South Africa is lost either through leakage or illegal use at a cost of R7.2bn a year. Proactive investments in infrastructure are recommended to prevent obsolescence (WWF-SA, 2016). These infrastructures can include new technologies and new materials used in the construction to prevent leakages. Another challenge related to water supply is that of pollution (RandWater, 2021) which has adverse health and environmental impacts, (RandWater, 2021) as well as increased costs to treat polluted water (WWF-SA, 2016). Current water treatment mechanisms are considered insufficient to address the acid water drainage (Basson, 2011). Improvements in wastewater treatment, sanitation and chemical runoff rates have been considered in order to address these challenge (WRC, 1995). These improvements can be linked to the circular economy principles (WWF-SA, 2016). There is therefore a dire need to address the water scarcity challenges through innovative approaches and mechanisms in to achieve economic, social and environmental sustainability in South Africa.

The water challenges, although dire, are not insurmountable as is illustrated by the City of Cape Town. This city faced an unparalleled water crisis in 2018 (DWS, 2018) which required large scale changes in water consumption patterns by both citizens and industries. Through this collective effort, the water crisis was averted and this scenario has been considered an international case study for addressing water crises across the globe (Weforum, 2019). It can be inferred from this case that South Africa has the mechanisms and potential to address a country-wide water crisis through local initiatives.

These mechanisms, however, cannot simply be a repetition of historic actions taken to address water scarcity. New and indigenous ways of dealing with water challenges are required. Innovation is therefore critical to addressing this problem (Habiyaremye, 2020) with innovative process, business models, products and services related being required. From an environmental perspective, renewable energy is the largest environmental technology import in South Africa followed by wastewater technologies (Potgieter et al., 2020). Local innovation, secondary innovation and tertiary innovation can be considered alongside these technology imports for a holistic solution to address water challenges. Currently, government institutions are such as the Department of Water and Sanitation (DWS) are partnering with private sector organisations in order to address the challenges faced by the water crisis (WWF-SA, 2016) by addressing the scarcity, infrastructure and pollution challenges (WWF-SA, 2016). In addition, many innovative initiatives are underway which aim at innovation activity, policy changes and opportunities for job creation through entrepreneurship (Nepfumbada & Seetal, 2020). These initiatives may be indicative of a changing new techno-economic paradigm in South Africa.

1.2.2 The Circular economy

In simple terms, the circular economy (CE) provides a framework that individuals, companies, industries and countries can use to maintain resources, such as water, as considered in this research report, within a closed system of production across the entire value chain of production for the maximum possible period (Ghisellini et al., 2016). The CE is an economic and environmental theory (Ekins et al., 2019) and is therefore fundamental to the understanding of possible solutions to the water crisis in South Africa which seeks economic recovery (South African Government, 2020) but with limited resource availability.

The CE model in various forms has been adopted across the globe with developed countries and Asia being the global leaders in terms of framework development and implementation (Ghisellini et al., 2016). Internationally, circular economy frameworks for water and wastewater have been developed and policies adopted (Smol et al., 2020) which show the applicability of the CE to water and water scarcity challenges. Of particular interest is the notion that the circular economy is enabled by integration, innovation and business models (Smol et al., 2020). The role of innovation within the CE is therefore fundamental to its success and it is this innovation within the circular economy framework that will be considered in this report.

The governance of the CE in South Africa is in its initial stages (Richards, 2020) with several policies such as the NDP (South African Government, 2012) which talks to the green economy and the Circular Economy Guideline in South Africa which was developed in 2020 as the initial circular economy strategy for South Africa (Richards, 2020) being the most notable policies in this area. However delays due to the Covid-19 pandemic saw the rollout of the new Circular Economy Guideline in South Africa being delayed (Creecy, 2020). In addition adoption of the CE within South Africa will not be without the challenges related to funding, capacity building, enforcement of the CE principles and policies, and difficulties in transitioning resource intensive industries such as mining, are expected (Richards, 2020). Overall, the commitment by the South African government to developing a CE is a positive sign that the underlying resource constraints of water scarcity concerns can be addressed.

Specifically from an industrial perspective, there are five main sectors which the CE framework can be applied to, namely, in waste (including wastewater), plastics, electronics, agriculture and construction (Potgieter et al., 2020). The input requirements of water in industrialisation is highlighted through the need for water in industries such as mining, manufacturing and agro-processing (Godfrey et al., 2021). Notably, the role of ICT in delivering the CE in South Africa has been identified as an opportunity (Godfrey et al., 2021; Potgieter et al., 2020)

The most appropriate articulation of the water CE model for this study is the 5R framework created by the World Business Council for Sustainable Development which refers to "Reduce, Reuse, Recycle, Restore and Recover" These principles form the basis of defining water CE innovation for industry (Delgado et al., 2021) which is the focus of this study.

From a water innovation perspective the World Business Council for Sustainable Development (2017) has recognised several innovative technologies that can be adopted to address circularity within the water sector. These include: phase separators for oil and water, coagulation and precipitation for the removal of chemicals, dissolved air flotation, artificial wetlands, aerobic and anaerobic biological treatment of sludge, membranes, sand and nanofilters, reverse osmosis (used in desalination), ion exchange, activated carbon adsorption, scavenging of organic materials, chemical oxidation processes and evaporation and crystallization processes (WBCSD, 2017). The adoption of these types of technologies will in part be considered in the data findings and analysis.

1.2.3 Special economic zones in South Africa

Special economic zones (SEZs) in South Africa are areas which have been set aside for economic activities which improve economic development. This is done by promoting exports and by including mechanisms to attract foreign investments and technologies (SARS, 2014). Special economic zones are also created to address issues of unemployment and act as a testing ground for new policies (Altbeker et al., 2011). Internationally, in countries such as China, Mauritius and in the Philippines, SEZs have been shown to have a "demonstration effect" in which a successful SEZ creates widespread economic reform (Altbeker et al., 2011). The SEZ is therefore a unique formation which creates economic development.

South Africa currently has ten special economic zones across the country (DTI, 2021) with primary areas of focus being agro-processing, automotive, beneficiation and logistics. SEZs are expected to play a critical role in South Africa's economic recovery and it is therefore beneficial to use the SEZ as the unit of analysis for economic development (South African Government, 2020).

1.2.4 Techno-economic paradigms

A techno-economic paradigm (TEP) is defined as "a complex learning process, a best practice model for economics, technology and organisational practices" (Perez, 2010). The TEP is created during a technological revolution which has an initial installation phase for the technology followed by a deployment phase which usually follows an economic turning point such as a recession (Perez, 2010). It is during the transition from installation to the deployment phase that a new TEP becomes dominant. The TEP is therefore a mechanism for articulating a large scale change in behaviour, organisational policy and innovation across an industry and even globally, as a result of the migration of the technological revolution.

At present the world is in the midst of the information and telecommunications revolution (Mathews, 2013; Perez, 2010; Stewart, 2021) which began in the 1970's. This revolution is characterised by information intensity, decentralisation , knowledge capitalisation as the emergent paradigm in this installation phase (Perez, 2010). It was expected that after the 2008 recession, an opportunity would emerge to build a green, sustainable, ICT led paradigm (Perez, 2016) with technologies that dive environmental sustainability, leading global economies into a “green golden age” (Perez, 2016). The CE has been identified as a holistic approach to change the techno-economic paradigm (de Jesus et al., 2019; Mazzucato & Perez, 2015). It is this green paradigm that this report is purposed to understand particularly as it relates to water sector innovation and its role in enabling this paradigm.

1.2.5 Innovation categories

There are many types of innovation with three main categories noted, being original, secondary and tertiary. South Africa as a developing country has an opportunity for all three innovation types to be present. Original innovation is sourced from R&D and follows an observable commercialisation path (Wu et al., 2008). The South African White paper on Science, Technology and Innovation is purposed to develop human capabilities, expand knowledge and innovation performance and increase investment which provides an opportunity for original innovation (DST, 2019). The next category of innovation is secondary innovation, this type of innovation is typically observed in the “global south” context and includes the assimilation, structural, functional and conceptual understanding of a foreign technology (Wu et al., 2009) moving beyond the adoption of technologies. In the South African context, wastewater technologies are largely imported into the country (Potgieter et al., 2020) and these imports may provide an opportunity for secondary innovation in the water context. The final category of innovation is tertiary innovation which includes knowledge intensive business services which provide a connection between organisational technologies and ICT services (e.g. digital payment platforms, cloud based solutions) and product innovation for the adoption of an innovation and for creating scale (Soumonni & Ojah, 2022). South Africa’s service sector was ranked as the top business services sector location in the world (dtic, 2021) with the service sector contributing 69% to GDP in 2014 (Stewart, 2021). Additionally, significant imports of wastewater technologies (Potgieter et al., 2020) may require innovative services and digital services that facilitate their diffusion. There is therefore high potential for tertiary innovation within the water sector.

1.2.6 Context of the study

Based on this background, this study will focus on the role of circular economy innovation in SEZs within South Africa with specific attention to the water sector, and the impact of innovation from an environmental and socio-economic perspective. The guiding innovation theory of the TEP will be used to assess the extent to which ICT water technologies are driving a green TEP through lower costs, increased opportunities for entrepreneurial innovation and organisational change. Innovation will be categorised using the CE framework (i.e. reduce, reuse, recover, restore and recycle) and considered for the potential to increase different categories of innovation therein (i.e. original, secondary and tertiary).

1.3 Research problem statement

Under the ambit of South Africa's aim to drive economic recovery (South African Government, 2020) the circular economy has been identified as an environmental and economic model (Ekins et al., 2019) which is aimed at minimising virgin resource usage and limiting waste (Ghisellini et al., 2016). Although CE activity in water has been adopted into various government policies and activities, a formalised circularity guide for water has not been developed (Godfrey et al., 2021). Furthermore, there are inconsistent applications due to differing definitions and policies across the globe (Gonçalves et al., 2022; Kirchherr et al., 2017). The CE in South Africa is also considered to be high cost and lacking in the designation of accountability to the responsible actors (Tahulela & Ballard, 2019). However, the CE principles have been utilised to address water scarcity and quality challenges internationally (Smol et al., 2020) and on a more informal basis, locally (Godfrey et al., 2021). The CE therefore has merit for South Africa, which is a water scarce country (WWF-SA, 2016). The CE is also noted as being an enabler of the green TEP (Mazzucato & Perez, 2015) which is a sustainable, society benefitting paradigm or "golden green age" (Mazzucato & Perez, 2015) driven by innovation. It is clusters of innovations, particularly data driven technologies, that are driving the prevailing ICT technological revolution (Perez, 2010). Both the TEP and the CE require innovation as a driver (Perez, 2010) and enabler (Kirchherr et al., 2017) respectively.

Special economic zones (SEZs) are geographically demarcated areas focused on economic development through foreign direct investment and infrastructure support (Nel & Rogerson, 2014). These SEZs have had mixed results across the globe and locally (Boniface, 2015; Frick et al., 2018). However, the most successful SEZs have appropriate clustering of industries, government support and linkages to education and financing facilities (Zeng, 2021). In addition, the purposeful facilitation of innovation within the SEZ has been noted as a success factor in international cases (Zeng, 2021). An understanding of the ways in which circular economy principles applied to water sector innovation can drive green economic development within SEZs in South Africa is therefore required in order to share this knowledge as part of South Africa's economic recovery.

1.4 Significance of the study

The study is aimed at building the wealth of knowledge related to circular economy innovation, to provide a use case on the fundamentals of sustainability and identify pragmatic solutions for the community of practice.

For innovation studies

The report will categorise water innovation into a circular economy framework for South African industrialisation. Secondly, the report will consider how this innovation impacts the state of the green TEP in South Africa. This information is significant for academics seeking to understand how this global TEP is exhibited in water sector innovation in South Africa, as well as those seeking to develop the circular economy literature for water.

For the water sector community of practice

Practically, the report aims to identify local, implementable solutions which can be implemented by business in order to address water challenges in South Africa. Local development, adaptation and facilitated adopted of technologies should reduce implementation costs and increase technical diffusion. This report can inform policies for the green economy by using practices which are working well particularly in innovation particularly in the circular economy.

For sustainability practice

The use of the CE framework and the TEP theories incorporate the social, environmental and economic elements of sustainability which provides a use case for how these elements interact in a manner that is both beneficial to the environment and economy. In addition, understanding the ways in which the onset of the TEP can be accelerated through policies, incentives and knowledge sharing, may be beneficial in driving the green paradigm and associated societal change.

1.5 Delimitations of the study

1.5.1. **Local innovation**

The study will focus on innovation in South Africa (original, secondary and tertiary) in response to supply and demand challenges within the water sector. An analysis of patents will not be performed to determine locality in order to determine whether they are original; however, cost and implementation times will be considered. New foreign technologies which are not currently adopted in South Africa but potential applicability to the water sector will not be considered.

1.5.2. **Circular economy**

Only the innovation which conforms to circular economy principles will be considered and therefore, innovation related to the use of virgin water sources (i.e. through groundwater and boreholes) will be excluded from this study unless specifically addressed by interviewees. The CE includes many principles embodied in the XR’s (Ghisellini et al., 2016) which refers to the varying interpretations of the CE as articulated through “R” activities such as “reduce”, “reuse” etc. (Smol et al., 2020). This study will focus on the basic 5R model of “reduce, reuse, recycle, restore and recover” as developed by the World Business Council for Sustainable Development for water.

1.5.3. **Special economic zones**

The focus will be channelled towards the innovation which support industrialisation. Furthermore, overall industrialisation in South Africa will not be considered but rather the industrialisation in Special Economic Zones. Domestic water use, challenges and innovation will not be considered as part of this study.

1.5.4. **Techno-economic paradigms**

The guiding framework used in the study is the TEP and the determinants used to assess the TEP will be related to cost, entrepreneurship opportunities and organisational changes within the water sector. A detailed analysis of the governance structures and public sector initiatives will not be performed.

1.5.5. **General limitations**

The use of case studies are sometimes regarded as being low on validity and reliability (Ferreira et al., 2020) and this will be addressed through data triangulation. The use of purposeful non-probability sampling rather than random sampling may reduce generalisability (Saunders et al., 2019), but has been overcome through multiple case study analyses rather than a single case study (Saunders et al., 2019). The use of interviews introduces an element of bias and subjectivity as well as the possibility that confidential data may be gathered which cannot be shared with the general public (Bewley, 2002). This problem will be addressed in the structuring of the questions and the interpretation of results.

1.6 Assumptions

- It is assumed that the qualitative case study research method is adequate to provide data required to test the research hypothesis.
- It is assumed that South African water sector representatives, who are interviewees, have the sufficient level or expertise and knowledge on the topic and understand the questions in order to provide appropriate responses.
- It is assumed that answers provided by these interviewees are honest.
- It is assumed there will be an adequate response rate to triangulate data gathered and build a depth of knowledge.

1.7 Definition of key terms

- Circular economy: “[CE] an industrial system that is restorative or regenerative by intention and design. It replaces the ‘end-of-life’ concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models.” (EMF, 2018)
- Techno-economic paradigm: “a complex learning process, a best practice model for economics, technology and organisational practices” (Perez, 2010).

- Special Economic Zones: “Special Economic Zones (SEZs) within South Africa are geographically designated areas set aside for specifically targeted economic activities to promote national economic development and exports by using support measures to attract foreign and domestic investments and technology“ (SARS, 2014).

1.8 Research questions

The research questions have been based on the research problems:

- **Question one:** What are the characteristics of water innovation within the circular economy that have a positive impact on economic development?
- **Question two:** Does water innovation drive the green techno-economic paradigm in South Africa? If so to what extent?

1.9 Outline and structure of the report

- Chapter 1: Introduction
- Chapter 2: Literature Review
- Chapter 3: Research Methodology
- Chapter 4: Presentation of data
- Chapter 5: Analysis of Results and Discussion
- Chapter 6: Conclusions and Recommendations
- References
- Appendices: Questionnaires

1.10 Conclusion

South Africa, a water scarce country is in the midst of implementing an economic recovery plan. At the same time, a global techno-economic paradigm around ICT enabled green growth is developing. Innovation linked to this paradigm can therefore be used to improve economic development and the inclusion of water innovation will address South African water scarcity challenges. An appropriate identified framework for developing these technologies and innovation is the circular economy theory which seeks to maintain resources in a closed cycle for the maximum period possible. Research in the area of CE related water innovation spanning original, secondary and tertiary innovation and their role in driving and creating a ICT enabled green TEP in South Africa is therefore a requirement in understanding and driving economic development.

Chapter 2: Literature Review

2.1 Introduction

This literature review is aimed at consolidating and summarising the existing bodies of knowledge related to the research themes. The purpose of the review is to guide the direction of the research by creating delimitations for the study where research has already been performed in order to avoid duplication, to identify potential gaps and misalignments in the research, to determine those variables important to each theme, and to identify appropriate methodologies within the research. A reinforcement of the significance of the research problem will therefore be highlighted through this process.

The type of literature review performed wasan outcomes-based view aimed at analysing and synthesising the existing literature (Randolph, 2009) on each of the identified themes. For the theories identified as being relevant to the study, a broader literature review was performed in the theoretical framework to provide a description of the theory and its importance to this research.

The selected theories of the circular economy and the techno-economic paradigms were combined with the categories of innovation during the development of the theoretical framework to illustrate innovation driven growth and sustainability. The conceptual framework was developed using the literature review and theoretical frameworks and these informed the research methodology.

The literature review covers six primary themes related to the research problem with each concluding on the implications for economic development and sustainability.

1. **Water in South Africa:** South Africa's water sector is considered with specific focus on the demand and supply challenges, the governance and commercialisation considerations and the future state of water as it relates to innovation.
2. **SEZs**: Special economic zones will be discussed in the South African context, through international best practices and failures and by understanding the role of water within the SEZ.

3. **Circular economy**: An overview of the circular economy theory in South Africa to determine the current state will be performed along with an overview of international uses of the circular economy in the water sector and in the role of innovation therein.
4. **TEPs:** The current global TEP has been identified in the literature and considered in the South African context as it relates to opportunities and barriers and lessons from international best practices.
5. **Innovation capability categories:** The three categories of innovation (i.e. original, secondary and tertiary) have been outlined and considered in the South African context as it relates to opportunities for innovation in the water sector.
6. **Finance and innovation:** The role of finance in the CE and TEP were understood in the context of the need for finance as well as the types of finance and enablers of finance.

2.2 The water sector

Literature related to water is considered in the context of three themes, demand and supply, governance and commercialisation, and the future of water and innovation.

2.2.1 Demand and supply considerations

A recuring theme in the understanding of the current state of water in South Africa is that of water scarcity (Godfrey et al., 2021; Soyapi, 2007). South Africa receives less rainfall per annum than the global average (Godfrey et al., 2021; Muller, 2008). This is the starting point for much of the literature particularly because the issue of water scarcity is not expected to diminish and may result in water shortages in South Africa by 2030 (Godfrey et al., 2021; Habiyaremye, 2020). Water shortages are expected to be driven by an increase in demand coupled with a limited and deteriorating supply. The demand side increase is driven by population growth (Soyapi, 2007) and urbanisation (Matchaya et al., 2019). The supply side constraints relate to water pollution and the resultant deteriorating water quality (Soyapi, 2007), poor and aging infrastructure particularly in dams and finally water abstraction, afforestation and the negative impact of alien vegetation (Pitman, 2011).

From an industrialisation perspective, demand for water is primarily driven by use in agriculture (60%) and industry (10%) (Pitman, 2011). However, there are increasing demands for water across multiple industries spanning construction and mining to tourism (Enqvist & Ziervogel, 2019) and hydropower (Matchaya et al., 2019).

Industrialisation has had a negative impact on water systems internationally. Land transformation for industry has led to soil erosion and has prevented groundwater replenishment, as well as the contamination of water with chemicals being released into the water system as a by-product of agriculture and industry (Sauvé et al., 2021). In South Africa, according to a study performed on the environmental impact of effluent discharged from industry, there has been a negative impact of industry on water quality through pollution and the discharge of harmful chemicals (Iloms et al., 2020). Furthermore, access to water is a challenge particularly in the inland areas where 60% of South Africa's GDP (Muller, 2008) is created through industrialisation. Shortages in water supply will therefore impact the country's industrialisation, particularly in water intensive industries. The demand and supply challenges are commonly noted as a consensus within the literature.

There is therefore a case to be made for the continuous study of water in order to address the scarcity challenges and the potentially adverse impact on the economy and environment.

2.2.2 Water governance and commercialisation

An area of much contention related to water in South Africa is that of water governance (Enqvist & Ziervogel, 2019; Muller, 2008; Partzsch & Winkler, 2009; Soyapi, 2007). The South African Constitution includes water as a basic human right, with the implications and governance of this designation having resulted in differing views on how water should be provided, priced and governed (Muller, 2008). Currently water management falls within the mandate of the Department of Water and Sanitation, which executes its mandate through various governmental bodies at a regional level regional level (Muller, 2008) including waterboards and research councils. This results in differing mechanisms of commercialising water and various private public partnerships being formed (Rose & Winter, 2015). The primary area of contention relating to the commercialisation of water is price. In some areas such as Johannesburg and Queenstown the price of water has doubled and tripled since 2004 (Partzsch & Winkler, 2009). This has resulted in protest action with consumers expressing their dissatisfaction with the pricing of a commodity meant to be a human right (Partzsch & Winkler, 2009). Cross-subsidisation and block tariffs are being imposed in some provinces (Partzsch & Winkler, 2009) in response to price concerns. Furthermore privatisation of water management has been heralded by some authors as an opportunity from the perspective of growth and increased access (Enqvist & Ziervogel, 2019; Rose & Winter, 2015) and is regard as negative by others from the perspective of high prices and increased inequality (Partzsch & Winkler, 2009; Soyapi, 2007).

Another area related to both governance and commercialisation is the matter of creating water markets within the country and within Sub-Saharan Africa (Matchaya et al., 2019). Water markets occur when there is water scarcity (Matchaya et al., 2019) and where mechanisms are introduced to transfer water to areas of high demand for a price. These water transfers have had adverse economic effects (Muller, 2008) as well as adverse environmental impacts (Matchaya et al., 2019).

This reinforces the economic and environmental need to resolve the water challenges in South Africa. It also highlights the potential challenge of the implementation of water sector innovation due to varying regional policies and varying degrees of interaction between the public and private sectors. An innovation might therefore exist that can address water challenges but be overlooked due to these obstacles. Notably missing from the literature on water policies are the principles outlined by (Mazzucato & Penna, 2015) which describe the ways in which the state empowers the private sector to innovate in order to solve for grand societal problems. Nor does the literature consider the ways in which the State in takes on risk in providing funding for major long term innovation projects (Mazzucato, 2011) but rather sees the State as being politically charged in a detrimental way (Muller, 2008) and inefficient (Soyapi, 2007) as it relates to water. Innovative policies for water governance and commercialisation are therefore required in addition to water innovation itself.

2.2.3 The future of water and water innovation

From a forward-looking point of view, the future of water in South Africa does not appear to be negative from the perspective of the literature. Most recently, the water crisis in Cape Town in 2018 and the subsequent recovery have been heralded both nationally and internationally as a case study in successful water management (Enqvist & Ziervogel, 2019). The general consensus reached in the literature is that the water sector requires the active attention of both businesses and individuals and that the future of water in South Africa is driven by inclusive (Enqvist & Ziervogel, 2019), environmentally sustainable (Muller, 2008;

Pitman, 2011) and collaborative processes (Pitman, 2011; Rose & Winter, 2015). From an opportunity perspective, the water sector is primed to include: anticipatory climate change mitigants (Pitman, 2011); a focus on infrastructure investment and maintenance (Muller, 2008); the consideration of new water markets which are efficient, a balance of the ecological elements with the economics (Matchaya et al., 2019); and the development of technologies to monitor and assess water quality and surface and groundwater interaction (Hughes, 2019; Pitman, 2011). These forward-looking views all include the potential to innovate and consider novel solutions to these opportunities.

From an innovation perspective, funding for water research and development was nearly R1.3bn, but the implementation of research is hampered by high costs to adopt new water technologies as well as low levels of support from municipalities (Habiyaremye, 2020). This creates a barrier to scale for water innovation in South Africa. A study in 2015 found the top enablers for water innovation include: mechanisms for knowledge sharing on infrastructure, building strong science, technology and innovation networks to link research with execution, creating opportunities for small enterprises; and technical skills accumulation entrepreneurship and support (Rose & Winter, 2015). Finally ICT enabled water innovation has been flagged as an opportunity for South Africa (Pitman, 2011). The potential for technological innovation in South Africa is observed across the value chain and ranges from drone technology used in exploration and abstraction to nanotechnology used in wastewater treatment (Habiyaremye, 2020). These enablers, particularly the use of ICT, are pertinent in this study as the current technological revolution is being driven by ICT technologies (Perez, 2016). ICT enabled green technologies are considered the best mechanism to advance the green sustainable economic paradigm (Perez, 2016). A sufficient consensus exists on the future of water in South Africa and there exists potential to identify innovative solutions which address the water challenges in an environmentally conscious manner while still supporting industrialisation, such as those related to the circular economy.

2.3 Special Economic Zones (SEZs) in South Africa

The SEZs represent the units of analysis for which the research is performed. It is therefore important to perform a high level overview of the SEZ landscape in South Africa, to consider international best practices as they relate to innovation within the SEZ and water resources, and finally, to identify the opportunities for SEZs in South Africa as they relate to water sector innovation.

2.3.1 An overview of SEZ's in South Africa

An SEZ is defined as "geographical designated area of the country set aside for specifically targeted economic activities, which are then supported through special arrangements and support systems which are different from those which apply to the rest of the country" (Nel & Rogerson, 2014). The Special Economic Zones Act (DTI, 2021; Nel & Rogerson, 2014) provides governance on SEZs in South Africa. Special economic zones have been created to improve the observed unevenness in economic development across different geographies in South Africa (Nel & Rogerson, 2014). Their focus is to promoted economic and industrial development in the long term, to attract investment from local and foreign sources and to enhance the infrastructure of the targeted industries with the tangible benefits of increased employment, improved manufacturing activities and enhanced exports (Nel & Rogerson, 2014). Previous iterations of the SEZ in South Africa did not attain the expected catalytic and industrial outcomes they were created for (Boniface, 2015; Nel & Rogerson, 2014), and lessons learned should be adopted into the development of a strong and successful SEZs. Lessons in this study specifically relate to how successful SEZs in South Africa have adopted circular economy practices and water and how the associated water technologies are contributing to a green TEP.

There are 10 SEZs in South Africa, each with a unique industrial focus The designated zones and focus areas (in brackets) are as follows (DTI, 2021): Atlantis in Cape Town (green technologies),Nkomazi in Nelspruit (agro-processing), Coega in East London (agro-processing, energy and logistics), Richards Bay in Kwa-Zulu Natal (manufacturing and beneficiation), Saldanha Bay in Cape Town (oil, gas and marine engineering and logistics), Dube in Durban (manufacturing and agriculture), Maluti in the Free State (logistics and agro-processing), OR Tambo (beneficiation), Musina in Limpopo (mineral beneficiation, agro-processing and petrochemicals), Tshwane Automotive Special Economic Zone in Gauteng (manufacturing and logistics). The performance of some SEZs in South Africa has not been aligned to expected employment and growth targets in the past (Boniface, 2015).

There are several challenges related to SEZs in South Africa including the structural challenges related to industrialisation in remote areas where resources and skills are limited and the lack of surrounding infrastructures to support industry (Nel & Rogerson, 2014). Investment in technologies and innovation as well as adequate resources (i.e. water) management are not noted as potential solutions to these challenges (Boniface, 2015). There is therefore an opportunity to investigate the role of innovation in enabling the SEZ in South Africa in greater detail.

2.3.2 International best practices and the role of innovation and water in the SEZ

The success of SEZs has been inconsistent globally (Boniface, 2015; Frick et al., 2018) with underperformance having been noted in many of the SEZs of emerging countries (Frick & Pose, 2021). The challenges which led to the failures of global SEZ's include infrastructure insufficiency, limited skillsets and a lack of a competitive advantage (Frick et al., 2018).

China remains an industry case study for best practices and standards (Zeng, 2021). There are several success factors which China has attributed its SEZ success to but critical to the success is the adequate clustering of firms in a related field with the supporting government structures, financiers and educational institutions (Zeng, 2021) located close by. Furthermore, the Chinese government is strategic in the mechanisms used to foster SEZ success. Innovation is one of the notable mechanisms used (Zeng, 2021), Chinese SEZs are focused on creating innovation (and not just imitation) through culture and knowledge transfers as well as in the specific funding of innovation activities (Zeng, 2021). Although there is a focus on innovation in Chinese SEZs, globally the correlation between high technology focus in the SEZs and growth has been negative (Frick & Pose, 2021). This does not imply that innovation is not a success factor, it implies that technological development and innovation focus is limited in some global SEZs due to the conditions not being conducive to innovation (Frick et al., 2018). International SEZs are low technology focused and the transition from low technology to high technology remains a gap in the research (Frick et al., 2018). Sourcing local inputs remains a challenge globally (Frick & Pose, 2021) with the development of local supply chains in China (Zeng, 2021) being a differentiator which adds to the SEZ success. Localisation of innovation may therefore also be an opportunity for South African SEZs.

The need for water in industries is critical (Godfrey et al., 2021) however the role of water in the SEZ context is not a prominent focus of literature. However, the need for the SEZ to be located near a water source is considered important from an export perspective (Frick et al., 2018). Enhanced focus should be placed on developing environmentally responsible SEZ's (Nel & Rogerson, 2014; Zeng, 2021). This understanding of the factors which have enabled success of international SEZ's, and areas of caution can be used to strengthen the performance of SEZ's in South Africa and increase economic development.

2.3.3 Opportunities for SEZ's in South Africa as they relate to water sector innovation

Although innovation and water are not specific focus areas in the SEZ literature, opportunities exist to include innovative resource policies and practices within the SEZ. The need for supporting infrastructure (Boniface, 2015) can be considered through the lens of water infrastructure and the opportunity to create a competitive advantage and strategic focus (Boniface, 2015) can be addressed by developing world class strategies and processes which include green technologies for a green economy (Boniface, 2015; Nel & Rogerson, 2014). One notable example is the Atlantis SEZ, which is a green technology focused SEZ and uses innovation in the sourcing and generation of water and electricity (Grant et al., 2020). The Coega SEZ has made notable progress in desalination innovation, which is used to address water scarcity challenges (Burgess et al., 2015). An understanding of the relatedness of water innovation in driving the green economy through SEZ activities should be developed.

2.4 The Circular Economy

The circular economy will be understood through the lens of the South African context and linkages with innovation and the water sector.

2.4.1 Circular economy in South Africa

The CE in South Africa, although evident in varying activities since the 1980's (Godfrey et al., 2021) is still emerging from a national policy perspective with national guidelines still being developed for different resources. The "Circular Economy Guideline for the Waste Sector" was developed in 2019 and was created as a national entry point to understanding the benefits of circular economy principles in South Africa (DEFF, 2020). Current CE policies in South Africa are primarily related to waste and waste management (DEFF, 2020; Tahulela & Ballard, 2019) with other policies related to water including some form of circular principles (Godfrey et al., 2021).

Challenges in the circular economy in South Africa are related to recycling (Mativenga, Ejon, et al., 2017) which is considered to be of low priority by businesses (Tahulela & Ballard, 2019), the high expected costs associated with implementing CE principles (Mativenga, Ejon, et al., 2017), and the allocation of responsibility (between government and institutions) for addressing the CE principles (Tahulela & Ballard, 2019). This element of responsibility is particularly pertinent with the "Extended Producer Responsibility" policy (Tahulela & Ballard, 2019) being included in the industry waste management plan which places the onus on industry for addressing the toxic constituents of certain products beyond the point of sale. In addition, the "National Guideline for the Discharge of Effluent From Land-based Sources into the Coastal Environment" regulates the discharge of (industrial) effluent into coastal water sources (DEFF, 2014). Further challenges include: a lack of measurement criteria, weak supporting policies to govern the CE, and undefined timelines for implementation (Tahulela & Ballard, 2019).

Although not prevalent in the broad circular economy discourse, there is emerging literature on the water, energy and food nexus in South Africa, which recommends using circular economy principles as a mechanism for building this new approach to sustainable resource management (Naidoo, Nhamo, Mpandeli, et al., 2021; Nhamo et al., 2020).

In South Africa, the environmental outcome of the CE is expected to be reduced pollution (Wright et al., 2019), reduction in the use of virgin resources, the regeneration of natural systems and the achievement of climate targets (Godfrey et al., 2021). From an economic development perspective, the CE in South Africa is noted as having job creation potential through green jobs (Godfrey et al., 2021), and can contribute to cleaner production and promotes industrial efficiency (DEFF, 2020). The CE can be viewed as a sustainability tool which fosters economic development and the nature and impact of the CE activity in South Africa is an area of opportunity to be understood and replicated.

2.4.2 Water and the circular economy

Internationally, the CE for water has been articulated in many ways. Frameworks and applications are available for water and wastewater (Smol et al., 2020), which consider the mechanisms to recycle water, improve water quality and prevent the loss of crucial chemicals such as phosphorus (Smol et al., 2020). Digitisation and the monetisation of water technologies within the CE have been noted as opportunities for water in international literature (Smol et al., 2020). In addition to the broader CE opportunities identified in the previous section, in South Africa, water CE opportunities include decoupling production in agriculture from the demand for water, reducing waste and creating water efficiencies, and performing onsite wastewater treatment (Godfrey et al., 2021).

From an environmental impact perspective, achieving water security is a direct impact of the CE (Godfrey et al., 2021) in South Africa. The United Nations defines water scarcity as a population's ability to access quality water for sustained livelihoods and wellbeing as well as for ensuring protection against pollution and preserving ecosystems and political stability (UN, 2013). Current water policies in South Africa are aimed at inclusive economic growth (Nepfumbada & Seetal, 2020) with scope to consider frugal and socially inclusive innovation as an enabler.

2.4.3 Innovation in the circular economy

From an innovation perspective, innovation is considered a key enabler of the circular economy (Ghisellini et al., 2016). Innovation in the CE is considered to be a collaborative approach wherein knowledge, resources and technologies are shared, resulting in creative destruction within existing industries. Part of this creative destruction requires innovation in business models (Suchek et al., 2021). Specifically related to sustainability and the CE in developing countries is the concept of frugal innovation. Frugal innovation has been noted as being inherently sustainable in its nature and directly linked to the circular economy in the manner in which it addresses the minimising of resources in an affordable and accessible manner (Albert, 2019). Frugal innovation cuts across innovation categories and can encompass primary, secondary and tertiary innovation because it involves the design or redesign of systems, business models, products and services as a way of lower costs and complexity, particularly for low income users (Leliveld & Knorringa, 2018). It can therefore be original and research driven, or an efficient and cheap way of localising imported technologies or the low cost ICT services used to increase adoption of existing technologies. Therefore, frugal innovation may therefore a mechanism that addresses the challenges of cost and sustainability while maintaining circularity and promoting innovation.

It is therefore evident that the CE has vast potential for innovation, economic development and environmental sustainability in South Africa. There is therefore a need to understand the nature of innovation and the impact thereof in the South African context in order to provide a use case for building future circular practices and policies for water.

From a South African perspective, innovation in the CE is considered a primary sustainer of long term business practices (Godfrey et al., 2021; Mativenga, Mohamed, et al., 2017). Opportunities for innovation in the CE in South Africa include those related to co-creating policies to develop new ownership models, to increase cost optimisation (Mativenga, Ejon, et al., 2017; Roberts & Schöer, 2021) and to build private public partnerships (Tahulela & Ballard, 2019). Critical enablers of the CE include industrial buy-in for CE principles (Tahulela & Ballard, 2019), digitisation, innovative finance models, and policies. Finally, a systematic approach is needed to drive behavioural and widescale change (de Jesus & Mendonça, 2018; Godfrey et al., 2021).

2.5 Techno-economic paradigms (TEP's)

There is a consensus in the literature that South Africa, like other countries is currently in the midst of the ICT revolution (Amankwah-Amoah, 2019). The opportunities, challenges and lessons from international best practices will be outlined in the literature review.

2.5.1 Techno economic paradigm global trends

At present the prevailing technological revolution is known as the age of information and telecommunications (Stewart, 2021). This is characterised by information intensity, decentralised integration and inward and outward collaboration, among other attributes (Perez, 2010). This revolution began in the early 1970s with many technologies existing and pre-dating that time having been observed as being upgraded to become more efficient because of this revolution. An example of these technologies related to water are desalination technology, which have been used in varying contemporary forms across the globe since the 1950's (Angelakis et al., 2021) and adopted in South Africa in 1997 (Turner et al., 2015). These desalination technologies were historically considered to be high cost, but have evolved to become more energy efficient, digitised and lower cost (Turner et al., 2015) because of the ICT revolution which has reduced operating cost. The result of the current revolution is expected to be an ICT led green paradigm which is a subject designated much attention from a literary perspective. This paradigm seeks to build a green and sustainable economy using ICT technology (Perez, 2016) and data (Amankwah-Amoah, 2019). Much attention has been placed on renewable energy technology (Amankwah-Amoah, 2019; Mathews, 2013; Perez, 2016) and the role of these in creating a new paradigm. A green growth strategy which is co-created, adequately funded and properly measured is a key enabler for success of this TEP (Abrahams & Goldstuck, 2012; Amankwah-Amoah, 2019). However, an understanding of the role of other natural resources such as water and minerals is yet to be developed. From a green growth perspective, the circular economy has been identified as driver of the green TEP (Mazzucato & Perez, 2015) with circular practices driving sustainability and sustainability focused technologies.

2.5.2 Techno economic paradigm opportunities in South Africa

According to the literature, South Africa is currently in the installation phase of the TEP. This is evidenced in part by low investment levels and high inequality which imply that the TEP and improved socio-economic conditions have not emerged (Stewart, 2021). Furthermore there is an opportunity for specific technological sectors to drive the TEP as noted by Mathews (2013) in his paper on renewable energy. The opportunity exists for South Africa to benefit from the latecomer advantage (Amankwah-Amoah, 2019) in the evolution of the TEP. South Africa can use its latecomer status to firstly, adopt existing technologies related to ICT and benefit from the low costs and increased efficiency (Amankwah-Amoah, 2019) and secondly, to enhance and improve on these technologies through the secondary innovation process (Wu et al., 2009). Given that the cost of adoption in technologies particularly in the CE has been raised as a challenge (Mativenga, Ejon, et al., 2017) this latecomer advantage may be beneficial to South Africa in the development of ICT enabled green technologies. This latecomer advantage allows the country to leapfrog and further innovate on the latest technologies available without having to endure the long process of technological development, research and development and the high cost of technical change (Amankwah-Amoah, 2019).

2.5.3 Techno economic paradigm challenges in South Africa

From a challenges perspective, limited investment in technology and low enforcement of government policies focused on innovation and the development of technical capabilities remains a challenge across the continent with the rate of adoption of technologies is noted as being slow (Amankwah-Amoah, 2019). Limited firm knowledge on new technologies and the mechanisms for capturing value from innovation are also a barriers to adoption

(Amankwah-Amoah, 2019) and these barriers hinder the development of a new TEP. In South Africa, the state of innovation required to support the ICT revolution was historically noted as being insufficient (Abrahams & Goldstuck, 2012). Furthermore, there is heavy reliance on foreign technologies and an uneven distribution of technical change and advancement in South Africa (Stewart, 2021). This inequality in technological advancement may see those who are beneficiaries of inequality seeking to prolong the installation phase in order to delay the wide scale societal benefit associated with a new TEP (Stewart, 2021). There is also a lack of strategic focus and long term planning for technologies required to drive a new paradigm (Abrahams & Goldstuck, 2012) and the current ICT-based technologies in the water sector require renewal (Pitman, 2011). It would appear that South Africa exhibit many barriers to adopting a new TEP. Therefore these obstacles will need to be addressed in order to achieve green and inclusive economic development.

There therefore exists an opportunity to understand the role of innovation linked to natural resources in driving the green TEP. An analysis was performed by Mathews (2013) in order to determine how renewable energy is driving a new techno-economic paradigm using the criteria of 1- falling cost, 2- costs lower than incumbent technology and 3- pervasive effects. A similar analysis will be performed in this study with regards to water.

2.6 Categories of innovation capabilities

The three categories of innovation capabilities: original, secondary and tertiary and the applicability for the South African water context will be outlined in the literature review.

2.6.1 Categories of innovation capabilities defined

Innovation is defined by the OECD as a substantially changed product or service, production or delivery method, marketing method or business practice (OECD, 2010). These types of innovation are associated with the definition of original innovation used in this report due to the emphasis on newness and significant improvement. This type of innovation follows a linear path from R&D towards development and production and eventually marketing for commercialisation (Wu et al., 2008) and original innovation is typically a characteristic of developed countries (Wu et al., 2008). Technical capabilities are created through research which can be basic research or applied research (Wu et al., 2008) through the traditional scientific and technologically (STI) mode or it can be result of learning by doing, using or interacting (DUI) mode (Jensen et al., 2007).

According to (Wu et al., 2008) innovation in developing countries is different from developed countries and the path followed is non-linear. Knowledge and technical capability do not have to be completely new or significantly improved in order to be considered innovation. Secondary innovation is a prevalent form of innovation in developing countries and is the process of knowledge acquisition of from firms in developed countries in order to duplicate, create, explore and exploit the innovation in the local context over time (Wu et al., 2008). There are typically four stages of secondary innovation assimilation, structural understanding, functional understanding and conceptual understanding of a technology (Wu et al., 2009). Secondary innovation is primarily associated with technological innovations and has been observed in the manufacturing context (Wu et al., 2008). Secondary innovation is a mechanism for developing countries to catch up which where a country closes the gap between itself and a forerunner country (Lee, 2019) economically or technologically. Coupled with catch up is the concept of the latecomer advantage which is where firms take advantage of globalisation to enhance their technical capabilities through acquisitions from developed countries (Wu et al., 2008).

The final category of innovation is tertiary innovation. Tertiary innovation refers to the adoption of an innovation through techno-organisational modes of innovation (e.g. digital platforms and systems) that are complemented with innovative business and management capabilities in order to achieve scale (Soumonni & Ojah, 2022). Tertiary innovation is a characteristic observed in knowledge-intensive business services and is based on the premise that these business services are not simply users of innovation but also create a locus of innovation (Corrocher et al., 2009). Knowledge intensive business services (KIBS) can be classified into technical KIBS (which include engineering, R&D consulting and IT services etc.) and professional services (which include inter alia accounting, legal and business management services) (Corrocher et al., 2009). These KIBS provide a bridge of innovation and a mechanism for the redistribution of information (Corrocher et al., 2009). Tertiary innovation is characterised by DUI learning (Corrocher et al., 2009) however the intangible nature of both the inputs and outputs related to this type of innovation make measurement difficult (Corrocher et al., 2009). The important differentiator in tertiary innovation is that the technological innovation may not be novel to the world, and the ability to assimilate, or imitate may not be observed or possible at the onset, but it is the coupling of organisational systems with knowledge intensive business services which increase the scale of the innovation in the market.

2.6.2 Applicability of innovation capability categories in the South African water context

The different categories of innovation capability increase the scope of innovation from being limited to original R&D-led knowledge and inventions to including imitation and assimilation (Wu et al., 2009) as well as knowledge intensive business services which support large scale adoption of a technology (Soumonni & Ojah, 2022). This is particularly pertinent for South Africa which is considered a developing country wherein R&D based innovation is not the only potential innovation category.

South Africa is ranked of 61 out of 132 on the global innovation index for knowledge and technology outputs in the (WIPO, 2021). There is therefore potential for original innovation as a result of this R&D expertise. In addition, the 2019 Whitepaper on Science, Technology and Innovation is purposed to develop human capabilities, expand knowledge and innovation performance and increase investment which provides an opportunity for original innovation (DST, 2019). However this policy has been viewed as not yet having translated into significant innovation (ESASTAP, 2021) there is therefore opportunity for development of knowledge and technology outputs which are included in the original innovation category. In the South African context, the manufacturing sector accounted for 12% of the country's GDP in Q2/2021 (SARB, 2021) which is significant. The size of this sector when considered in the context of the high levels of wastewater technology imports into South Africa (Potgieter et al., 2020) provide an opportunity for secondary innovation in the water context. Finally in 2021, South Africa's service sector was ranked as the number one location for business services in the world (dtic, 2021) and this strength within the business services sector creates an opportunity for tertiary innovation particularly in the knowledge based business services related to the water sector.

2.7 The role of finance in the CE and TEP

The role of finance in the CE and TEP will be considered through the lenses of the nature of financing as well as the types of finance available.

2.7.1 Financing the circular economy

2.7.1.1 Considerations for a circular economy

Innovation and new business models are considered enablers of the CE (Winans et al., 2017) and the cost of adopting the CE in South Africa has been flagged as a challenge (Mativenga, Ejon, et al., 2017) with digitisation and new finance models required (de Jesus & Mendonça, 2018; Rodrigo-González et al., 2021). These new models require additional funding sources (Gedam et al., 2021). Furthermore, investors and shareholders of companies who seek to adopt CE principles are now requiring sustainable finance mechanisms and adequate monitoring (Gonçalves et al., 2022). These financing mechanisms and modes require further understanding for their applicability to the CE.

2.7.1.2 Financing options for the CE

The financing of the circular economy has historically been the role of the government through subsidies, incentives and R&D support. However current levels of state funding are considered insufficient (Gonçalves et al., 2022) particularly in light of growing opportunities related to circularity and the related cost (Gonçalves et al., 2022). It is estimated that the capital funding gap in South Africa for water security is R33bn per year for the next 10 years (Nepfumbada & Seetal, 2020).

Private sector funding is another mechanism that can be used to fund CE activities. The private sector can contribute to CE financing in a number of ways. Firstly, through traditional balance sheet financing in the form of loans and working capital (Rizos et al., 2016), but access to capital in order to finance the CE being noted as a significant barrier to SMEs (Rizos et al., 2016). Additionally, green bonds can be used which are ring fenced funds sourced from debt capital markets in which the proceeds are used specifically on environment and climate beneficial projects (Flammer, 2021). In addition to these bonds, there are now CE investment funds specifically focused on investing in CE projects (e.g. the international investment management company BlackRock based in the US has a Circular Economy Investment Fund) (Dewick et al., 2020) which firms can access funding from.

The circular economy is a collaborative model (Tahulela & Ballard, 2019) and therefore collaborative financing mechanisms which include both private and public finance should also be considered. This may require an intermediary in the form of development finance institutions. Development finance institutions and multilateral development banks have been flagged as enablers in the funding of circularity, particularly in developing countries (Dewick et al., 2020), such as South Africa. Development finance institutes perform the role of attracting private sector investment (for circular projects and activities) while providing a risk mitigation role (Karani & Gantsho, 2007). The value in using development finance is that the financiers are able to attract funds at a discounted rate (i.e. concessional funds) and create blended finance instruments for use in circular projects (Karani & Gantsho, 2007).

2.7.1.3 Finance enablers for the CE

From a financing perspective, tools are required for monitoring both CE activities and the financing of CE activities (UNEP, 2020). Currently monitoring and strategies for circularity remain gaps at the corporate level for the CE adoption (Gonçalves et al., 2022). This will require measurement and tracking mechanisms that are used in a standardised way (Dewick et al., 2020).

In addition, for blended finance instruments in which private and public sector funding is combined, transparency has emerged as a key requirement (Dewick et al., 2020) in order to evaluate the flow of funds and the value created.

Private and public sector entities therefore are required to include transparent measures to monitor and track CE spend and to develop policies which promote the sufficient financing of the CE.

2.7.2 Financing the green TEP

2.7.2.1 The role of finance in the TEP

From a TEP perspective, finance has an important role to play in determining the extent (Mazzucato & Perez, 2015) and directionality that the technological revolution follows (Mazzucato & Penna, 2016). The installation phase of the technological revolution is a period wherein financial capital is noted as shaping the economy. Financiers seek to invest in the emergent technologies as these technologies move along the technological adoption curve. The role of finance is therefore to increase innovation and "drive the revolution"(Perez, 2002). This financing ultimately culminates in a financial bubble and economic crisis, after which the TEP emerges. The role of finance in the installation phase is to drive increased competition, cost cutting and technological adoption (Perez, 2013). Finance is therefore an integral component of the green TEP.

2.7.2.2 Types of funding within the TEP

Both the private sector and public sector have roles to play in financing the TEP. From a private sector perspective, it was noted by Mazzucato & Penna (2016) that the role of the state is market fixture as well as market creation. The public sector provides patient capital (Mazzucato, 2018) which is long term, risk taking investment in innovation, in order to address grand societal challenges and missions. This type of patient capital is observed before venture capital is involved in financing innovation and before the financial sector invests in the growing revolution (Mazzucato, 2018). Patient capital is particularly necessary where transformational innovation is required to create new industries. This process lasts between 15 to 20 years and therefore venture capitalists and private investors, who require a shorter return period, are considered too short-termist to invest in such innovation (Mazzucato, 2018). Without government finance directed in a mission oriented way, the revolution may be stifled (Mazzucato, 2018). The emergent grand challenges noted presently relate to green activities and the environment (Mazzucato, 2018) which corresponds to the emerging green paradigm.

There are therefore critiques of the concept of "mission-oriented finance". The first is that it is limited to the American markets and observations are made for only the 20th century. Critics of this concept argue that it ignores the activities of small entrepreneurial firms and researchers (Mingardi, 2015). Furthermore, it is noted by such a critic that governments do not pick the winning innovation or select the most appropriate grand challenge to address. It is believed mission oriented directionality is unintended and ignores consumer preference and investor guidance (Mingardi, 2015). There is therefore scope to consider whether the state can play a significant role in shaping the green TEP through finance and policy or whether it is the efforts of individual firms which drive the innovation required. In South Africa this is pertinent given that water supply is designated to the state (Muller, 2008), whereas water innovation is an amalgamation of private entities, non-profit organisations and public sector innovation.

2.7.3 Conclusion

Neither the private sector nor the government can solely fund the CE and green TEP. A collaborative effort is required with multiple funding sources considered in order to create innovation driven impact and the green paradigm. These collaborative measures require government led initiatives which are de-risked along with private sector buy-in to create scale and adoption. Strong partnerships, innovative financing models and policy support are therefore enablers of a circular economy driven green paradigm and a lack of adequate finance may stifle its advancement.

2.8 Summary

Based on the existing knowledge it can therefore be concluded that:

A meaningful understanding of how water sector innovation in the context of the CE can contribute to an increase in industrialisation particularly for SEZ's and create a new green technological paradigm in South Africa.

2.9 Theoretical framework

This section describes the primary theories used in the research which are the Techno-Economic Paradigm theory and the Circular Economy theory. Each theory is described according to its background and purpose, core definitions and concept structures, hypotheses and assumptions, applications of the theory and the way forward. These theories have been specifically selected to address the elements of innovation led economic development and resource scarcity which are the key variables within the research problem.

2.9.1 Techno-Economic Paradigms (TEP's)

2.9.1.1 TEP overview and purpose

The techno-economic paradigm is a well-known innovation theory and is defined as "a complex learning processes, a best practice model for economics, technology and organisational practices" (Perez, 2010). These paradigms are observed after the technological installation phase within any technological revolution. The techno-economic paradigm theory combines both Kondratieff's theory of long waves with Schumpeter's theory of economic development (Perez, 2010). The paradigm is referred to as "techno-economic paradigm" rather than a "technological paradigm" in order to illustrate the interrelated nature of technology, economics and developments in organisations (Freeman, 1991) rather than just technological development. The techno-economic paradigm is not only an economic theory but a societal one as well (Perez, 2010).

The theory is intended to address the way in which common sense innovation principles are created as a result of technological revolutions (Perez, 2010) and how these principles both impact and are influenced by economic and societal changes (e.g. the current zeitgeist of environmental awareness and protection). The theory also outlines the ways in which business and technology cycles coupled with the convergence of technologies have created new paradigms over time. A further phenomenon addressed by the theory is the impact of the techno-economic paradigms which cause economic development, develop environmental sustainability and create wealth and jobs (Perez, 2016). The existing and future business and technology cycles are impacted by the prevailing techno-economic paradigm. This is because these paradigms shape the way innovation is performed, change the way in which organisations are structed and operate and create a new way of living for society. Currently, the world is in the midst of the information and telecommunications revolution (Perez, 2010; Stewart, 2021) which has seen information intensity, decentralisation , knowledge capitalisation as the emergent paradigm in this installation phase (Perez, 2010). The current ICT era is the consequence of the way in which information technologies have led to the creative destruction (Perez, 2016) of analogue and paper-based processes and knowledge and ushered in the current economic revolution. It is expected that after the 2008 recession an opportunity exists to build a green, sustainable, ICT led paradigm (Perez, 2016) moving global economies into a "green golden age" (Perez, 2016).

2.9.1.2 TEP concept definitions and structure

The concept of a TEP was first defined by Carlota Perez in her paper on microelectronics (Perez, 1985) and can be summarised as "The vehicle of that wide-ranging change of direction in innovation is the technoeconomic paradigm, which is a best practice model gradually emerging from practical experience in applying the new technologies" (Perez, 2010). The paradigm represents the fusion of technological trajectories and technological systems theories (Perez, 1985). The theory illustrates how the impact of radical innovations along with the clustering and diffusion of these and incremental innovations, which include services, products and industries, along an observable trajectory explains market growth, technological revolutions and subsequently new techno-economic paradigms. The TEP is created during a technological revolution which follows the long wave cycle. Each revolution is characterised by an initial dynamic period of installation and development of new technologies followed by a more stable deployment phase which is created after an economic turning point such as a recession (Perez, 2010). It is during the transition from installation to the deployment phase that the TEP becomes predominant. Technological revolutions are defined as the cluster of technological systems which have a far reaching industrial impact (Perez, 2010). The technological trajectories are seen as the individual technologies which form the system (Perez, 2010) and follow a specific path. Thus, the TEP and its related concepts have been adequately defined to aid operationalisation.

The theory is cognisant that the paradigm cannot be created without constant feedback loops first through the development and diffusion of the radical and subsequent incremental innovations and secondly in the creation of the best practices, lower cost structures and entrepreneurial opportunities. The paradigms cannot be created without involvement by policy makers who make the choices for the directionality of the paradigm (Perez, 2016) and funders who finance the technological revolution (Perez, 2002). It is therefore a multi-level, multi-stakeholder process.

2.9.1.3 Theoretical propositions and assumptions within the techno-economic paradigm theory

The inherent proposition in the theory is that the impact of a technological revolution is the creation of a new, observable TEP. A more recent proposition related to the TEP states that the “ICT revolution has the capacity to facilitate wide-ranging sustainable innovations to radically reduce materials and energy consumption while stimulating the economy” (Perez, 2016). Further to this proposition is the requirement that the TEP has to occur simultaneously in the three areas (Perez, 2010) of practice (i.e. cost, spaces for innovation and organisational practices). The concept of a techno-economic paradigm is therefore explained by changes in these three explanatory variables (Perez, 2010): first, is through lowered cost structures meaning production inputs are cheaper, and decrease the cost of labour and capital; secondly, through increased entrepreneurial opportunities and the identification of new profitable innovation spaces which are created as technologies are developed and diffused; and thirdly through changes in organisations' principles and criteria where optimisation of business methods and organisation structures occur.

Other variables such as the impact of financing, society, the environment and policy are covariates which are related to the paradigm and drive its adoption. The variable of policy includes the promulgation and adoption of new best practices and common knowledge (Perez, 2010) created by the paradigm. The variable of society shows how a change in behaviour drives the creation of the innovations and also derives the benefit of the innovation (Perez, 2010). The variable of financiers highlights their role in investing in new profitable technologies (but may actually create a financial bubble (Perez, 2002)) The variable of the environment dictates the resources available to create the innovation and the types of innovation required. The impact of the natural environment on technology is therefore critical, with sectors such as energy driving the development of new technologies which inform a different paradigm (Freeman, 1991) . The techno-economic paradigm is dependent on how innovations interconnect and are used to create an increase in existing industrial productivity. The dependent variable is therefore the increase in efficiency for industry and activities as a result of new ways of thinking about and creating technologies (Perez, 2010). In addition, the techno-economic paradigm is practically observed in the rate of diffusion and use of new technologies and the multiplier impact of these technologies within the economy as well as the extent to which socio-institutional structures change in response to these technologies and best practices (Perez, 2010).

2.9.1.4 Application of the theory

The theory begun with the Schumpeterian notion of business cycles and Kondratieff cycles (Freeman, 2015) which has evolved into the understanding of how these cycles cluster together to form technological revolutions. The technologies which drive revolutions when adopted at a wide scale, create a new paradigm (Freeman, 1991) as evidenced by low technological costs, increased opportunities for entrepreneurship and organisational change(Perez, 2010). The notion of the TEP is different from the traditional evolutionary economics view (which focuses on the firm) because the TEP focuses on the systems (Freeman, 1991). Since the introduction of the TEP it has been modified and adapted across a wide spectrum such as country implications (e.g. how do later comer firms create techno-economic paradigms and the implications of these paradigms for small countries), and resources (e.g. energy sector technoeconomic paradigms, ICT techno-economic paradigms and green technologies) (Drechsler et al., 2009).

The theory can be applied when performing a backward-looking view of technological revolutions and their subsequent economic paradigms for the first to fifth industrial revolutions. The theory can also be applied to shape the current TEP and predict the next TEP which is ICT, green technologies sustainability (Perez, 2016).

2.9.1.5 Forward-looking view

Currently, the most pertinent application is in shaping this new TEP and it allows global leaders to address the legacy challenge of environmental degradation resulting from the previous era (Perez, 2016) the changing societal sentiment towards being environmentally aware and focused (Perez, 2016) is also being used to create this new TEP. The business strategies that can be learned from the theory relate to business model and business policy changes to adapt to new best practices. Financing strategies can also be created to capitalise on the current technological revolution while seeking to identify the next one but in a financially responsible context. Economic strategies to prevent severe depressions or recessions can be adapted to include TEP considerations primarily on the three observable characteristics. Although adoption of TEP principles is slow from a public institution perspective (Perez, 2016) policy makers and governments can use the current TEP best practices and ways of thinking to address socio-economic concerns by create jobs, alleviate poverty and reducing inequality (Perez, 2016). Finally, the circular economy has been noted as a mechanism of creating wealth, investment and economic growth in the deployment phase of the current technological revolution (Perez, 2013).

2.9.2 Circular economy

2.9.2.1 CE overview and purpose

The circular economy is a widely known concept aimed at decoupling environmental stress from economic performance (Ghisellini et al., 2016). The concept has evolved over time from an environmental model, to one which seeks to address the limitations of the current neo-classical economic view focused on efficient resource allocation, given the reduced availability of resources and resource atrophy (Ghisellini et al., 2016). The theory focuses on moving from an environmentally detrimental, linear economic model of producing and consuming (Ghisellini et al., 2016) where natural resources are depleted during the production process, to a closed loop model which minimises the use of new resources, maximises the use of waste and minimises the adverse environmental impact of production (Ghisellini et al., 2016). Various frameworks have been created to support the CE theory with the "3R's" principles (a subset of the "XR's" principles) of "reduce", "reuse" and "recycle," being the most common interpretation of the theory. The theory has advanced over time to include various sector and system applications and is now considered a mechanism to operationalise the SDG's (Kirchherr et al., 2017).

2.9.2.2 CE concept definitions and structure

There is no universal definition of the circular economy (CE) and this has led to the current concept being considered as lacking in transparency (Kirchherr et al., 2017). Critics of the concept highlight its broadness (Ghisellini et al., 2016) and degree to which the definition is open to interpretation by different groups (Kirchherr et al., 2017). There are also differing schools which see the CE framework as an economic model whereas some consider it an environmental one (Kirchherr et al., 2017). A seminal definition which is commonly used is that by the Ellen MacArthur Foundation which states that "the concept is characterised, more than defined, as an economy that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles" (Kirchherr et al., 2017). The concept is explicitly stated and understood as encompassing the various mechanisms for maintaining resources (e.g. water and plastics) within a closed system of production for the maximum possible period. The CE framework applies to the entire production value chain (Ghisellini et al., 2016; Kirchherr et al., 2017) with specific applications for resourcing, manufacturing and waste disposal. There are also implications for consumption by the end user (e.g. recycling). The size, nature and extent of circular economy is dependent on the application of the "XR's". The execution of these principles determine the extent to which environmental pressure has been decoupled from economic development (Ghisellini et al., 2016).

The independent variables within the framework are those which are related to the "XR's" principles (the "XR's" refers to the "R" elements included in the framework such as reduce, reuse etc.). An improvement in these "XR's are expected to have a causal impact on the circular economy, and this is observed as the extent to which an economy has migrated from a linear one to a circular one. It is the “R” variables which are operationalised to drive a circular economy forward. The operationalisation of “XR’s” variables are clear with the definition of “recycle” being succinct and with the activities considered as recycling being observable. Within the literature, each variable in the framework is described in detail with descriptions provided for the application of the variable in specific sectors, countries, industries and individuals. For example: the **reduce** variable means lowering the wastage and adverse environmental impacts of resources in production (Ghisellini et al., 2016), the **reuse** variable, is where products and non-waste materials are reused within a production cycle (Ghisellini et al., 2016), and the **recycle** variable refers to the reprocessing of products and materials that can be used for the original purpose or alternate processes. (Ghisellini et al., 2016). The definition and operationalisation of variables is therefore explicit and distinct.

The impact of each “R” principle on the advancement of a CE is considered in isolation and other “XR” principles are not considered pre-requisites for each other (e.g. there is no need to reuse prior to reduce). However, principles do have an impact on one another, for example, some resources can be recycled up to a point and thereafter alternate mechanisms such as reduce would be required (Ghisellini et al., 2016). There is also a degree of circular economy progression associated with each variable with refuse being considered to be adopted by a more circular economic model than the variable related to recovery of energy through combustion. All these varying considerations are factored into the causal analysis within the CE. The framework is therefore built on multiple feedback loops and levels within process. The CE frameworks have been illustrated graphically through various CE framework closed loop models, images and diagrams (Ghisellini et al., 2016; Kirchherr et al., 2017; Smol et al., 2020). “XR” variables within the framework move along the trajectory from linearity to circularity (Kirchherr et al., 2017) starting with recover (of energy releasing materials) and ending with refuse (which is the complete rejection of a unsustainable resource within a process). The causal impact of the micro, meso and macro systems on the CE are also discussed individually (Ghisellini et al., 2016; Kirchherr et al., 2017) with the interplay between them is still being developed (Kirchherr et al., 2017).

Although each variable within the framework is considered critical, the notable application of the framework is in waste reduction (Ghisellini et al., 2016). From a literary perspective the recycle variable is most commonly covered and understood as noted by Ghisellini (2016) and Kirchherr et al (2017). However it has been document that reduce and reuse would have a more significant impact (compared to recycling) with regards to advancing the CE (Ghisellini et al., 2016).

2.9.2.3 Theoretical propositions and assumptions within the circular economy framework

The CE frameworks and theory address the proposition that an increase in "XR" activities which underpin the circular economy will lead to a decoupling of environmental stress from economic performance (Ghisellini et al., 2016). Another proposition inherent in the CE theory is that the movement from a linear economy to a circular one will have a positive impact on the country's environment, society and economy (Kirchherr et al., 2017).

The theory is explicit in the assumption that a closed loop (rather than linear) production and consumption pattern within an economy will increase resources efficiency, create continuous growth and build a harmonious balance between the economy, society and environment (Ghisellini et al., 2016). An inherent assumption within the CE framework is that current linear economic models area birthed from the neoclassical view of efficient resource allocation into the market cannot be sustained due to resource depletion (Ghisellini et al., 2016) and therefore a new economic model is required. The premise within the framework is that it can be implemented at a macro, meso, micro and global level (Ghisellini et al., 2016). There are therefore many applications of the framework.

The actors within the CE include individuals and firms (at a micro level), Eco-Industrial Parks or EIPs (at the meso level) and governments (at the macro level) (Ghisellini et al., 2016). The assumptions made about these actors are that they willing to adopt the concepts contained within the CE principles. The assumption about firms is that they are enforcing agents within the framework and have the ability (business models and innovative technologies) and co-ordination capabilities to create mechanisms required to create a circular economy. It is assumed that EIPs are able to create the synergies and systems required (such as waste reduction) for the CE (Ghisellini et al., 2016) and the final assumption is that the role of government can vary from driving the CE policy from a top down regulatory perspective to allowing firms at the individual level to co-ordinate (Ghisellini et al., 2016) while providing certain enablers. Although the CE is meant to be applicable to consumers, with adoption of CE principles at the customer level being critical, (Smol et al., 2020), the assumptions about the role of the customer and the capability of the customer in enabling a CE are underdeveloped (Kirchherr et al., 2017).

The initial concepts that underpinned the circular economy were developed by Pearce and Turner in 1989 (Ghisellini et al., 2016), their focus was on environmental goods. This has evolved over time to include policies and economic instruments. Elements of industrial ecology were then added to the initial concepts. The first iteration of the CE framework only included "3Rs" (reduce, reuse, recycle), but more variables such as rethink (Smol et al., 2020) were added to the CE framework depending on the degree to which the existing economy has migrated from linearity to circularity (Kirchherr et al., 2017) and based on gaps identified. The framework has now evolved to include up to 9R's (recover, recycle, repurpose, remanufacture, refurbish, repair, reuse, reduce, rethink and refuse). Although the 8th variable, "rethink" is meant to challenge the ways in which circular economy principles are considered (Smol et al., 2020), an important variable of "policy" is omitted from the framework. The CE requires regulations which are created at a national level and which are bespoke to that country and the specific industries therein (Ghisellini et al., 2016) rather than the fragment efforts of individual players. Furthermore, CE principles and theories are yet to include a robust measurement criterion with some adopters having clearly defined metrics for measurement and some have little or loose measurement criteria. This has been flagged as a gap and barrier to the CE (Smol et al., 2020).

2.9.2.4 Application of the theory

The CE theory is an international concept with wide adoption across the world including the OECD, Japan, China (Winans et al., 2017). Developing countries are still in their initial stages of creating a CE (Ghisellini et al., 2016). Case studies on the empirical support of the CE framework have been conducted across the globe with China being the furthest along the circularity trajectory (Darla et al., 2018; Ghisellini et al., 2016). The CE concepts have been adopted in policy documents, the development of eco-industrial parks, the use and allocation of various production resources (coal, water, plastic, metal and paper etc.) as well as in driving innovation (e.g. biotechnologies) and in new business model development (Winans et al., 2017). A lack of widespread adoption can be attributed to several barriers primary of which is the technology (Darla et al., 2018) which is required to accommodate the "XR's", furthermore policy limitations and a lack of societal adoption required for the advancement of the CE have slowed the process (Darla et al., 2018). This links to the observation that the CE framework is driven by different participants depending on the country context. In some countries, it is driven by the state and in others by NGO's or at the firm level.

The CE framework challenges the existing neo-classical economic model which is focused on the efficient allocation of resources in an economy (Ghisellini et al., 2016). The economic shift is therefore significant (Kirchherr et al., 2017). Furthermore, the transition to a CE represents a major change in professional practice and will affect small and medium enterprises who do not have the resources to execute (Darla et al., 2018). Moving from a linear model to a circular model requires upstream and downstream engagement with suppliers and customers as well as inputs from government and organisations within the production process. Policy changes, taxation and regulation will also result in significant shifts from current business practices to circular one. Because of these many changes, the CE is considered as a long term economic goal (Kirchherr et al., 2017) and this long term perspective should be incorporated into CE planning and development. A systemic shift is required to enable the CE (Ghisellini et al., 2016) this shift explains the major changes observed in practice with new technologies being adopted to build a CE as well as new business practices being developed (Winans et al., 2017).

From a business perspective, the CE theory includes the two primary implications for business; the need for innovation and the need for new business models (Kirchherr et al., 2017). However, literature on the enabling business models is limited (Kirchherr et al., 2017). Other elements which will affect business strategies include consideration of the regulatory implications of non-compliance with mandatory policies, the potential cost savings and cost incurrences associated with the implementation of the "XR's" (Smol et al., 2020). The CE concept itself is being used strategically by governments and businesses as a mechanism for addressing the global SDG goals (Kirchherr et al., 2017).

Another empirical application of the CE framework is the use of CE enabling innovation to drive a new techno-economic paradigm as highlighted by (Perez, 2010). The expected outcomes of a CE are the efficient use of resources, a subsequent boost in the economy, an improvement in environmental conditions and an enhanced quality of life for society. These outcomes are comparable to the description of the deployment phase of the techno-economic paradigm where all spheres of society adopt the new technologies, policies are changed and costs are driven downwards (Perez, 2010), thus creating an improvement in the quality of life. If innovation (which includes technology) and new business models are considered key enablers of the CE (Ghisellini et al., 2016) and it can therefore be argued that there is a prominent position for technology to participate in driving the CE. Large scale technical change resulting from these new and complementary technologies within the CE will drive a market, behavioural and environmental change and therefore create a new techno-economic paradigm.

The circular economy theory is relevant for the purposes of this study as it seeks to maximise scarce resources such as water in the support of industrial and domestic activities in order to be economically sustainable. The principles of the 5R's outlined in the theory can be used to create a framework for understanding the CE in South Africa's water sector. Applications of the theory have also created a link to innovation and new business models which is the focus of this study.

2.9.2.5 Forward-looking view

The circular economy is a theory which is widespread and with multi-level applications. The impact of a circular economy is beneficial for businesses, individuals, governments and the environment. From a forward looking perspective the CE should be considered in the long term strategy of the business (Kirchherr et al., 2017) and the current "XR's" frameworks may be adapted to various resource sectors over time with bespoke policies being created to enhance the applicability (Smol et al., 2020). The barriers to adoption should be addressed with further policy enhancement coupled with measurement criteria. At present the extent to which the CE enhances social equity remains a gap in the overall body of knowledge (Kirchherr et al., 2017) and addressing this gap may assist in gathering the social buy-in required.

2.9.3 Conclusion

The TEP and Circular Economy theories are significant as singular theories, and fundamental when combined to develop an understanding of how industrialisation in South Africa can benefit from water sector innovation particularly innovation related to the reduce, reuse and recycle principles. The creation of innovation in order to support a green TEP can be used to create economic development.

2.10 Conceptual framework

The literature has shown that the techno-economic paradigm theory, the circular economy framework and the categories of innovation are all geared towards economic development. Water innovation is at the centre of these three elements because water contributes to the green economy, is a focus area of the CE and includes opportunities for primary, secondary and tertiary innovation. The overlap of different categories of innovation capabilities with respect to water innovation, which address scarcity challenges and are circular in nature and their contribution to green economic development have been consolidated into a conceptual framework below. It is important to note that the theories selected within the conceptual framework are mutually exclusive from each other and are not water specific. However it is the intersection of these economic development theories and tools, using water as the central focus, that will be the primary aim of the research.

2.11 Statement of propositions

An inductive proposition has been developed based on the literature review which shows that the circular economy model is one that addresses both environmental and economic challenges (Ekins et al., 2019) and can be used to address water scarcity challenges (Smol et al., 2020) in industry but has not been extensively executed in South Africa (Richards, 2020). In addition the CE is considered an enabler of the green TEP (Mazzucato & Perez, 2015). The first proposition is that circular economy innovation within the water sector for South Africa's SEZs has a positive impact on environmental social and economic development in South Africa. Furthermore the prevailing global ICT revolution is expected to result in a green TEP (Freeman, 1992) however this TEP has not yet emerged globally (Mathews, 2013) nor in South Africa (Stewart, 2021). It is innovation that drives the TEP (Perez, 2010). The second proposition is that water innovation in SEZs is currently sufficient to drive the green techno-economic paradigm in South Africa.

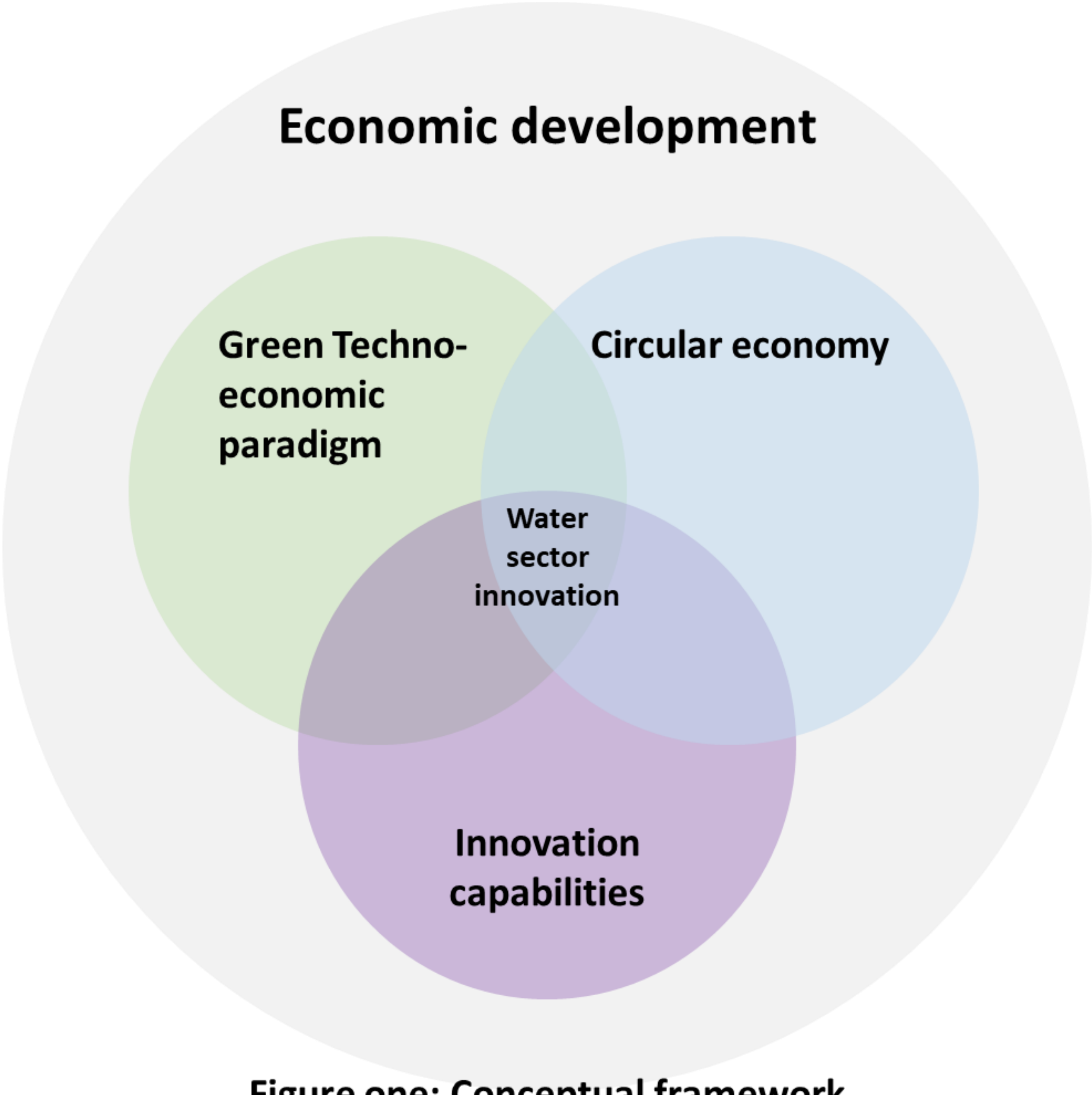


Figure one: Conceptual framework

Chapter 3: Research strategy and methodology

3.1 Introduction

This chapter outlines the research paradigm and design in order to contextualise the approach for the study. The methodologies related to participant selection and sampling in addition to the collection of data and analysis are defined, and the limitations and ethical implications and considerations related to the research are defined.

3.1.1 Research paradigm

The paradigm being used is a pragmatist view which is focused on real world, practical problem solving (Kaushik & Walsh, 2019). The paradigm is focused on action (Kaushik & Walsh, 2019) and is aligned to the notion in this paper that the concepts used by the circular economy require action for them to be effective and efficient. This research was purposed to develop an understanding of the current water challenges in industry and the practical innovation that can be applied to address these challenges and drive future practices of circularity and the green techno-economic paradigm. The research question required an emphasis on implementable innovation solutions. This research report also adopts the axiology that research should be value driven. This paradigm could be addressed by the various research methods (Kaushik & Walsh, 2019) and the qualitative method was used in research because the CE and TEP require a nuanced and contextual understanding. This understanding was developed through inquiry of interviewees views in order to add meaning to these concepts particularly in the South African SEZ water context.

3.2 Research strategy and design

3.2.1 Research design

The research design was a qualitative, multiple case study which included an in-depth inquiry into water sector innovation within special economic zones. This was performed through expert interviews and a document analysis of national reports and white papers detailing water innovation projects and case studies in South Africa. This method was appropriate to build an understanding of the TEP and CE theories and using an intersection of both to develop a conceptual framework, which provided the basis for the investigation. Case study research enables the researcher to either explore a theory or framework or describe the theory in practical contexts (Ferreira et al., 2020). This is a multiple case study, with a general focus on multiple SEZs and a focus on circular economy water innovation alone, and not other components of the circular economy. The use of multiple sites and document analysis allowed for improved triangulation of data and addresses the validity challenges associated with case studies (Ferreira et al., 2020). The use of multiple expert interviews created a greater degree of reliability (Bewley, 2002). The nature of the study was exploratory because it sought to understand the innovation available in the context of the theories. There is therefore a high appropriateness of this research design in answering the questions related to the nature, extent of impact, opportunities and barriers for water sector innovation as well as the questions related to the practical interpretations of the CE framework and the TEP state in South Africa.

3.2.2 Unit of analysis

The unit of analysis is the special economic zone. These zones are considered to be at the meso level of analysis, which is neither at the macro, national level, nor at the firm or organisational level. The SEZ is therefore selected at the intermediate level of analysis, out of many other possible units (e.g. regional, sectoral, etc.). This study excluded individual persons and firms and focuses on the cluster of firms within demarcated areas. The choice of the unit of analysis was influenced by the South African economic recovery plan which seeks to use SEZs to drive localisation and industrialisation in the short term (South African Government, 2020).

3.2.3 Feasibility of the study

The study was feasible in the context of the COVID-19 pandemic due to the use of telephonic and teams interviews which carry little to no cost and the use of secondary data research which was cost effective to collect. The qualitative nature of the research did not require software or an experimentation which carry additional costs. Information available at present was used to address the research question and therefore were no timeframe challenges. The study did not require the use of data limited to a single source which would have been costly and time consuming to collect rather multiple data sources were used to identify innovation.

3.3 Selection of participants

3.3.1 Research population

The research population included SEZ representatives, industry experts and on water innovation with applicability for SEZs.

3.3.1.1 Rationale for case study selection

For the given unit of analysis the SEZ, the ten SEZs in South Africa form the population (DTI, 2021). SEZ representatives with a focus on water and innovation formed part of the population of experts for interview. These experts provided a view on the state of the water innovation within the SEZ as well as the gaps, challenges and opportunities therein. SEZs were selected based on their focus on water and agriculture as noted in their description by the DTI. The SEZs selected include, COEGA, East London, Saldana, Atlantis, Dube Tradeport, Gauteng and the Vaal. The Vaal was specifically chosen, given its new designation, in order to understand how SEZs incorporate water innovation and circularity into their planning.

3.3.1.2 Industrial water innovation studies data and experts

Various long term studies on water sector innovation have been performed at a national level by research bodies, including the Water Research Commission, which is considered to be a primary water research organisation within South Africa (WWF-SA, 2016). These innovation studies add to the document analysis. Studies related to industry and industrial innovation were included in the population for the document analysis based on either their relevance to this study or at the recommendation of the water experts

3.3.2 Sampling

Purposeful sampling was used in the research. This sampling approach is considered a mechanism to identify and select “information rich cases” for the purposes of research (Palinkas et al., 2013). This sampling method requires the identification of individuals or groups who are knowledgeable or experienced with the topic under research (Palinkas et al., 2013). This method of sampling was therefore applicable for the research topic which required input from individuals who are experts in the water sector and who understand innovation and the circular economy. The sample of data used, and the sample of experts interviewed within the SEZs were selected to represent the state of water innovation.

The sample included:

- Industrial water innovation data
- Water experts who work with SEZs both directly and indirectly
- Research experts on innovation in water

A total of seven out of the ten SEZs in South Africa were included in the sample, with between one and two persons per SEZ being interviewed. A detailed profile of interviewees is performed in Chapter Four.

3.4 Research Methodology

Qualitative research methodologies are used as part of an interpretive philosophy where research seeks to understand the socially constructed meanings related to a specific topic (Aspers & Corte, 2019). The research approach selected was a qualitative one given that the purpose of the study was to improve the understanding of the water sector technologies by creating distinct categories for the innovation based on the circular economy principles. Furthermore the study was focused on interpretation and sometimes subjective view of the experts (Aspers & Corte, 2019) which lends itself to a qualitative approach. The data studied was not specifically categorial or nominal (Aspers & Corte, 2019) and did not require significant quantification or statistical analysis of data or a scientific approach (Aspers & Corte, 2019). Furthermore, the nature of the study included expert interviews and opinions which lent itself to a qualitative, interpretive analysis and was supported by the pragmatist philosophy (Kaushik & Walsh, 2019).

3.4.1 Data collection and instrument

Interviews and a water innovation document analysis were used as the primary and secondary data sources in this research.

3.4.1.1 Interviews

The manner that the interviews were held in was semi-structured and this along with the open ended nature of the questions (Bewley, 2002) improved the understanding of the CE and TEP theories. Interviews were conducted telephonically or via Teams.

All interviews were conducted by the researcher based on two main research questions and their sub-questions:

- **Question one:** What are the characteristics of water innovation within the circular economy that have a positive impact on economic development?
    - Sub questions 1: What are the areas in which circular principles can be adopted in the water sector?
    - Sub questions 2: What is the innovation within these areas?
    - Sub question 3: How does this innovation impact the environmental and socio-economic conditions?
- **Question two:** Does water innovation drive the green techno-economic paradigm in South Africa? If so to what extent?
    - Sub questions 1: To what extent has this innovation shown cost reductions?
    - Sub questions 2: To what extent has this innovation increased entrepreneurship activities?
    - Sub questions 3: To what extent has this innovation led to organisational change?

3.4.1.2 Archival data review

Water innovation studies performed in South African industries were analysed for comparison purposes in order to categorise innovation against the circular economy framework. Technologies were analysed to determine the extent to which the innovation has reduced costs, created increase entrepreneurship activities and facilitated organisational changes in order to determine the phase and extent of the green TEP in South Africa.

3.5 Data analysis

3.5.1 Thematic data analysis

The data analysis was performed using a thematic analysis. The purpose was to identifying themes and patterns (Braun & Clarke, 2006) within the water sector innovation that are related to the CE and which drive the adoption of the green TEP. The thematic analysis was used to interpret the different aspects of the research topic (Braun & Clarke, 2006) such as circularity of innovation and the stage of the TEP as it relates to the installation versus deployment phases. The analysis method supports the pragmatic paradigm as it seeks to find themes which inform actions based on prevalence and consistency. Finally, thematic analyses also lend themselves to qualitative studies because of the ease of access and flexibility of the data analysis approach (Braun & Clarke, 2006).

The thematic analysis process adopted as according to Braun & Clarke (2006) included six steps:

1. Gain familiarity with the data
2. Create codes for notable features within the data (e.g. Mentions "reduce" or "foreign supplier")
3. Search for recurring themes by gathering sufficient data related to each theme
4. Review the themes to check for overlap and applicability
5. Define and name the themes (e.g. Linked to reuse, reduce, recycle, other):
6. Producing a summary report which analyses the themes in the context of the study

Data gathered relating to water innovation related to the SEZ was analysed to determine whether they included circular principles and are ICT enabled. The data was then categorised according to the CE framework of "reduce, reuse, recover, restore and recycle". Finally, ICT enabled types of water innovation were assessed for the extent to which they reduce costs, create entrepreneurship opportunities and facilitate organisational change (pervasiveness). This assessment informed the determination of the nature and extent of water related CE innovation related to the SEZ as well as whether this innovation enables the green paradigm. The final conclusion is on the impact of these kinds of water sector innovation on economic development and the green TEP.

3.6 Limitations of the study

- The use of purposeful sampling is noted as being limited in the criteria of generalisability (Suri, 2011). However it is well suited for selecting cases which are information rich and provides a depth of knowledge to a research topic. It is also recommended by some scholars that an in depth understanding within a purposeful sample can be more beneficial to a study than an superficial understanding of a broad sample (Suri, 2011).
- The purposeful sampling of experts for interview may not take into consideration the views of those not regarded as an expert but with a valuable input into the process (e.g. policy makers at the regional level).

- The cost of implementation of the innovation uncovered in the findings is not discussed and therefore, the applicability of the recommendations is limited.

3.7 Ethical considerations

The research performed is in accordance with the university's "research integrity policy"

- Conflict of interest: no conflict of interest exists in this research and this was included in the formal declaration.
- Respect: the research was conducted in a manner that adhered to ethical standards including the respect for diversity in the interactions with participants
- Free and informed consent: participants in the project were provided with consent forms and were informed that they are not required to participate in the study.
- Vulnerable persons or groups: no vulnerable persons were included in this study
- Respect for privacy and confidentiality: non-disclosure agreements with participants in the study were signed to protect their privacy
- High quality peer review: the research performed in the study was subject to supervisor review as well as evaluation
- Public communication: no public communications related to this study were made
- Beneficence and non-maleficence: there are no risk of beneficence and non-maleficence as human the research did not affect human beings or animals
- Respect for justice and inclusiveness: there were no observed harms to society for this research.
- Reporting irresponsible research practices: no instances of misconduct were observed.
- Responding to irresponsible research practices: No instances of irresponsible research practices were noted.
- Scientific integrity: detailed records were kept of data gathered and interviews held were preserved to maintain integrity
- Authorship and public acknowledgement: a detailed list of references is included at the end of the research document.

- Academic bullying: No instances of academic bullying were noted

3.8 Reliability and validity

The use of multiple sites improves the validity of the research (Ferreira et al., 2020) Furthermore by performing a thematic analysis on the case studies and interviews, validity is increased via triangulation. The research instruments were reviewed multiple times for intelligibility prior to data collection with minor adjustments made to the follow-up questions during the interviews themselves. This enhanced the repeatability of the study.

The following mechanisms were used to enhance the reliability of the study:

- Transferability was addressed by illustrating how the findings in the study can be used in other contexts such as the application for excluded SEZs and wider industrialisation.
- Credibility was addressed through the triangulation of data and suggestions as well as the inclusion of "negative case studies" which show an adverse impact of the innovation on the TEP and CE.
- Dependability was addressed through supervisory review as external audits are not feasible.
- Confirmability was addressed through the questions asked which are intended to create a balanced response from any interviewee in order to prevent bias

3.9 Summary

In summary, the research methodology was centred around the pragmatist research philosophy which seeks practical solutions to water related challenges in industrialisation. This philosophy is supported by the existing theories of the TEP and CE are built on and developed based against real world applications. This approach is better suited to small sample sizes (Kaushik & Walsh, 2019). Semi-structed expert interviews and archival data analysis were used to gather data for interpretation. The overall research process sought to identify water sector innovation which addresses demand and supply challenges in South Africa through document analysis of water innovation and expert interviews of officials in the selected SEZ's as well experts in industrial water technologies. CE innovation was identified based on the nature of either being product, process and service focused or being value creation and business model focused and was categories according to the reduce, reuse, restore, recover and recycle framework. In addition, a determination of the impact of SEZ circular water innovation activities from an environmental and socio-economic perspective was made. Finally, an assessment of ICT innovation against the TEP criteria of cost reduction, entrepreneurship opportunities and organisational changes was performed in order to determine the whether the circular, ICT enabled water sector innovation to enable the green TEP in South Africa. A final conclusion will subsequently be made about the implications of water sector innovation in driving South Africa’s economic development. This research process has been highlighted in Figure 2.

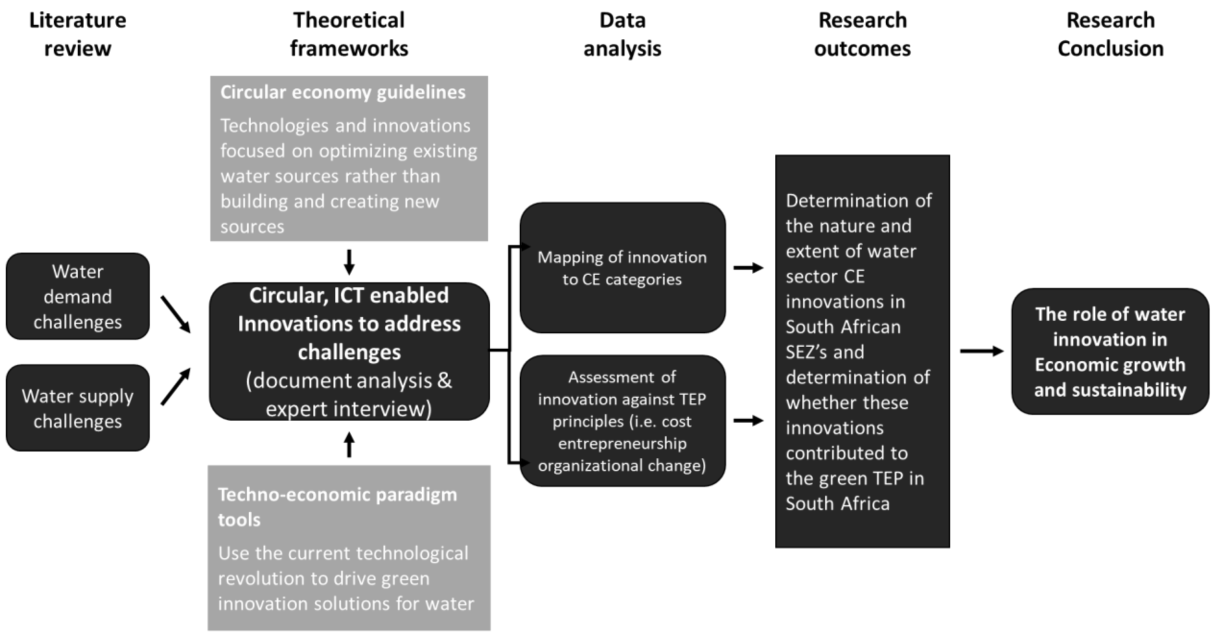


Figure two: Research process

Chapter 4: Presentation of findings

4.1 Overview

Overall findings are highlighted in this chapter based on the qualitative data gathered as per the semi-structured interviews and document review, as outlined in the research methodology in Chapter Three. Interviews were conducted with representatives from South Africa's Special Economic Zones as well as water sector experts from various bodies. Details around the interviewee profiles as well as data findings are presented in the following sections.

4.1.2 Introduction

SEZs in South Africa are managed through the Department of Trade, Industry and Competition, and derive their overall mandate from the Special Economic Zones Act of 2014. Each SEZ may have a specific focus area embedded in their mandate (e.g. the focus on Greentech at Atlantis is different from the focus on agro-processing at Dube Tradeport). Each SEZ employs individuals who are responsible for attracting new investors, managing the operations of the park and providing administrative and infrastructure support, among other roles. These employees work across the sectors and industries and have varying degrees of engagement with water-related challenges, projects and technologies.

Within the South African water sector there are various agencies responsible for the different functions along the water value chain. These include waterboards that are responsible for water services in a designated area, water research bodies that perform research as well as the organisations responsible for the environment and infrastructure. In addition, there are private and public sector organisations that co-ordinate and execute water projects in the SEZs.

4.1.3 Interview protocol including interviewee background and document review process

4.1.3.1 Interview protocol

A total of 27 interviews were conducted. Of these, nine individuals were interviewed who collectively represented seven of the 10 individual SEZs* in South Africa 8 interviews were conducted with experts in the water sector who have worked directly with South African SEZs

*Including one newly designated SEZ

on water-related activities or indirectly through municipalities and waterboards. The interviews were held via MS Teams and individuals were selected based on their familiarity with water technology, innovation and circular economy principles adopted within the SEZ, which had been determined in the pre-screening process prior to the interviews.

Interviewees were provided a consent form which confirmed their willingness for the interview to be recorded, their preferences for remaining anonymous, as well as the allowance to use their anonymised quotations in this research report. All interviews were recorded with permission, except two where organisational guidelines prohibited the recordings of such engagements.

Table 4.1 Interviewee profile:

	Representation	**Assigned Reference**	**Degree of involvement with SEZ**	**Familiarity with water innovation**	**Familiarity with CE principles**
1	SEZ one	SEZ1	Direct	Yes	Yes
2	SEZ two	SEZ2.1	Direct	Yes	Yes
3	SEZ two	SEZ2.2	Direct	Yes	Yes
4	SEZ three	SEZ3	Direct	Yes	Yes
5	SEZ four	SEZ4	Direct	Yes	Yes
6	SEZ five	SEZ5	Direct	Yes	Yes
7	SEZ six	SEZ6.1	Direct	Yes	Yes
8	SEZ six	SEZ6.2	Direct	Yes	Yes
9	SEZ seven	SEZ7	Direct	Yes	Yes
10	Water research expert one	WRE1	Direct	Yes	Yes
11	Water research expert two	WRE2	Indirect through municipalities	Yes	Yes
12	Water research expert three	WRE3	Indirect through various water programmes	Yes	Yes
13	Water implementation agent one	WII1	Direct	Yes	Yes
14	Water implementation agent two	WII2	Direct	Yes	Yes
15	Water implementation agent three	WII3	Indirect through various water programmes	Yes	Yes
16	Waterboard official one	WBO1	Indirect through municipality	Yes	Yes
17	Waterboard official two	WBO2	Indirect through municipality	Yes	Yes
18	Private sector water expert one	PSW1	Direct	Yes	Yes
19	Private sector representative two	PSW2	Direct	Yes	Yes
20	Private sector representative three	PSW3	Indirect through various water programmes	Yes	Yes

21	Private sector representative four	PSW4	Direct	Yes	Yes
22	Public sector representative one	GOV1	Indirect through various water programmes	Yes	Yes
23	Public sector representative two	GOV2	Direct	Yes	Yes
24	Public sector representative three	GOV3	Direct	Yes	Yes
25	Ex- Water specialist SOE	WS1	Indirect through implementation initiatives	Yes	Yes
26	Ex- Water specialist SOE	WS1	Direct	Yes	Yes
27	Circular economy expert	CE1	Direct	Yes	Yes

4.1.3.2 Document analysis

In addition to interviews, a document analysis was performed. Various thought pieces, reports, guidelines and journal articles have been written about the circular economy for water and water innovation in South Africa and internationally. Based on their relevance to the research the following documents were reviewed for the purposes of additional data gathering and triangulation:

- Water in Circular Economy and Resilience (WICER) (Delgado et al., 2021) – a new publication by the World Bank dated September 2021.
- Water Market Intelligence Report 2021 (Mpofu & Botha, 2021) – a report by GreenCape a market intelligence report on water created in collaboration with businesses, investors, government, and academia.
- Water Innovations Report 2019/2020 (WRC, 2020) – a report by the Water Research Commission (WRC) which showcases the range of innovation available to address water challenges.
- South African Water innovation story (Amis & Lugogo, 2018) – a report by the African Centre for a Green Economy to the WRC covering the South African National System of Innovation, water innovation case studies and the emerging trends in the water innovation ecosystem.
- Circular economy introduction (EMF, 2018) – an introduction to CE principles by the Ellen McArthur Foundation.

- Guidelines for the evaluation and selection of advanced water metering systems (Zyl et al., 2018) – a report on water metering technologies by the Water Research Commission

4.2. Presentation of findings

Responses to each of the sub-questions embedded in the three research questions are highlighted below. Responses were summarised firstly through an illustrative chart which shows the thematic analysis and secondly through a write up of the of the main takeaways, areas of agreement and areas of contention. Finally a triangulation of data was performed through the document analysis where findings of this study were compared to the documents in order to determine whether they were was either found to be congruent with this study, in contrast to this study, or in addition to the study.

The thematic analysis process followed was to match each response from the interviewee to codes created based on the conceptual framework. Each code corresponds to a sub-question under each of the two research questions. The coding is attached at the annexure to this document. The collected units of data were then analysed to identify themes. Information is considered a theme when it recurs either multiple times within an interview and/or is observed as recurring across multiple transcripts (Huddersfield, 2022).

The interpretation of these findings and implications for this study are discussed in subsequent chapters

4.2.1 Research question one: What are the characteristics of water innovation within the circular economy that have a positive impact on economic development?

Questions asked to interviewees in this section of the interview related to their understanding of the CE, the opportunities for SEZs to adopt CE principles, CE innovation within the SEZs and the environmental and socio-economic impact of innovation.

4.2.1.1 Sub question 1: What are the areas where circular principles can be adopted in the water sector?

4.2.1.1.1 The primary understanding of the circular economy

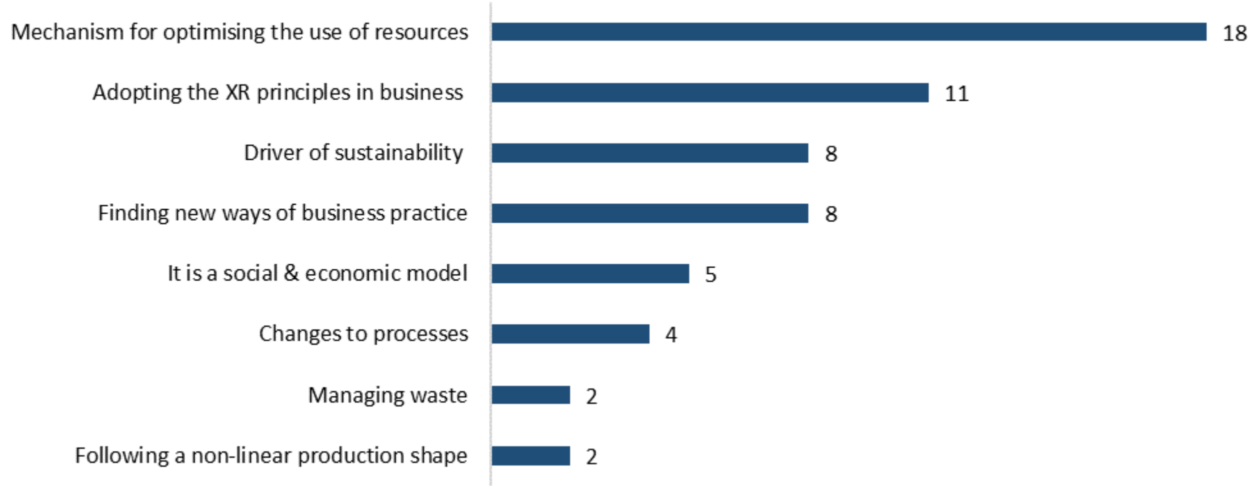


Figure 4.2.1.1.1 Interviewee interpretation of the circular economy

The primary interpretation of the circular economy is that it is a mechanism for optimising the use of (scarce resources), and secondly, it was noted as being a tool for adopting the principles of reduce, reuse, recover and the other XR's.

- *WS1 - "It's about minimising resources in a system"*
- *SEZ5 - "The circular economy is about moving from cradle to grave to cradle again"*
- *WRE1 - "Circularity is about reuse, recycle and how to be smarter about the use of by-products and how to make secondary resources from waste."*

In seven instances respondents consider circular economy principles a driver of sustainability with five respondents considering the CE a socio-economic model and a mechanism for optimising business practices in new ways practices. This understanding includes resources other than natural resources within circularity principles and includes human capital and collaborative business practices.

- *PSW1 - "It is how we prevent the take, make waste models of the past"*
- *SEZ2.2 - "It is a way of optimising underutilised resources which including human resources or logistics"*
- *WRE1 - "The circular economy is a way to create opportunities for socio-economic development"*

The definitions of the circular economy echo the themes used by the seminal Ellen McArthur Foundation's report viewed in the document analysis. This common definition which includes designing pollution and waste out of a system, maintaining the use of materials and restoration of natural systems. SEZ representatives and water experts are therefore aligned from an international understanding of the circular economy (EMF, 2018).

4.2.1.1.2 The opportunities presented with the adoption of circular economy principles

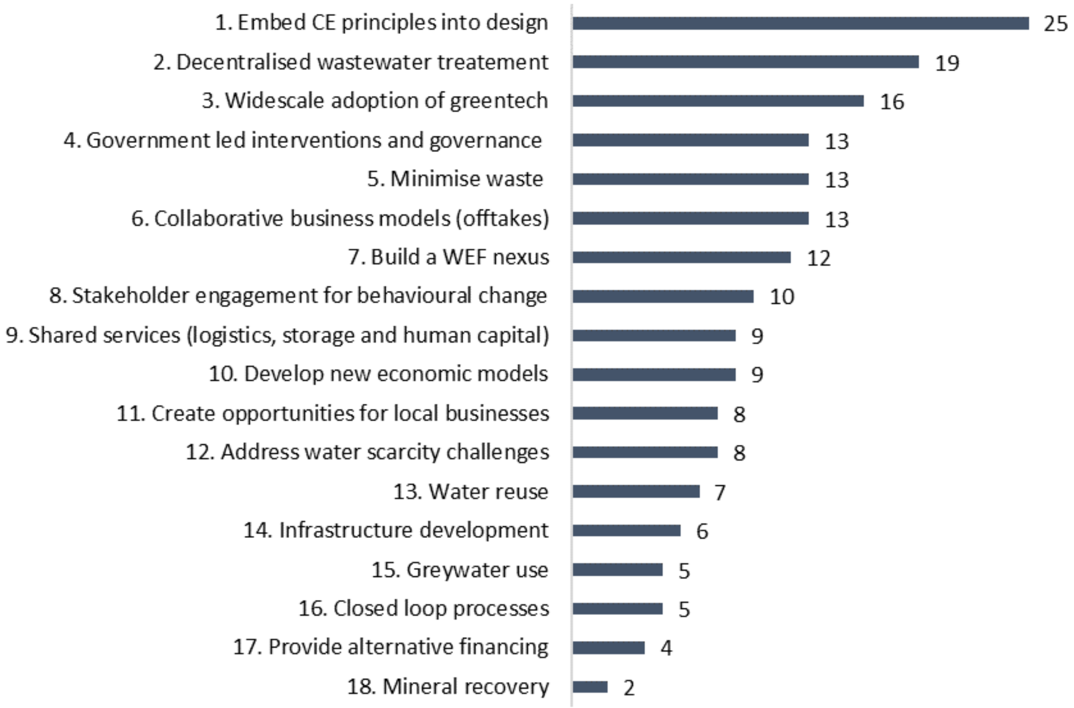


Figure 4.2.1.1.2 Opportunities for the circular economy

As part of developing the understanding of the impact of the CE, the opportunities for the adoption of CE principles were considered. A total of 18 opportunity themes were identified. The primary opportunity to adopt circularity within the SEZ context is firstly to embed circular principles into the design of the SEZ (opportunity 1). This was noted as including planning for circular activities within the SEZ through the use and sharing of resources in a collaborative manner.

- *GOV3 – "To effectively incorporate the circular economy, you need to use design thinking"*
- *GOV1 – "The design of the SEZ should be inspired by nature which is circular on its own"*
- *WRE1 – "You need to find the anchor business within the SEZ and what are the complements within the value chain and design for that"*

The second most notable opportunity is to perform decentralised (i.e. not done at the municipality) wastewater treatment (opportunity 2) for the tenants of the SEZ at the SEZ premises. This water can then be reused in industrial and agro-processing activities, with minerals and nutrients recovered from chemical and organic sludge used in alternate industries such as those that develop biogas and fertilisers. The adoption of green technologies (opportunity 3) such as hydroponic irrigation systems and microturbines was noted as the third type of opportunity the CE presents and implies the CE can be used as a mechanism for technological take-up. Of note was the recurring theme that the adoption of CE principles is an opportunity for the government to lead through policy direction and through government-led initiatives and governance (opportunity 4). This links to the policy question below, which shows that policies are insufficient to stimulate innovation.

- *PSW4 – "The adoption of the circular economy can be improved through legislation"*
- *SEZ2.1 - "There is definitely a role for better governance and legislation"*
- *SEZ3 – "The private sector and parastatals are required to advance this agenda and they need to work together to advance the circular economy"*

The opportunity related to the minimisation of waste (opportunity 5) is related to the challenges of non-revenue water in South Africa and infrastructure leakage as well as the focus on circular economic activity related to waste at a government level.

- *WBO1 – "Non-revenue water can be reduced"*
- *PSW2 - "Water stewardship is required"*

The emergence of the Water, Energy & Food (WEF) nexus as an opportunity for circularity (opportunity 6) is particularly interesting. The WEF nexus refers to the ways in which water, food and energy are interconnected (Mpandeli, 2017). Respondents noted several opportunities to build this WEF nexus predominantly through using energy generated during the pumping of water (i.e. hydropower).

- *GOV2 – "We can build the WEF nexus"*
- *WBO2 – "The water, energy nexus can create jobs"*

"Designing out waste and pollution" were noted as opportunities for water circularity in the World Bank report (Delgado et al., 2021). There is therefore congruence on this opportunity and its application for the SEZs.

4.2.1.2 Sub question 2: What is the innovation within these areas?

In conjunction with the opportunities identified, the observable innovation activity within the SEZ was considered. Opportunities unaddressed by innovation would imply a gap in the

CE. Innovation activities were separated into those related to products, processes and services and those related to novel mechanisms of creating value through business models, policies and behavioural change. A total of 145 innovation activities across products, processes and services were noted along with 57 innovation activities related to new business models, policies and behavioural change. These activities were synthesised into unique and independent high level themes with a total of 28 themes noted in products, processes and service innovation, and five themes noted in business models, policies and behavioural change innovation.

4.2.1.2.1 Innovation in products, processes and services (PPS)

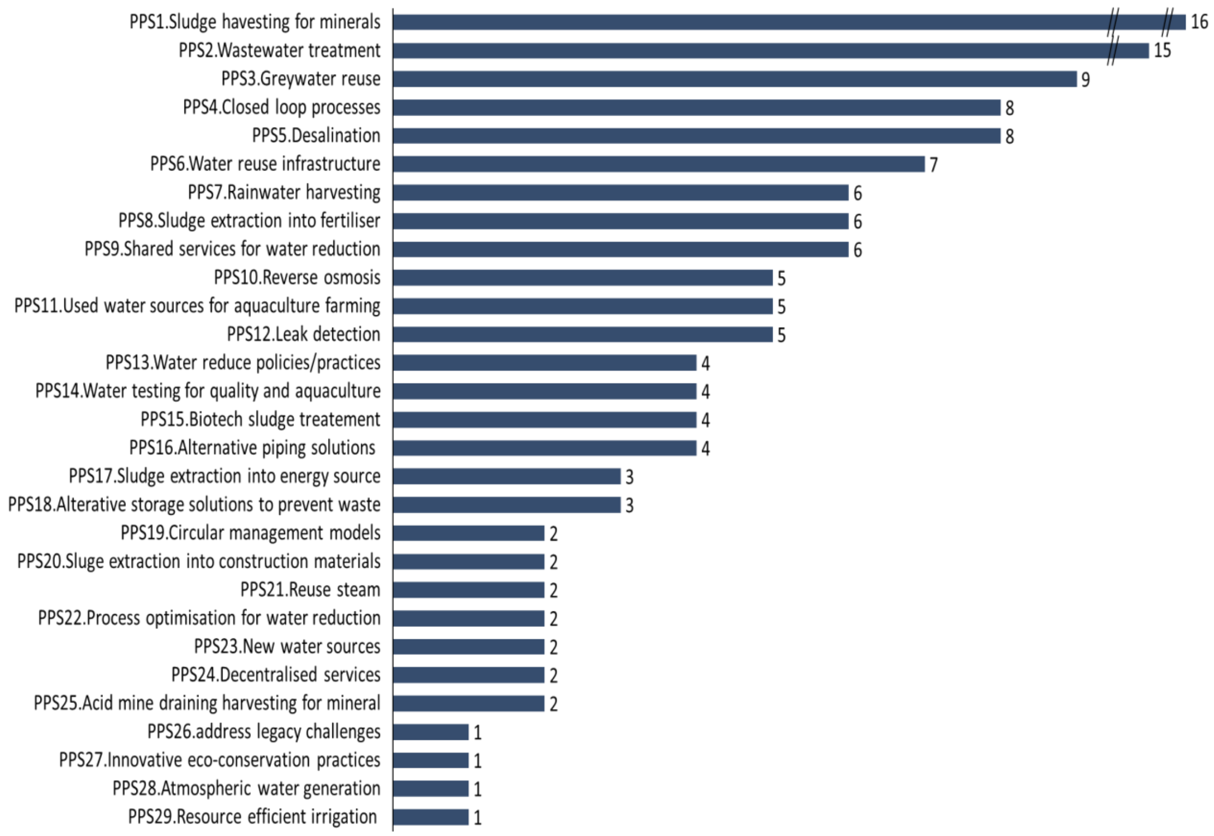


Figure 4.2.1.2.1 Innovation in products, processes and services

A total of 29 areas of innovation were identified in the data. In congruence with the opportunities for circularity noted in question 2, innovation in sludge harvesting *(PPS 1)* and wastewater treatment processes *(PPS 2)* have emerged as the top two innovation activities within the SEZ. Sludge, which is a by-product of treated wastewater can be chemical or biological in nature (Zuloaga et al., 2012). This sludge when processed can be produced into a fertiliser and biogas and the nutrient chemicals extracted from sludge (e.g. vanadium, methane, phosphorus, gypsum, struvite etc.) and then used as resource inputs into alternative industries.

- *WRE2 - "It (treated sludge) can be used as a substitute for coal"*
- *GOV 3 - "Anaerobic digestion (of sludge) is used to produce methane"*
- *WBO1 - "(SEZ name) is transforming wastewater into fertiliser"*

From a wastewater treatment perspective, water may be treated independently from sludge harvesting and as such, the innovation activities were themed separately in the data. Wastewater innovation includes onsite (non-municipal) wastewater management services and mobile water treatment facilities as well as wastewater filtration and ponding systems. The third most notable innovation process within the CE for SEZs is the repurposing of (largely untreated) greywater primarily in irrigation and in certain agro-processing wash cycles *(PPS 3)*. Closed loop processes *(*PPS 4) relates to the retaining and treatment of water within a circular system and according to the "Sustainable development in industry through closed loops report" (Rulkens, 2005) requires specific infrastructure and treatment mechanisms. Novel types of water infrastructure (e.g. low cost pumps) and their supporting ICT enabled monitoring technologies *(PPS 6)* as well as desalination *(PPS 5)* in coastal regions for new water sources were the remaining primary opportunities.

4.2.1.2.2 Innovation for value creation (VC) - business models, policies and behaviour

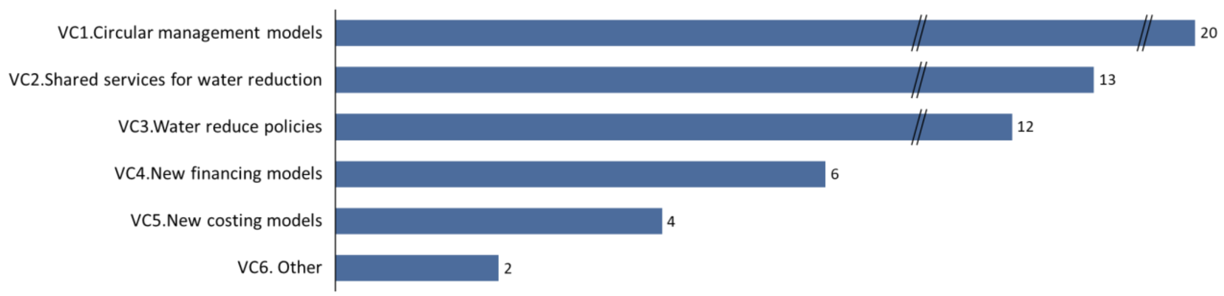


Figure 4.2.1.2.2 Innovation for value creation (business models, policies and behaviour)

Circular management models *(VC1)* are the primary form of business model innovation noted within the SEZ context. These models incorporate ecological principles into resource planning and design business processes for circularity. Designing for circularity is where individual companies and the SEZs overall, plan their processes and firm interactions with the upfront intention of being circular. This aims to reduce the quantity of input resources, to maximise the use of resources within the production cycle and to limit waste. This proactive design is created with the purpose of preventing long term inefficiencies in resource usage. Circular management models also include business process reengineering to improve existing processes for water efficiency.

- *SEZ6.1 – "Early stage (SEZ) design includes planning for water scarcity"*
- *WII1 – "Water master planning includes circularity"*
- *WS1 – "We see it in BPR (business process re-engineering)"*

Shared services models *(VC2)* are another type of business model innovation employed by firms within the SEZ to incorporate circularity. These shared service models see firms sharing cold storage for products, sharing logistics and administrative functions and sharing knowledge on what offtakes are being produced by the firm. A single notable business model innovation noted is where firms within the SEZ were described as looking for new ways to adopt international technologies in the local context. This alludes to secondary innovation where international technologies are imported and duplicated, re-created, explored and exploited for the local context. In addition, tertiary innovation wherein novel business services, ICT and marketing are used to created widescale adoption of technology may be present in these business models.

From a business policy perspective, corporate policies are also being innovated to incorporate the principles of sustainability and are seeking to drive behavioural changes for a culture aimed at water stewardship *(VC3)*

- *PSW2 - "there are now capacity building initiatives on water stewardship and seeking knowledge on how to be innovative in water stewardship "*

Training programmes focused on sustainability, the inclusion of international best practices into policies and the enforcement of ESG requirements have seen firms create sustainability policies which are different from their predecessors.

- *SEZ6.2 – "We have policies which restrict water usage (in the zone)"*
- *SEZ3 – "Large firms are driving these behavioural changes"*
- *GOV3 – "firms are adopting green principles"*

Innovation in costing models *(VC5)* has also been observed with firms choosing lifecycle costing in relation to water and costing for sustainability over time. Lifecycle costing is traditionally used when calculating the cost of physical assets over the lifetime of their use but has become a mechanism to measure environmental impacts and sustainability (Muthu, 2018).

- *GOV1 - We use ecological models*
- *SEZ5 – "We have to use lifecycle costing to determine the cost of not being circular"*
- *WRE1 – "Big firms are able to add a cost to their margin in order to price for sustainability"*

South African reports reviewed on the circular economy do not mention the types of innovation specifically. The Water Research Commission's report was the only one identified that considered digitally enabled wastewater treatment processes which produce water and biochar as the primary innovation in the circular economy for water (Zvimba & Musvoto, 2018). In addition, the World Bank prioritises: 1- the use of energy efficient resources within the water circular economy, 2- the optimising of operations and 3- the recovery of resources in that order (Delgado et al., 2021). Optimising operations is covered in the circular business model innovation and the recovery of resources is addressed in wastewater treatment innovation. Addressing energy challenges (priority 1 of the World Bank) is addressed partly in solar and wave powered desalination processes but did not emerge as a significant area of priority when considering the circular economy for water in the SEZ context.

4.2.1.3 Sub question 3: How does this innovation impact the environmental and socio-economic conditions?

In order to determine whether the circular economy for water is observed to have a socio-economic impact, the overall impact of the CE was questioned from both an environmental and socio-economic perspective.

4.2.1.3.1 Environmental impact

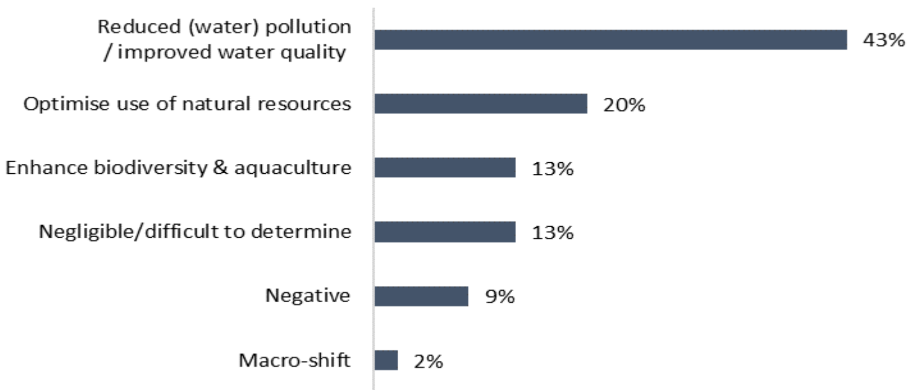


Figure 4.2.1.3.1 Environmental impact of circular economy innovation

The primary impact of the adoption of CE principles within the SEZ context is the reduction in pollution. The adoption of CE principles, primarily the treatment of wastewater has been noted by interviewees as having a positive impact on water quality. The second most notable environmental impact is the reduced used of potable and freshwater resources within industry through the adoption of reuse and reduce mechanisms.

4.2.1.3.2 Socio-economic impact

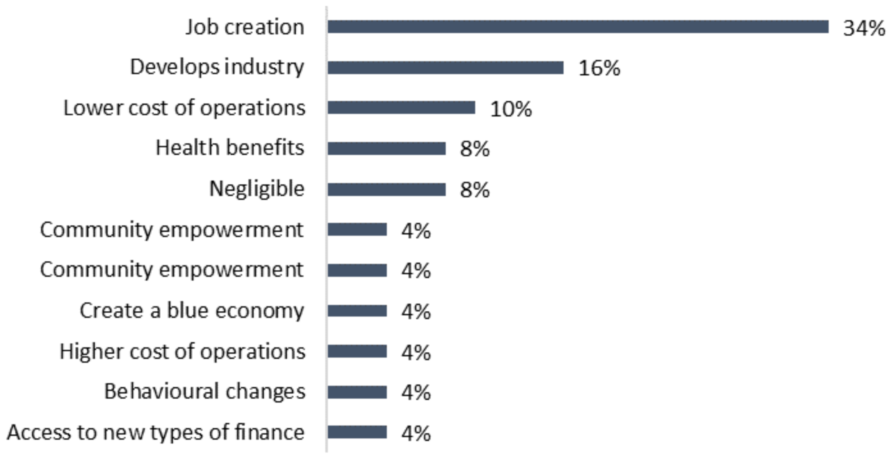


Figure 4.2.1.3.2 Socio-economic impact of circular economy innovation

From a social and economic impact perspective, job creation is the primary outcome of the adoption of circular principles within the SEZ. New ways of treating water and shared service models as well as collaborative offtake sharing models are creating new jobs within the SEZs. In addition, the use of minerals, fertiliser and biogas enable the growth of existing businesses, which benefit from either a reduced input cost or lower logistics costs. However, it was noted that the exact socio-economic impact is difficult to measure as it is combined with the environmental impact of having clean water and the effect of clean water on human health.

- *SEZ5 –We were importing all the inputs from America and just by using offtakes from our dairy producer we are able to produce cheese locally. This saves on logistics costs, and it is local"*
- *WRE3 – "Circular systems create jobs"*
- *WBO1 – "Water is a catalyst for economic growth and development"*
- *WRE2 – "We still need to measure the exact societal and economic returns"*
- *GOV3 - There is a financial cost to treat water downstream as well as a negative health impact (when circularity is not adopted)*

The environmental and economic impacts are similarly highlighted by the World Bank, which states that adopting circular economy principles creates sustainability in resources, reduces wastage and water pollution and that an investment in circular systems results in economic payoffs (Delgado et al., 2021).

4.2.2 Research question two: Does water innovation drive the green techno-economic paradigm in South Africa? If so to what extent?

Respondents were asked to highlight the most notable new and novel ICT enabled water technologies (watertech) adopted within the SEZ. These technologies were interrogated to understand the nature of the technology, the extent to which the cost of the technology has been observed as decreasing, the level of entrepreneurship opportunities related to the technologies and the pervasiveness or wide scale adoption of technologies. These criteria inform the green techno-economic paradigm. In addition, the policy structures related to water innovation were understood as well as the nature of relationships for knowledge sharing which both impact the adoption and pervasiveness of technology. A total of 75 individual responses were received which were then themed into ICT technology types.

4.2.2.1 Water technologies adopted within the SEZ

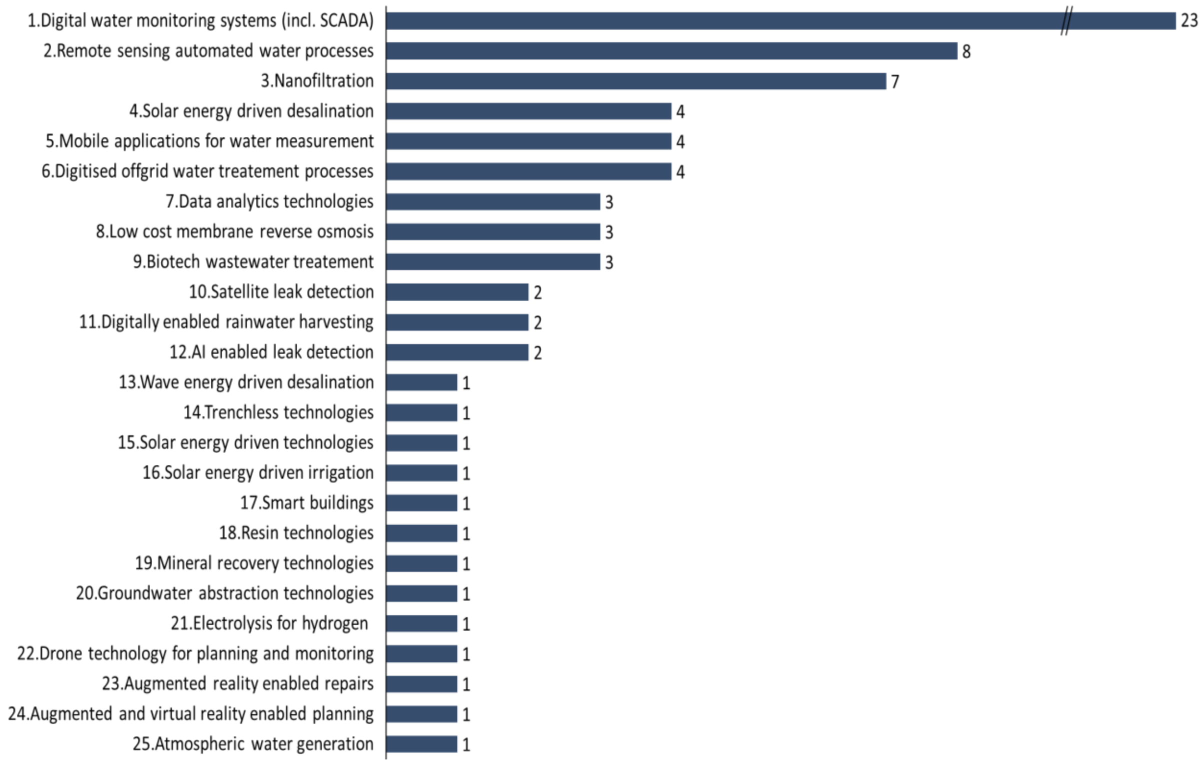


Figure 4.2.2.1 ICT innovation in water

The most prevalent ICT technology relates to the use of advanced water meters. Water metering as noted in the document analysis is a South African requirement for every point where water is supplied (Zyl et al., 2018) and advanced water meters enable companies to detect leaks, to identify peak periods of water usage, meters allow water pumps to be switched off automatically when not in use (Zyl et al., 2018). These meters allow the firms that install the technology to collect vast quantities of data which can be analysed an used in business planning and to predict when leaks may happen and for infrastructure maintenance (Zyl et al., 2018). Robotic and remote sensors have a similar function to advanced water meters and additionally are used to regulate processes as part of automation and digitisation of manual processes. Remote systems are also used in desalination processes to pump sea water into the factory at a controlled rate.

- *SEZ5- "Our remote systems pump seawater into the system automatically based on sensors."*
- *SEZ4 – "We use smart logistics, smart meters and smart monitoring"*
- *WBO1 – "They (the SEZ firm) use robotic process automation"*
- *SEZ2.1 – "We have installed remote sensors in the effluent discharge process"*
- *SEZ5 - "Our water sensors are installed for a quick reaction to water changes in the system"*

Nanofiltration was the third most predominant technology which uses nanotechnology to purify water and maintain water quality.

In the document analysis which included the "Water innovations report 2019/2020" and the "The South African water innovation story" as well as the "Water Market Intelligence Report 2021" 60 novel water innovations were noted. These were then compared to the water innovation used at the SEZ. A total of 29 of the innovations were noted as being adopted in some form by the SEZs (i.e. either the innovation itself or a technology with a similar functions), 25 related to agricultural solutions or domestic sanitation and are excluded from this research and 6 had applicability for the SEZ (i.e. have industrial or agro-processing implications) but are not currently adopted.

Table 4.2: The adoption of ICT innovation per document analysis within the SEZ.

	Innovation	**Adoption in SEZ**
1	Benchmark performance indicators used in long term water distribution	Yes- in some form
2	Practical estimation of water uses in orchards on farm	Yes- in some form

3	Hydrological models which include social systems and ecological systems	Yes- in some form
4	Microwave based method to quantify toxic elements in water	Yes- in some form
5	Mechanisms for setting and intervening in water temperatures	Yes- in some form
6	Bule economy scenario models	Yes- in some form
7	Water recovery from gas	Yes- in some form
8	Decision making tools for water source management	Yes- in some form
9	Analytical tool for measuring water footprints	Yes- in some form
10	Forecast tool for rainfall and temperature	Yes- in some form
11	Salt measurement tool used on agricultural soil	Yes- in some form
12	Agro-forestry which combines alternative crops in cattle feed	Yes- in some form
13	Intelligent geysers	Yes- in some form
14	Biotelemetry system to measure aquaculture	Yes- in some form
15	Costing manual to predict water costs	Yes- in some form
16	Guideline to enhance service delivery on water and wastewater	Yes- in some form
17	Method for the Recovering Semi-precious and precious elements	Yes
18	Microbial fuel cell to treat sludge and produce biogas	Yes
19	Social franchising sanitation model for small businesses	Yes
20	Ponding system which includes algae	Yes
21	Leak detection	Yes
22	Bio-cement production	yes
23	Solar desalination	Yes
24	anaerobic digestion and advanced oxidation processes for wastewater treatment	Yes
25	Monitoring tool for illegal discharge	Yes
26	Wave energy reverse osmosis pump	Yes
27	Eutectic freeze crystallisation	Yes
28	Alternative reverse osmosis	Yes
29	Small scale hydropower systems	Yes
30	Guideline and decision tree to assess wetlands	Not covered in the research
31	Guideline for wetland rehabilitation	Not covered in the research
32	Indicators for supply capability of wetlands	Not covered in the research
33	Flood estimation application	Not covered in the research
34	Small scale rural water schemes	Not covered in the research
35	environmental sustainability guideline for pit lakes in mine closures	Not covered in the research
36	Visualisation of excreta flows	Not covered in the research
37	Dry sanitation toilet (vaporisation)	Not covered in the research
38	Decision Support Tool for Grassland Rehabilitation	Not covered in the research
39	Rural communities’ nutritional status assessment manual	Not covered in the research
40	Alternative crops in Limpopo	Not covered in the research
41	Small scale farmer platforms for market access	Not covered in the research
42	guideline for alternative wetland use	Not covered in the research
43	Decision support tool for monitoring nitrogen and phosphorus in agriculture	Not covered in the research
44	Communication guide for uptake of irrigation technology	Not covered in the research
45	Water footprint measurement for grape crops	Not covered in the research
46	Biosurfactant Compounds	Not covered in the research

47	Rapid biological assays for the detection of antibiotic resistant genes	Not covered in the research
48	Dicerocaryum plant extracts as water treatment chemicals	Not covered in the research
49	Pour flush toilet 1	Not covered in the research
50	Pour flush toilet 1	Not covered in the research
51	Microfiltration gravity filter	Not covered in the research
52	Barrel roller for water collection	Not covered in the research
56	Aquaculture measurement tool	Not covered in the research
53	Software tool for modelling erosion and sediment	Not covered in the research
54	Hydrological modelling of water and nutrient fluxes in crops	No
55	Tool to evaluate water literacy	No
57	Role Playing Game (RPG) for training	No
58	Biological treatment for acid mine drainage	No
59	Programme to manage information about river flows and the ecosystem	No

Sub question 1: To what extent has this innovation shown cost reductions?

4.2.2.1.1 General change in cost for water technology

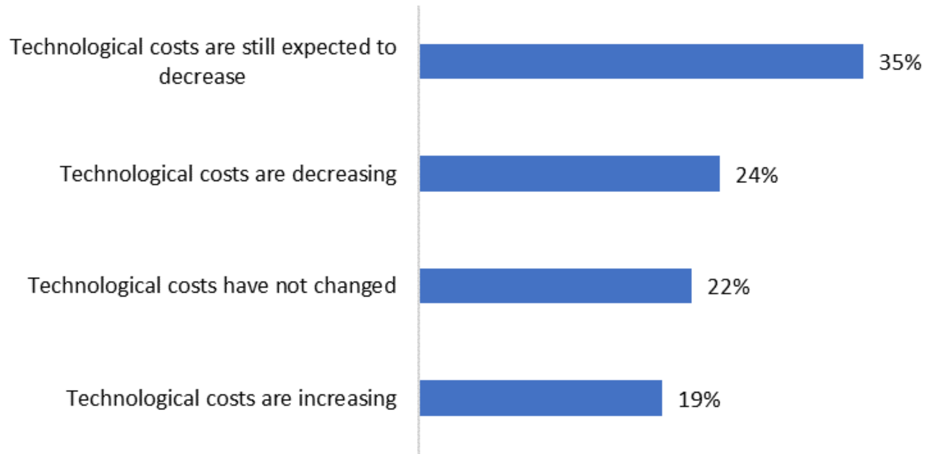


Figure 4.2.2.2.1 Technological cost trajectory

From a cost perspective, interviewees believe that the full extent of cost reductions of water technology innovation has not been experienced and that costs are expected to decrease further as technologies become more widespread. Companies have invested in watertech infrastructure with a high initial capital outlay and are expecting to see cost reductions over time.

- *WRE2 – "Bulk purchases for new technologies such as pumps may reduce costs."*
- *SEZ4 – "At this stage it is capital intensive to install the new technologies and cost benefits will be recognised in the long run once the impact is realised."*
- *WRE1 – "Big companies can invest in high tech solutions which will decrease costs over time."*

- *WS1- (the decreased cost of monitoring) "is because of telemetry costs which have come down a lot in the last decade"*

As per the document analysis on water meters, technological costs for smart meters have decreased with a number of low cost solutions being noted in the market (Zyl et al., 2018) Interviewees have also noted a decrease in cost for cost of atmospheric water generation In addition, the cost of reverse osmosis membranes and energy used in desalination are declining in South Africa.

It should be noted that low adoption of water technology has seen limited take-up of new technologies (except for water meters) and that in some instances the technological cost remains unchanged. Furthermore, interviewees noted that the high capital expenditure cost is unaffordable or not economically viable when compared with the relatively low cost of potable water.

- *GOV2 – "Water is cheap in South Africa and therefore there have not been significant decreases in water technology costs"*

4.2.2.2 Sub question 2: To what extent has this innovation increased entrepreneurship activities?

4.2.2.2.1 General change in entrepreneurship opportunities for water technology

Figure 4.2.2.3.1 Opportunities for entrepreneurship in water technologies

Overall, 20 interviewees were aligned with the notion that opportunities exist within the sector for entrepreneurship activities. However, market entry is flagged as the major barrier to entrepreneurship with challenges related towards existing technology biases, the convenience of foreign suppliers and lengthy and expensive piloting requirements being noted.

- *WRE2 – "The private sector struggles to write proposals to move innovation forward"*
- *WS1-The venture capital market and financing of technologies is very low.*
- *WS1- Financiers do not have the expertise to finance these technologies*
- *PSW4 – "potential to pilot and test is limited, and regulation prevents this piloting process"*
- *WRE1 – "Business plans are not strong to create a level of confidence. The state needs to fund risk. "*
- *PSW2 – "The market is biased towards large manufacturers"*

In addition, interviewees noted that opportunities are available, but have not been taken-up at present (i.e. remain opportunities).

- *GOV1 – "There are opportunities in rooftop farming"*
- *WRE3 – "There are opportunities available for packaged treatment plants and membrane companies"*
- *WRE3 – "We are on a new pathway for decentralisation"*

There is, however, an observable increase in entrepreneurship related to wastewater treatment.

- *SEZ4 – "There are opportunities for entrepreneurship related to water reuse and wastewater treatment in the SEZ and entrepreneurs are available to address these challenges"*

Finally, five respondents mentioned the need for an external intervention to spur entrepreneurship, which is currently not being organically created.

- *SEZ6.2 – "A level of upskilling is required for entrepreneurs"*
- *GOV3 – "We need PPP's (private, public partnerships) in the delivery of the services"*
- *PSW1 – "Incubation of firms with local technologies and for those adopting international technologies"*
- *SEZ7 – "We have to incubate SMMEs and test innovation"*
- *SEZ5 – "We can help investors not be dependent on foreign activities."*

Funding challenges for innovation and lack of access to markets have been flagged as a challenge to water innovation in South Africa in the document analysis of the "Water innovation Story" for small businesses particularly to move innovation into the commercialisation stage. This is congruent with the challenge of market entry noted as the primary barrier to entrepreneurship in this study.

4.2.2.3 Sub question 3: To what extent has this innovation lead to organisational change

Interviewees were asked about the nature of technological take-up and whether watertech is becoming central to business practices. Although not specifically questioned, many interviewees were able to provide an estimate of the period of time it may take before watertech becomes prevalent in the market and be observed as having widescale market adoption. The impact of policies, the selection processes for watertech and the knowledge sharing systems which allow watertech take-up were interrogated to understand the promoters and detractors of watertech take-up in the market.

4.2.2.3.1 General changes in adoption of water technology

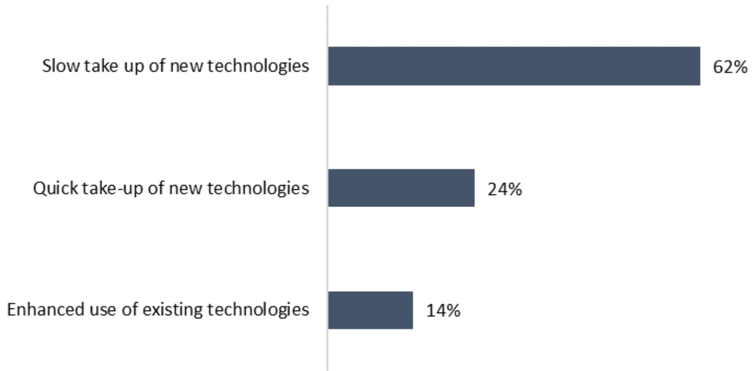


Figure 4.2.2.4.1 Take-up of new technologies

According to interviewees, the take-up of new water technologies has been slow. The reasons stated for this are the risk aversion to try new technologies related to water. This is because water is considered "high risk" and any technological failure has the potential to create large scale societal damage.

- *WBO2 – "We need to test these technologies before operation because we cannot risk failure"*
- *WRE2 – Water is high risk, there is a high risk of messing up people's water"*

Furthermore, the process and cost to pilot new technologies in order to provide a proof of concept are seen as detractors for technological take-up. Finally, in areas where the cost of water is not considered to be high, the cost of installing new technologies is not commensurate with the cost of saving water in the short term.

It should be noted, however, that in SEZs with current and historical water challenges, the take-up of watertech has been noted as swift given the dire need to create water use efficiencies. This is also true for large firms and multinational firms that are investing in water efficiency technologies at a rate faster than small firms.

- *WRE1 – "The water crisis is a driver for adoption"*

- *PSW4 – "The pandemic has sped the take-up on digital technologies"*
- *PSW1 – "The large retailers are using the technologies"*

In 4 of the interviews, respondents noted that existing technologies related to water are now being used in a more efficient way.

4.2.2.3.2 Centrality of water technology within the SEZ

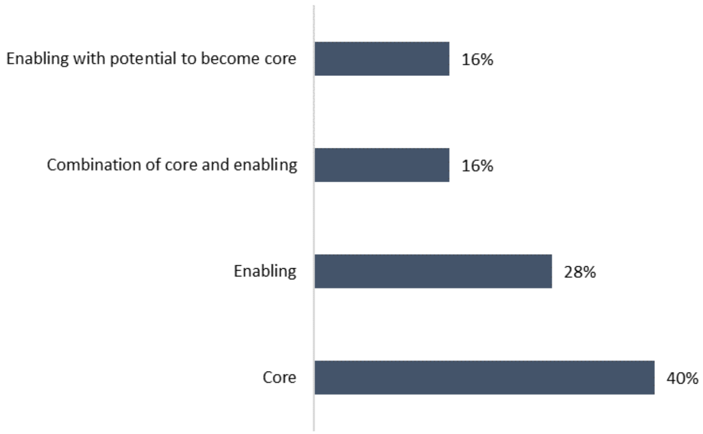


Figure 4.2.2.4.2 Centrality of water innovation to the SEZ

Although take-up of new technologies has been noted as being slow, eleven the interviewees agreed that water technologies themselves are considered to be part of the core functioning of companies within the SEZ. It was also noted that in industries which are heavily reliant on water, new water technologies are at the core of their operations, but this is less so in industries where water is not as heavily relied upon.

Some interviewees have noted that water technology has the potential to become part of the core functioning within organisations and processes as widescale adoption takes place.

4.2.2.3.3 Anticipated period for widescale watertech adoption

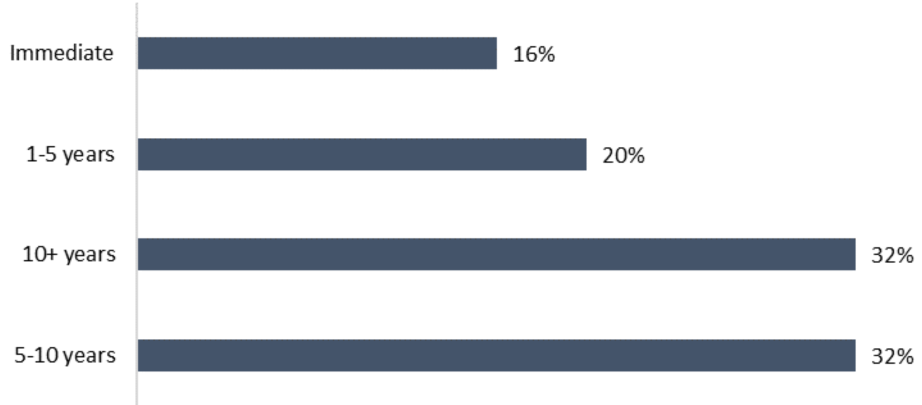


Figure 4.2.2.4.3 Anticipated time for technological take-up

According to the interviewees which included subject matter experts in the water sector, it should take between five to 10 years or even more than 10 years before water technologies which are considered new in 2022 terms have been adopted at scale and are considered prevalent or generic in the market.

4.2.2.3.4 Impact of policies on watertech

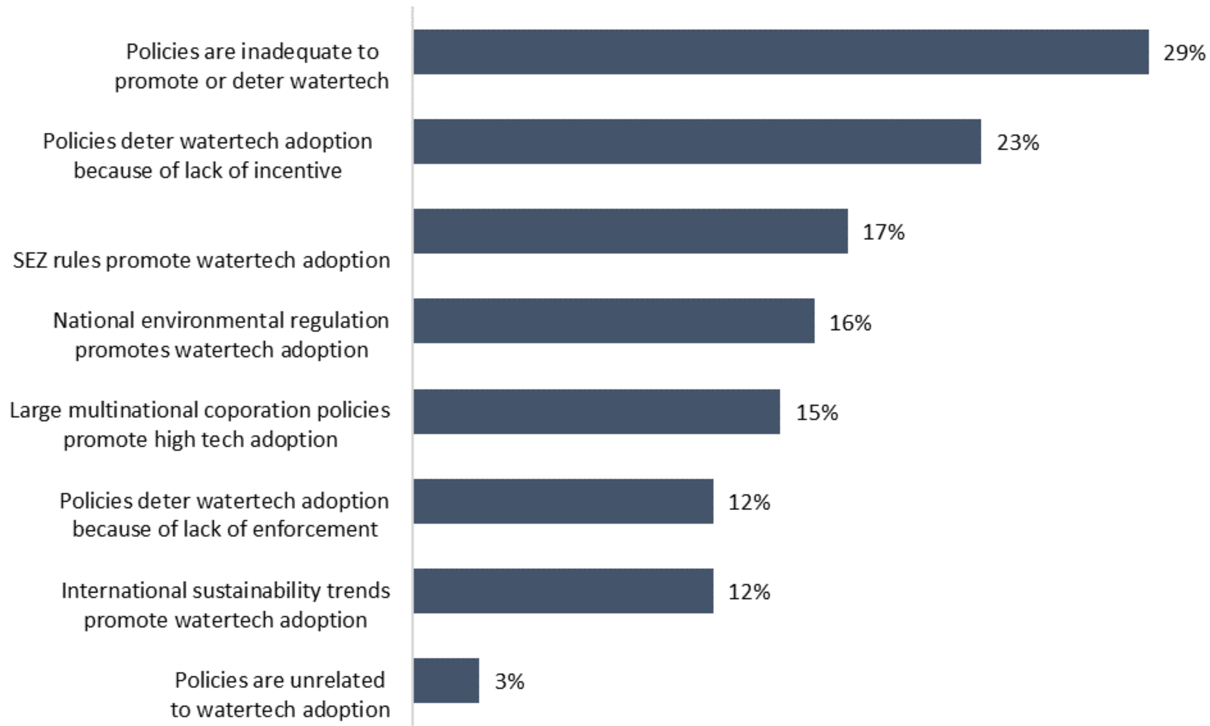


Figure 4.2.2.4.4 Impact of policies on water technology innovation

With respect to policies in South Africa and global policies, interviewees are of the view that government policies are inadequate to promote or deter the development of new technologies or the adoption of existing technologies.

- *WII1 – "Water use licences for groundwater is complex and difficult to navigate"*
- *WII1 – (circular economy policies) are more on driving regulations in organic waste and not driving on the water side"*
- *WS2 – "there is no concerted effort to create this green economy in South Africa"*
- *WS1 – "Our policies are not innovation forward"*
- *WS1 – "we have no standards and policies for some of these (new) technologies"*
- *GOV1 – "(there is) fragmentation in decision making and policy environment"*
- *WRE1 – "The policies are ambiguous, and the interpretation is different."*

In addition, policies in South Africa are considered a deterrent of innovation due to a lack of incentives to innovate in the water sector.

- *SEZ1 – "We need a carrot (incentive) like the availability of grant funding from government sources like the SEZ fund and funding for green projects creates an incentive for green innovation"*
- *SEZ2.1 – "There should be an incentive for adopting water technologies."*
- *WS2 – "Policies are in place but there is no incentive to adopt them. There is no stimulation based on the policies"*
- *WRE3 – "There are great policies to enable greening but no tax incentives for greening"*

Policies are seen to promote water technology innovation where the SEZ has created rules on water conservation and where large multinational corporations have cascaded sustainability practices into their value chain and supply chain.

From the document analysis on the "Water Innovation Story", South Africa's intellectual property policies are considered to be strong, but a lack of awareness prevents the adoption of these policies with a subsequent negative impact on innovation transfers. The implication of innovation policies and their impact on innovation in the SEZ is therefore pertinent to the adoption process.

4.2.2.3.5 Selection process for watertech within the SEZ

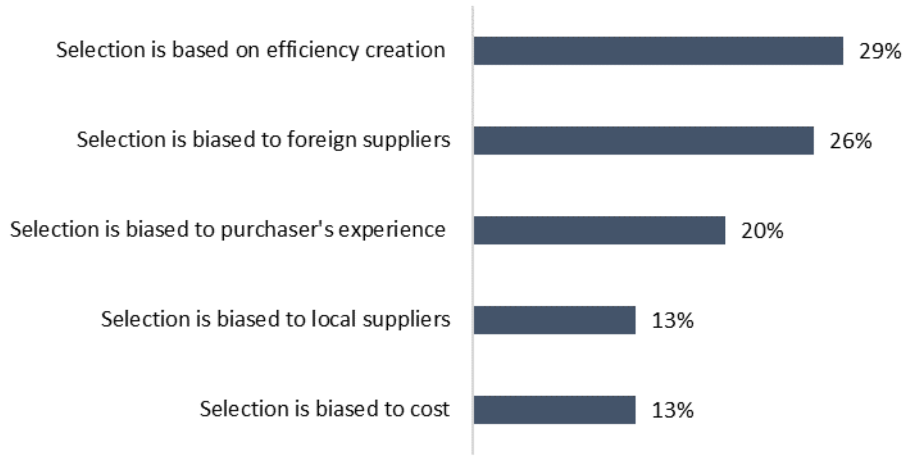


Figure 4.2.1.3.1 Technology selection and selection biases

When selecting water technologies in 9 interviews, selection was noted as being based on technologies which create efficiencies in their processes and are fit for purpose. Firms select a technology that can lower production costs, increase output and is easy to implement and maintain.

- *PSW4 – "Technologies are selected based on how they can achieve better results with a lower financial input."*
- *SEZ2.2 - "Firms are seeking to improve on efficiency"*
- *WRE1 - "Operations and maintenance influence selection"*

Factors which also influence selection include the origination of the technology. South African firms are noted as having a distrust for local technologies and preference for foreign solutions which are purchased off the shelf.

- *GOV1 – "Local knowledge is not fully utilised"*
- *WBO2 – "There is a high availability of foreign technologies"*
- *WRE2 – "They buy Chinese solutions with local implementation"*

In contrast, where there is a distinct localisation drive within the SEZ, then local technologies are selected.

Of note is the bias against new technologies based on the purchaser's knowledge with procurement officers and selection panels favouring those technologies which have been used historically, over those which are new and unfamiliar despite the potential for efficiency creation.

- *WRE1 – "Firms need to spec their (technology purchase) requirements differently to get different solutions."*
- *PSW2 – "They tend to go with what you know"*
- *PSW4 – "Purchasers of technologies stick to what they know (because of a compromised procurement policy)"*

Cost is the final driver of selection and this is most notable where firms are subject to national regulations which include the Public Finance Management Act. This has been observed as a major impediment to innovation by interviewees with a lengthy and complex procurement process which includes multiple quotations being required, and in the case of novel innovation, are not available.

From a selection process, inadequate support for innovation has been identified as a barrier to innovation from the document analysis on the "Water Innovation Story" where radical innovation is resisted by selectors of new technologies.

4.2.2.3.6 Knowledge sharing mechanisms

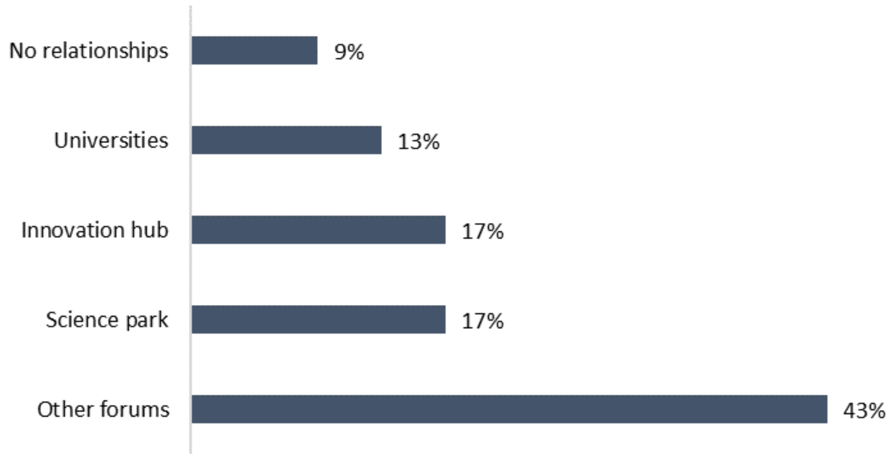


Figure 4.2.2.4.6 Relationships for knowledge sharing

Within the SEZ context, research and information is primarily gained through external forums followed by onsite science parks and innovation hubs. External forums include those programmes run by the private and public sector dedicated to identifying new technologies which address water challenges and provide a mechanism for market entry (e.g. the WADER programme run by the Department of Science and Innovation in partnership with the Water Research Commission and SASTEP programme which is focused on sanitation) in seminars for knowledge sharing (e.g. WISA seminars and reference groups) are included in the other forums used for knowledge sharing and commercialisation of technologies. Within the SEZs, innovation and science parks have emerged as the primary mechanism for knowledge generation and sharing, piloting and testing and small scale manufacturing (e.g. through 3D printing). Notably, only 3 of respondents mentioned relationships with universities. This lack of interaction between actors within the water NSI has been flagged as a challenge in water innovation in general in the document analysis of the "Water Innovation Story".

4.3 Summary of data findings

4.3.1 Circular economy innovation and the impact on economic development

The circular economy has varying meanings to water specialists and SEZ representatives. These meanings range from the management of resources either by using the XR principles or through the management of human capital and space.

Opportunities for the adoption of circular economy principles primarily relate to design and including circularity in the planning of processes, in manufacturing spaces and in how the SEZ is designed around specific value chains. Wastewater treatment is the second most predominant opportunity closely followed by the potential to adopt green technologies and for the government to lead circular activities and provide adequate governance structures.

The opportunities are addressed by innovation in sludge harvesting to collect nutrients, fertilisers and biogas, which can then be used in alternate industries. Sludge is harvested as part of wastewater treatment activities through a decentralised model (i.e. not at the municipality) performed at the SEZ. Recycled wastewater is then used within the various operations of the SEZ. Greywater is used within the SEZ primarily as irrigation and closed loop processes are being adopted for reuse.

From a value creation perspective, circular business models address the opportunity of designing for circularity. These business models include adopting ecological models into the business practices, planning with circularity in mind and new costing methods which price for, and include the cost of sustainability.

Shared services are a novel collaborative business model adopted within the SEZ that incorporate circular principles. Firms share cold storage, logistics and space with rental models being used to reduce wasted administrative resources.

The environmental impact of circular innovation is noted as being a reduction in pollution with firms no longer releasing as much polluted water into sewerage systems. The socio-economic impact, although difficult to quantify across all SEZs, is an increase in jobs. Increased industrial activity has also been observed as increasing with sludge offtakes from one industry being used as an input into another industry.

4.3.2 Water technologies and the green techno-economic paradigm

There are numerous ways in which innovation can be applied in minimising water challenges in the SEZ. Smart meters are the most prevalent technology type and are used to monitor water usage and prevent waste. Robotic sensors are similar to smart meters, but the former execute actions and make decisions based on real time data. These sensors are used for process efficiency. Nanotechnology is also used for filtration purposes.

From a cost perspective, the cost of smart meters has decreased. However, costs for water technology are still expected to decrease as companies realise the benefits of the infrastructure they have installed. In some cases, the capital expenditure cost for new watertech prevents technological adoption as firms are unable to afford the initial capital outlay. The cost reduction in these instances has therefore not been observed.

Addressing the water challenges within the South African SEZ context presents many opportunities for entrepreneurship, but market entry is prevented because of an expensive and lengthy piloting process as well as low levels of venture capital. SEZ officials and water experts agree that there are untapped market opportunities that entrepreneurs are yet to take-up (primarily in the area of green tech). Notable findings are the expressed notions that external intervention is required from the state to support entrepreneurs, and that a partnership model with foreign suppliers should be explored.

From a pervasiveness perspective, the take-up of new technologies is slow except where water scarcity has driven firms to adopt water saving technologies and where large corporations are driving technological adoption. Where the technologies have been taken up, they are considered core to the function of the firm, particularly those firms that require high levels of water (SEZ6.2 – “wet industries”). The policy environment is not seen as an enabler of technologies and innovation with policies considered ambiguous and inadequate to address technological change. Selection of technologies is based on whether they are fit for purpose, but a bias towards foreign suppliers with market ready products and services is observed, as well as the behaviour of firms sticking to the technologies they are familiar with. Knowledge sharing is primarily through forums, innovation hubs and science parks, rather than through relationships with universities through a system of innovation.

The implications of these findings in relation to the peer-reviewed literature are analysed in the following chapter.

Chapter 5 – Data analysis

5.1 Introduction

This section is an analysis of the data findings in Chapter 4. Analyses will be performed based on the research questions as developed through the conceptual framework. This analysis determines the relationship between the literature and the research findings. The overall purpose of the data analysis is therefore firstly to determine what the CE means in the context of SEZs and whether the opportunities identified in this context translate into innovation, which has an environmental and socio-economic impact. The second component is to identify the ICT water innovation within the SEZs and assess whether examples of this type of innovation are driving the green techno-economic paradigm based on the criteria of decreasing costs, entrepreneurship opportunities and pervasiveness (i.e. behavioural and organisational change). The outcome of the data analysis will be to develop a catalogue of water CE innovation within the SEZ and make a determination as to whether this innovation has a positive impact on economic development. The analysis will also make a determination as to whether ICT enabled water technologies within the SEZ are driving the adoption of a green techno-economic paradigm.

5.2 Research question one: What are the characteristics of water innovation within the circular economy that have a positive impact on economic development?

5.2.1 *The meaning of the circular economy*

From a definitional perspective, the observation by Kirchherr et al (2017) that there are different interpretations of the circular economy holds true based on the data in this study. This study found that the CE could be described through at least eight different themes.

As per the literature the definition of the CE which is most widely referred to is that used by the Ellen MacArthur foundation (Kirchherr et al., 2017). This definition first includes “designing out waste”, second, “keeping resources in a closed loop” and third, “regenerating natural systems”. The first two concepts in this definition correspond with the themes in this study related to “optimising resources” and the “adoption of XR principles”. The third theme of “regenerating natural systems” was not specifically addressed by interviewees with the closest comparison being the theme 4- “driver of sustainability” as noted in this study. Therefore, from a definitional standpoint, specific consideration should be given to the regeneration of natural systems in the SEZ. Although a critique of the CE is that there is no single definition and the concept is too broad (Ghisellini et al., 2016; Kirchherr et al., 2017), this study has observed that multiple definitions of the CE have given rise to the identification of multiple opportunities for adoption. This is evidenced by the 149 opportunities identified by interviewees in this research. This sentiment is echoed by the document analysis of the World Bank's WICER guideline which notes that the CE (framework) is not an "all or nothing proposition" (Delgado et al., 2021) and cities and industries may adapt and adopt CE principles in the manner and mechanisms best suited to their needs.

5.2.2 *Opportunities for innovation in the circular economy*

5.2.2.1 Overview of eight opportunity areas

In the South African context, the primary opportunities for broader circular principles to be adopted were noted in the literature as being as follows: 1.) co-create policy to develop new ownership models; 2.) increase cost optimisation (Mativenga, Ejon, et al., 2017; Roberts & Schöer, 2021); 3.) build private public partnerships (Tahulela & Ballard, 2019); 4.) decouple production in agriculture from the demand for water; 5.) reduce waste and create water efficiencies; 6.) perform onsite wastewater treatment (Godfrey et al., 2021) and to a lesser extent, 7.) circular planning for a WEF nexus approach (Naidoo, Nhamo, Mpandeli, et al., 2021; Nhamo et al., 2020). Finally the notion of 8.) restoration of water sources was included as part of the opportunities particularly because it was observed as being a gap in the overall definition and therefore required investigation as to whether the opportunity to restore is being recognised.

5.2.2.2 Comparison of opportunities identified in the literature with those identified in this study

When compared to the findings in this study, the opportunities for circularity are aligned to five of the eight opportunities outlined in the literature.

Table 5.1: Comparison of the CE opportunities noted in the literature with those identified in this study

Opportunity per literature review	Opportunity per this study
1- Co-create policy to develop new ownership models (Mativenga, Ejon, et al., 2017; Roberts & Schöer, 2021)	• Opportunity 1 - Embed CE principles into design • Opportunity 8 - Shared services (logistics, storage and human capital) • The co-creation elements of policy creation is a potential area of exploration by the SEZs
2- Increase cost optimisation (Mativenga, Ejon, et al., 2017; Roberts & Schöer, 2021)	• Opportunity 1 - Embed CE principles into design • Opportunity 7 - Develop new economic models
3- Build private public partnerships (Tahulela & Ballard, 2019).	• Opportunity 4 - Government led interventions and governance
4- Decouple agricultural production from water demand (Godfrey et al., 2021)	• Decoupling production from demand is a potential area of exploration by the SEZs
5- Reduce waste and create efficiencies	• Opportunity 5 – Minimise waste
6- Onsite wastewater treatment (Godfrey et al., 2021)	• Opportunity 2 - Decentralised wastewater treatment at the SEZ • Opportunity 3 - Widescale adoption of greentech
7- Adopt circular planning for building a WEF nexus approach (Naidoo, Nhamo, Mpandeli, et al., 2021; Nhamo et al., 2020)	• Opportunity 5 – Build a WEF nexus
8- Restoration of water sources (from definition) (EMF, 2018)	Not specifically noted as a standalone opportunity however innovation in water restoration related to water quality has been observed in this study.

5.2.2.2 Data interpretation

The **co-creation of policy was not noted** as a primary opportunity for CE innovation by interviewees with the closest comparative opportunity noted in this study being opportunity 1 – embedding CE in the design of processes. This design does include some elements of policy design and planning. Co-creation of policy is therefore an additional untapped opportunity for those SEZs where collaborative policy making is not a focal point. This is specifically pertinent in the South African context where circular economy policies for water have not been developed.

The second untapped opportunity is closely linked to co-creation of policy and relates to the development of private-public partnerships. Again, it may be argued that private-public partnerships are embedded within opportunity 4-government led interventions noted in this study. However, private-public partnerships were only mentioned in two interviews *(SEZ2 and GOV3)*. This represents another mechanism that SEZs can adopt to finance, plan and execute circular activities particularly because the CE model is considered a collaborative one (Mbavarira & Grimm, 2021; Pomponi & Moncaster, 2017).

The decoupling of production from water demand was notably absent from the opportunities identified in this study. This decoupling is one of the primary outcomes of the CE (Ghisellini et al., 2016; Godfrey et al., 2021) and therefore represents a major opportunity for innovation.

Finally, the last opportunity for consideration by SEZs relates to an element within definition of the CE related to the "regeneration of natural systems" through restoring water sources. Restoring natural water systems did not emerge as an opportunity in this study and should be explored by SEZs in order to attain circularity in all spheres of water management. It should be noted that although decoupling and restoration were not identified as prominent areas of opportunity identified in this study, actual decoupling and restoration activities have been noted in the environmental impact and innovation activities respectively.

From an overall perspective, the SEZs in South Africa are aligned with the recognition and identification of CE opportunities, as noted in the literature. This is particularly notable, because this alignment has occurred in the absence of national guidelines for water circularity and may provide an impetus to co-create policies that are based on theory and real life practices.

5.2.3 Circular economy innovation in the SEZs

Circular economy innovation activities in the SEZ were separated into those related to products, processes and services and those related to novel forms of value creation through business models and policies. Changes in business models and policies may provide an indication of the pervasiveness of technologies and the type of innovation, which are tested in research question two.

5.2.3.1 Innovation in products, processes and services (PPS) and value creation (VC) -

The review of the international literature review in Chapter 2 of this report identified a total of ten areas for innovation in the CE. Specifically, water and wastewater contained six opportunities and for the broader CE, four general opportunities for innovation were noted. The areas of innovation include: 1.) reuse of wastewater; 2.) recovery of water from wastewater; 3.) recovery of nutrients from wastewater; 4.) the prevention of wastewater from the onset; 5.) removal of pollutants from wastewater; 6.) finding new ways to use resources in order to be free from waste and other emissions (Smol et al., 2020); 7.)

innovation in financing the CE; 8.) innovation in policies; 9.) the adoption of a systematic approach (de Jesus & Mendonça, 2018); and 10.) the digitisation and monetisation of water technologies (de Jesus & Mendonça, 2018; Smol et al., 2020).

A total of 29 areas of innovation were identified in the data, which included products, processes and services. The primary areas of innovation identified in this study were: PPS1- sludge harvesting, PPS2- wastewater treatment, PPS3- Greywater reuse and PPS4- Closed loop processes. A total of six types of innovation for value creation were noted in this study. The primary mechanisms for value creating innovation are through: VC1- circular management models, VC2- shared service models, VC3- water reduction policies and VC4- new financing mechanisms.

The 10 areas for innovation from the literature were then compared to the 35 innovation themes noted in this study in order to determine to the degree of alignment between them.

Table 5.2: Comparison of primary opportunities for CE innovation per the literature with those identified in this study.

Innovation area	Innovation actions per the literature review	Innovation per this study
Water specific (Smol et al., 2020)	1. Reuse of wastewater	• PPS2.Wastewater treatment • PPS3. Greywater usage • PPS6. Water reuse infrastructure • PPS11.Used water sources for aquaculture farming • PPS20.Reuse steam • PPS25.Resource efficient irrigation
	2. Recovery of water from wastewater	• PPS2- Wastewater treatment •
	3. Recovery of nutrients from wastewater	• PPS1.Sludge harvesting • PPS8.Sludge extraction into fertiliser • PPS13.Biotech sludge treatment • PPS17.Sludge extraction into energy source • PPS19.Sluge extraction into construction materials • PPS24.Acid mine draining harvesting for mineral
	4. Prevention of wasted water and wastewater from the onset	• PPS4. Closed loop processes • PPS24.Decentralised services • PPS18.Alterative storage solutions to prevent waste • PPS21.Process optimisation for water reduction • PPS14.Alternative piping solutions
	5. Removal of pollutants from wastewater	• Embedded in PPS3.Greywater usage requires some treatment before use • Embedded in PPS16.Water testing for quality and aquaculture
	6. Rethink of the ways in which resources can be used to be free	• VC1.Circular management models • VC2.Shared services • VC3.Water reduce policies

	from waste and emissions	• PPS7.Rainwater harvesting • PPS9.Shared services for water reduction • PPS12.Leak detection • PPS14.Alternative piping solutions • PPS15.Circular business processes • PPS26.address legacy challenges • PPS27.Innovative eco-conservation practices
Not water specific (de Jesus & Mendonça, 2018)	7. Innovation in circular finance	• VC4.New finance models are linked to innovation for the monetisation of water technologies in the CE.
	8. Innovation in policies	• VC3.Water reduce policies
	9. Systematic approach for behavioural and wide scale change	• VC1.Circular management models • VC2.Shared services • VC3.Water reduce policies
	10. Digitisation & monetisation of eco-innovation	• Addressed in research question two • Monetisation remains a gap
Not emergent in literature	11. Access to new water sources	• PPS5.Desalination • PPS7.Rainwater harvesting • PPS23.New water sources • PPS28.Atmospheric water generation

5.2.3.2 Innovation products, processes and services-

Overall, the innovation identified in the literature is executed in multiple ways within the innovation activities of the SEZs. Innovation Area 5- The removal of pollutants from wastewater was not an emergent innovation finding in this research with the closest comparison being the pre-treatment of greywater (PPS3) before reuse, the reuse of water in aquaculture (PPS11) and water quality testing (PPS14). It may also be argued that inherent in the theme related to wastewater treatment (PPS2) is the removal of pollutants. Wastewater pre-treatment is a legislative requirement in South Africa (DEFF, 2014) and there have been specific chemical contaminant challenges related to the reuse of greywater in irrigation (Naidoo, Nhamo, Lottering, et al., 2021). Innovation in the removal of pollutants from water before release into the water system may represent an untapped area to increase efficiency and reduce treatment costs in order to meet legislative requirements with minimal disruption to business practices. This notion of low-cost water treatment to meet regulatory guidelines was did not emerge in interview findings.

In addition to the innovation areas identified in the literature alternative innovation related to new ways of accessing water from non-potable sources were identified in this study. These relate to desalination and reverse osmosis (PPS5), rainwater harvesting (PPS7) and atmospheric water generation (PPS28). These innovations were also noted in the document analysis of the World Bank WICER guidelines (Delgado et al., 2021). However these were notably absent from the literature reviewed on water and wastewater innovation opportunities. This may be due to a preponderance of the literature in favour of a CE for waste and wastewater rather than potable water in general, particularly in the European (Smol et al., 2020) and South African contexts (Godfrey et al., 2021).

5.2.3.2 Innovation for value creation (VC) -

From a literature-based perspective, the innovation areas of "rethinking" and "systematic approaches" are closely linked. Rethinking in this context means considering the ways in which resources can be used to be free from waste and emissions (Smol et al., 2020) and a systematic approach is a broader opportunity to include multiple counterparties and systems in order to drive behavioural change and widescale adoption (de Jesus & Mendonça, 2018). These two innovation areas "rethinking" and "systematic approaches" are adequately described by the value creation (VC) innovation noted in this research specifically (with the product, process and service innovation being examples of this value creation executed in business). Circular management models (VC1) and finance models (VC4), shared services models (VC2) and water reduction policies (VC3) are all developed with the purpose of looking at new systems and management approaches in order to be purposefully circular. The systematic nature of this innovation is evidenced in the collaborative business models which consider more than one entity when planning for circularity. In the area of circular finance, the literature recognises the challenges associated with the financing of circular activities and the need to consider new and innovative models of financing to finance the CE activities (Dewick et al., 2020; Mativenga, Ejon, et al., 2017). Specific types of innovation related to financing were expressed by interviewees in two ways. Firstly, through alternative subscription models and mechanisms where the potential beneficiary of technologies pays a fee to access new to market technologies with fees gathered used to fund the pre-commercialisation phase of technologies. Secondly, new and alternative financial instruments are adopted (i.e. mezzanine finance and blended finance) in the financing of water technologies. The monetisation of eco-innovation remains a challenge to innovation, as noted in both the interviews and literature (Matchaya et al., 2019). The role of government finance for circular economy innovation is an area to be further explored particularly in light of the challenges experienced by innovators in the commercialisation phase (Habiyaremye, 2020). This investment by government is linked to the principles of mission-oriented finance (Mazzucato & Penna, 2015) with water scarcity being the "grand challenge" to overcome. The government therefore plays a role in financing innovation at the pre-commercialisation phase and over the long term (in the form of patient capital), therefore de-risking innovation (Mazzucato & Penna, 2015) for subsequent financing by venture capitalists and the private sector.

5.2.3.3 Innovation catalogue -

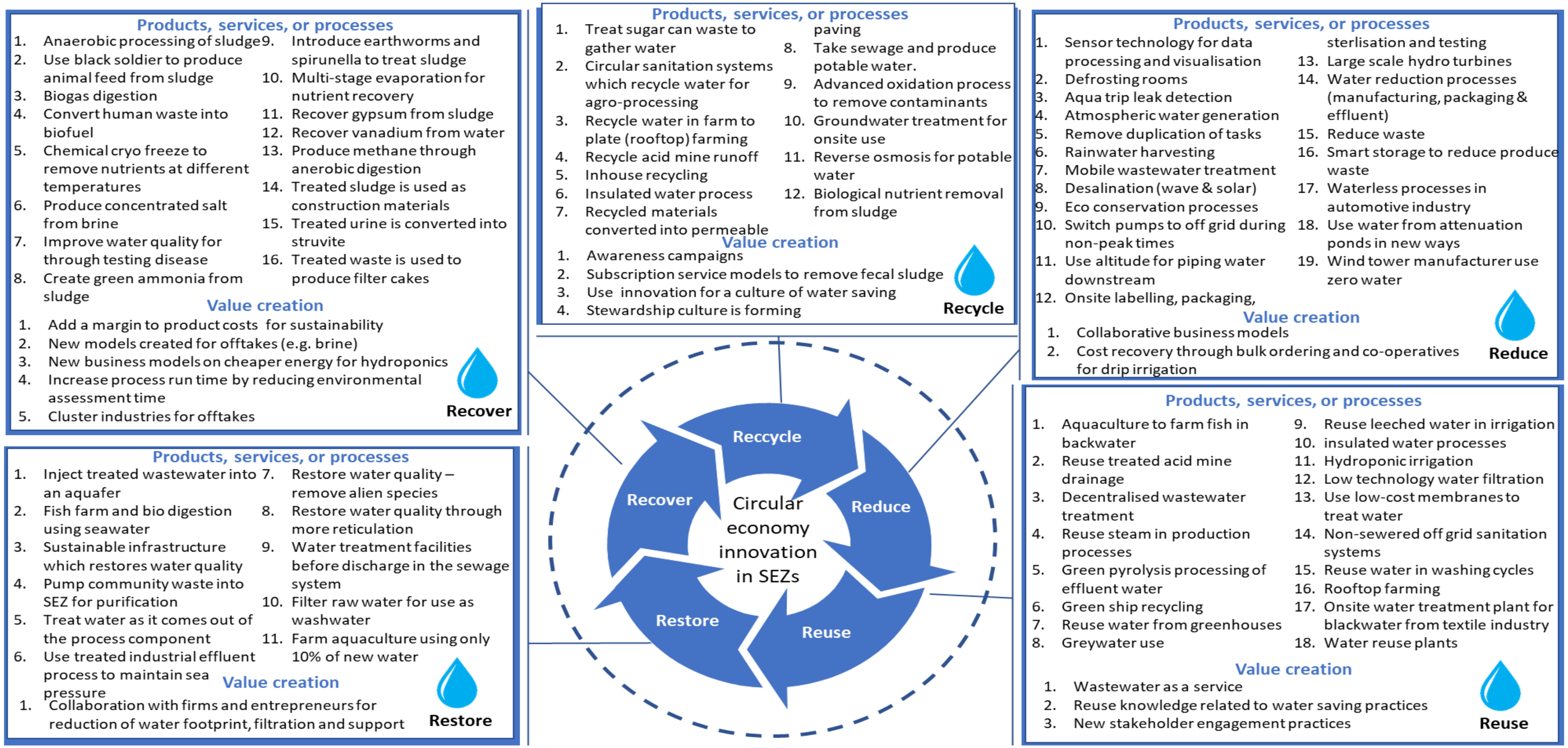
In addition to the comparison above, the circular economy innovation has been catalogued into a CE summary. This summary shows each innovation as identified in the interviews classified according to the CE activity to which it corresponds. The catalogue highlights the characteristics of innovation within the water CE in response to research question one. Its purpose is to serve as a comparison tool (for currently established SEZs) or a reference guide for use when designing circularity within the SEZ (for new SEZs and those under development). A catalogue of such nature has not been observed in South African literature and is beneficial for an industrial environment that faces water challenges which require innovative solutions.

In order to categorise the CE innovation, a guideline is required. The 9R's used in the CE literature (Ghisellini et al., 2016) is based on the EU guidelines and is not deemed appropriate for this study given that South Africa is in the early stages of its CE development. The South African CE guideline uses the 3R's of "recycle", "re-use" and "refurbish" (DEFF, 2020). This South African guideline is in reference to waste and does not prioritise the principle of "reduction" (DEFF, 2020). The use of the 3R framework as per the CE guideline for waste may not be comprehensive given the water scarcity challenges noted in four out of seven SEZs interviewed, which have forced companies within the SEZ to specifically **reduce** water consumption. A framework which then includes "reduce" is more appropriate for this study. The approach used to categorise the CE innovation in South African SEZs is that created by the World Business Council for Sustainable Development for water which the World Bank has noted as being more applicable to the business context (Delgado et al., 2021). It is therefore considered better suited to this study when compared to the 9R and 3R guidelines given the specific focus on water and industrialisation. This classification uses 5R's namely: "reduce", "reuse", "recycle", "restore" and "recover"(WBCSD, 2017).

Based on these classifications, the characteristics of the innovation identified in this study have been classified according to the extent in which it (WBCSD, 2017):

- **Reduces** water losses and creates efficiency in water usage. Here the focus was on reducing potable water losses.
- **Reuses** water in multiple processes. This is largely untreated or semi-treated water (e.g. greywater) and is different from the reuse of treated wastewater
- **Restores** water to the source at the same quality or at a better quality to where it came from.
- **Recovers** resources (i.e. nutrients and chemicals from sludge) from wastewater and uses them. Recover in this context only refers to the chemicals and nutrients extracted from sludge (e.g. vanadium) which are used in **new processes**.
- **Recycles** resources and wastewater into a usable product and can be **used again for the same purpose**. This is different from recover in that **recycle** also refers to the use of the resources and nutrients **again in similar processes** whereas **recover** refers to the use of resources in **new processes**. There are some instances of overlap between recycle, reuse and recover.

For the purposes of this catalogue, duplicate responses (e.g. low cost reverse osmosis) were removed.



Cross cutting innovation

Products, services, or processes

1. Adopt and tailor international mechanisms (secondary innovation)
2. Dealing with legacy challenges of waste in new ways
3. Matrix models of management
4. Water master planning for circular processes in the SEZ
5. Create insulated water process
6. Business process re-engineering to be water efficient

Value creation

1. Blended finance programmes
2. Design for circularity in the processes and at organisational level
3. Design for water scarcity
4. Financiers who either provide higher risk mezzanine or equity financing
5. Financing model where developer pays for the technology
6. Develop new sustainable practices for long term benefits
7. Skills development for circular practices
8. lifecycle costing
9. Matrix models of management which recirculate learnings
10. Innovation for water stewardship programmed
11. Shift away from economies of scale
12. Use data to drive circularity
13. Adopt a value chain approach
14. Domestic effluent subscription model
15. Water purification and steam - reuses water within the zone
16. Adoption of green principles
17. Adopt international business models
18. Policies which restrict water usage
19. WISP programmed (link to companies for recovery, reprocessing and re-use)

Figure 5.2.3.3: Water circular economy innovation in SEZs

From this catalogue it can be seen that most of the innovation related to the circular economy from a products, process and services perspective is in the “Reduce” category with a total of 19 innovation activities noted. The second most prevalent category in which innovation occurs is in water “Reuse”. These findings correspond to the water scarcity challenges faced in South Africa (Godfrey et al., 2021; Habiyaremye, 2020; Soyapi, 2007) and the limited availably of potable water which has led SEZs to focus on using less potable water and reusing the water available.

From a value creation perspective innovation in the “Recovery” category, new business models and cluster industries developing around offtakes, as well as the pricing models which include the cost of sustainability, are the most prevalent. This is consistent with the literature, which states that new business models are required as part of the creative destruction caused by circular industries (Suchek et al., 2021). “Recycle” and “Restore” were the categories with the least innovation activities. For “Recycle” this could partly be due to the overlap between “Recycle” and “Reuse” but may alternatively be an indicator that recovered minerals are not being used in the same process but rather are being used in new and different processes. From a “Restore” perspective, the injection of water back into the water supply was not a predominant research outcome in this study and may be the reason responses relating to restore were sparse. Alternatively, it could imply that SEZ innovation on water circularity is not specifically focused on restoring water sources which then represents an opportunity for innovation. This is also consistent with the absence of innovation in the remove pollutants from wastewater innovation category noted above. Cross-cutting innovation activities (i.e. those which span multiple if not all the 5R elements) relate primarily to the business model changes in designing for circularity and the finance of circular water innovation as well as the adoption of green principles and international sustainability models.

5.2.2 Impact of circular economy innovation on the environment and economic development

The CE is noted as being an environmental and an economic model (Ekins et al., 2019). The expected outcomes of a CE based on the definition and literature are therefore efficient use of resources, a subsequent boost in the economy, an improvement in environmental conditions and an enhanced quality of life for society (Sauvé et al., 2021). Furthermore, two vital impacts of CE adoption are the decoupling of environmental pressure from economic development (Ghisellini et al., 2016; Godfrey et al., 2021) in addition to water security. Water scarcity includes sustained livelihoods and wellbeing, protection against pollution, preserving ecosystems and political stability (UN, 2013).

5.2.2.1 Environmental impact

From an environmental perspective, the South African literature on the impact of the water circular economy emphasises lower pollution, health benefits to communities and the restoration of natural systems and reduced virgin materials (Godfrey et al., 2021). The literature is also clear on the negative impact of industrialisation on water which is pollution (Soyapi, 2007), soil erosion and depleted groundwater reserves (Sauvé et al., 2021). In addition, the literature suggests that SEZs should focus on becoming environmentally responsible (Nel & Rogerson, 2014; Zeng, 2021). A positive environmental outcome from the CE in SEZs should therefore be observed.

Based on the interview results, the primary environmental impacts of CE activity have been an improvement in water quality with a reduction in pollution, the optimised use of water (less wastage and more reuse) and an improvement in biodiversity. It therefore appears that CE adoption has had a positive environmental impact by addressing the challenges in water in South Africa of water pollution and depletion due to increased demand. However, the exact environmental impact of circular activity has been noted by two interviewees as being difficult to quantify (Interviewees *WII and SEZ2.1*) with monitoring tools being noted as an opportunity for the water and the CE in the literature (Gonçalves et al., 2022; Pitman, 2011)

It should however be noted that in some instances, circular activities may have an adverse environmental impact. For example, reverse osmosis used in the desalination process is used to recycle seawater in order to produce potable water. This process produces a highly concentrated brine which if discharged into the water and sanitation systems without being treated will have a negative impact on aquaculture (Interviewee *WII*), a negative impact that is noted in the literature (Lattemann & Höpner, 2008). Desalination is also considered to be energy intensive, and the production of potable water may come at a significant energy cost (Turner et al., 2015). Consideration should be given holistically to the impact of CE activities in order to prevent a whole new set of environmental damage and resource depletion. SEZs should be aware of these unintended consequences.

5.2.2.2 Socio-economic impact

From a socio-economic perspective, new ownership models, increased cost optimisation (Mativenga, Ejon, et al., 2017; Roberts & Schöer, 2021) and private public partnerships (Tahulela & Ballard, 2019) create opportunities for industrialisation, economic growth and cost reductions (DEFF, 2020; Godfrey et al., 2021). In addition, the literature has noted potential for jobs in wastewater (Smol et al., 2020) with the CE guideline identifying the potential and need for new green jobs (DEFF, 2020). Green jobs include jobs in new industries created from circularity, jobs in organisational sustainability through strategy and management as well as other environment focused jobs (Sulich & Sołoducho-Pelc, 2022). This study has found that job creation, industry development and lower production costs were the three primary socio-economic impacts of circular innovation in the SEZ context. Job creation was observed specifically in industries for offtakes and sludge, in decentralised services (e.g. onsite wastewater treatment) and the installation of infrastructure that supports circularity. In addition, new industries generated from offtakes creates economic growth. The use of offtakes in circular processes and water reuse activities (closed loop) have the impact of lowering production costs. There is also an indirect social and economic benefit noted in this study where workers have access to cleaner water and are able to participate in the economy. This benefit is however difficult to measure.

In contrast to these positive impacts, instances have been noted where the high installation cost of innovation renders them unaffordable by some firms. The high cost of CE implementation has been flagged as a challenge in the literature (Tahulela & Ballard, 2019) and may have negative short term, profitability and economic implications. This was confirmed by the literature (Gedam et al., 2021) which recommends that private sector subsidies should be considered to counter this impact. The low adoption due to cost stifles potential economic development and the socio-economic benefits of the CE.

5.2.2.3 Overall impact

The impact of innovation in the water CE in South Africa is a reduction in pollution which improves water quality. This is beneficial to human health and biodiversity. From a social and economic perspective, job and industry creation are the primary outcomes of CE innovation in water. These outcomes address water security, in part, with greater scope to investigate the preservation of ecosystems and political stability factors as noted by the (UN, 2013).

There is therefore a direct positive environmental and socio-economic impact of CE innovation in the SEZ context. It should be noted that measurement of CE activities remains a gap (Nepfumbada & Seetal, 2020) and tools for monitoring would therefore be an enabler of success (Dewick et al., 2020).

5.3 Does water innovation drive the green techno-economic paradigm in South Africa? If so to what extent?

From a literature perspective a new techno-economic paradigm is characterised in three ways: 1.) declining costs, and 2.) increased opportunities for entrepreneurship and new organisational models (Perez, 2010). This section of the research is focused on understanding ICT enabled water technologies (which are circular) and the extent to which the criteria required for a new TEP are met. A similar exercise was performed by Mathews (2013) for the renewable energy sector. In this analysis the criteria used for assessment included: “1) falling costs; 2) costs lower than the incumbent technology; and 3) pervasive effects”(Mathews, 2013). Pervasiveness in that analysis was used as a broader term to identify the widescale adoption of renewable energy technologies. For the purposes of this study, Perez’s original three criteria will be used with pervasiveness being substituted for organisational change due to its broadness. Pervasiveness in this study includes the take-up of technologies, the centrality of the technology to organisations operations, the policies which impact technological take-up and the selection process which impact the take-up of new technologies. The literature review showed that ICT enabled water innovation has been flagged as an opportunity for South Africa (Pitman, 2011). The top enablers for water innovation include: mechanisms for knowledge sharing on infrastructure, building a strong science, technology and innovation networks to link research with execution, creating opportunities for small enterprises and technical skills accumulation entrepreneurship and support (Rose & Winter, 2015). These enablers are investigated in the sub-questions related to entrepreneurship and knowledge sharing.

5.3.1 *ICT innovation*

Innovation has many forms as identified in the literature review. The focus of this research question is on ICT enabled water technologies and the extent to which ICT water innovation is impacting the prevailing techno-economic paradigm.

From an innovation perspective the are many forms of ICT enabled innovation which address water challenges. This innovation spans the entire water value chain and include: drone technologies used in exploration and abstraction, nanotechnology used in water treatment, digital monitors used to prevent leaks in the storage and distribution, water saving devices which reduce potable water use and finally wastewater treatment technologies and robotics for repair of technologies post water usage (Habiyaremye, 2020). A comparison of the technologies noted in the literature and those identified in this study is performed in the table below. This comparison will assess water technologies used within the SEZ and their alignment with the technologies available in the market. A significant gap in innovation adoption may represent a gap in innovation within the SEZ and may stifle the progress of the technological revolution. From an innovation perspective it is the groups of technologies that may form a technological cluster and it is these clusters which drive the technological revolution and TEP (Perez, 2010).

Table 5.3: Comparison of water technologies used within the SEZs with the technological innovation opportunities per the literature

Value chain	Technological innovation opportunities noted in literature (Habiyaremye, 2020)*	ICT innovation in the SEZ
Exploration and abstraction	Satellites and drones for imagery	• Drone technology for planning and monitoring • Satellite leak detection
	Renewable energy sources	• Solar energy driven technologies • Solar energy driven irrigation
	Design for water sensitivity on rain-water and greywater harvesting	Digitally enabled rainwater harvesting
	Increase groundwater sources in agriculture	Groundwater abstraction technologies
Water treatment	Nanotechnology for filtration	Nanofiltration
	Membranes (i.e. high productivity & reverse osmosis membranes in manufacturing)	Low cost membrane reverse osmosis
	Desalination	• Solar energy driven desalination

		• Wave energy driven desalination
Storage and distribution	Digital monitors for leak detection and water pressure measurement	• Mobile applications for water measurement • Remote sensing automated water processes • Digital water monitoring systems (incl. SCADA)
	Storage technologies which reduce evaporation	Gap
	Frugal innovation for transport	Gap
User consumption	New materials for	Trenchless technologies
	Climate sensitive agricultural production	Gap
	Industrial water saving devices	Smart buildings
Wastewater collection and treatment	Irrigation which reuses non-contaminated effluent	Solar energy driven irrigation
	Water treatment onsite	Digitised off grid water treatment processes
	Water recovery for valuable products	Mineral recovery technologies
	New treatment and reuse components	Electrolysis for hydrogen
	Advanced decontamination	Ion exchange resin technologies
	Biological treatment processes	Biotech wastewater treatment
	Robotics for repairs	Augmented reality enabled repairs
Not identified in literature		Data analytics technologies
		Atmospheric water generation
		Augmented and virtual reality enabled planning

**As part of this comparison duplicates categories were removed (i.e. nanotechnology and renewable energy) as were technologies related to domestic sanitation and agriculture which are outside the scope of this study.*

This analysis shows that across the value chain, SEZs in South Africa have adopted the most notable water technology innovations. Potential exists for the consideration of new storage methods which seek to reduce evaporation (primarily in agro-processing), mechanisms to adapt to climate change and finally to use local and frugal innovations. Frugal innovation, in particular, may be a significant opportunity for technological innovation in the SEZ. Frugal innovation is the practice of simplifying processes into basic components and look for efficiencies and cost effectiveness therein (David-West et al., 2019). Frugal innovation also has a social and inclusiveness element (David-West et al., 2019). The inclusion of frugal technologies which address water challenges in the SEZ may be a cost efficient, socially beneficial way to improve technological diffusion and the green techno-economic paradigm. Frugal innovation may also be a mechanism to address inequality within the TEP which is a challenge for South Africa (Stewart, 2021).

In addition to the innovation opportunities identified in the literature, SEZs have adopted innovation in the use of atmospheric water generation and augmented and virtual reality based planning (used in exploration and abstraction) and big data analytics used across the value chain.

In this study, the primary source of ICT enabled water technology are the digital water meters. These advanced water meters have a low investment cost compared to the other technologies, address the challenge of water leakage and therefore address the circular innovation category of "reduce". These meters evidence how existing technologies (i.e. standard water meters) have been transformed through ICT within the current technological revolution. Technologies within the revolution have three characteristics information intensity, decentralised data integration and collaboration (Perez, 2010). Advanced water meters are used to build and gather large volumes of data (information intensity) and this data is used in a decentralised (non-municipal, onsite) and integrated manner for water monitoring. These activities foster inward and outward collaboration as the companies in the SEZ work with each other and the municipalities to lower their water usage and water losses. The second most prevalent ICT innovation noted in this study relates to remote sensors. These sensors are used to monitor and adjust the flow, pressure and humidity in the water system and can be used to make real time decisions based on data gathered (Javaid et al., 2021). When these water meters and remote sensors are combined with the mobile applications and data analytics technologies identified in this study, these technologies have potential to form a cluster which occurs at the onset of a new techno-economic paradigm. Another potential cluster relates to desalination technology which requires the use of low cost membranes, nanotechnology and renewable solar and wave energy. The cluster of technologies is observed in the installation phased of the technological revolution rather than at the deployment phased once the TEP has emerged (Perez, 2010).

5.3.2 Technological cost

From a cost perspective, a new TEP is characterised by declining technology costs and inexhaustible inputs and technologies which are universal in their application and have the ability to increase the power of labour and capital while decreasing the cost (Perez, 2010). Interviewees were asked whether the innovation noted in the previous question were observed as reducing in cost. Ten interviewees have observed potential for cost to decrease further (i.e. either costs have come declined partially or remained stagnant at present but will decline in upcoming years). Technologies for which the cost is still expected to decline include desalination in response to the use of renewable low cost energy and reverse osmosis due to lower cost membranes. This reducing cost is confirmed by a comparative study by (Blersch & Plessis, 2017) which noted the ongoing improvement in desalination cost since the author's previous 2006 study.

Seven interviewees have noted a decline in water technology costs. The decrease in technological cost was attributed to the declining cost of telemetry with the real time monitoring of water supply now costing less than manual water monitoring. This is confirmed by a comparative study on which showed that cost of real time digital monitoring was as low as 2% of the cost manually monitoring data (Calderwood et al., 2020) with lower telemetry and IoT functionalities (Ogudo & Ayodele, 2020) noted in the South African context as well. The cost to transfer data gather is now cheaper. Cost reductions were also noted in atmospheric water generation which is confirmed by a Life Cycle and Cost Assessments performed in the United States. This report noted that the cost per litre of atmospheric water generation is lower than the cost per litre of the bottled water system (Eastern Research Group Inc, 2018).

Of note is the observation by five respondents that costs have increased. This is attributed solely to the high infrastructure and installation costs of new technologies as compared to their non-digital and in-use infrastructures and machinery as well as the low cost of water. According to interviewees, these factors make produce a perceived negative return on investment for water tech in the short run. However these high capital expenditures are expected to reduce operating costs in the future particularly in water metering technologies (Zyl et al., 2018).

From a cost perspective as it relates to the TEP criteria, water technology costs are declining, but the inputs are not inexhaustible at this stage (i.e. there is still a high input cost), the applications of the water meter technologies are universal (i.e. have applicability for energy and other resource monitoring) and the use of digital inputs reduce labour costs (because they are no longer monitored manually). This criteria of the TEP are therefore regarded is being met.

5.3.3 Opportunities for entrepreneurship

From an entrepreneurship perspective, a characteristic of a new TEP is in new spaces for innovation. These spaces produce increased entrepreneurial opportunities where entrepreneurs are able to further develop new technologies and to use them in existing sectors (Perez, 2010). In addition, the TEP sees new “innovator – entrepreneurs” entering the new and growing sectors of the economy (Drechsler et al., 2009). From an entrepreneurship opportunity perspective 20 interviewees agreed that opportunities exist within the water sector for entrepreneurs, primarily from a wastewater and low cost infrastructure perspective. It would therefore seem as though this criterion for the TEP is met. However only five interviewees noted that opportunities are being taken up. Market entry (25%), an overall lack of take-up for existing opportunities (17%) and limitations due to external intervention required (14%) were noted as the primary barriers to entrepreneurship in the water sector. The literature reiterates the market potential for small enterprises and the need to provide technical skills support (Rose & Winter, 2015), and recognises the barrier firms face of limited information on how to capture value from innovation (Amankwah-Amoah, 2019). There are therefore significant challenges to overcome before entrepreneurship opportunities are fully realised in the water sector. From a market entry perspective, the requirement to have a strong business plan and a workable pilot is a deterrent for entrepreneurs given the limited opportunities for piloting and skills shortages on business planning. A lack of funding was also noted as a barrier to market entry with limited knowledge on the part of investors for green projects as well as a low venture capital market. These barriers have previously been identified by Ojah & Mokoaleli-Mokoteli (2010) who acknowledge the need for new types of finance for green technologies and alternatives to venture capital (in South Africa) respectively. The need to de-risk water technologies was noted as part of the interventions required. South African companies have been noted as being risk averse when it comes to new technologies and tend to stick to the technologies, they are familiar with. External intervention is therefore required to provide a proof of concept and to mitigate the risk associated with new technologies in the market. This is currently addressed through certain private sector initiatives as well as the Water Technologies Demonstration Programme (WADER) (WRC, 2017) and South African Sanitation Technology Enterprise Programme (SASTEP) (WRC, 2018) programmes both run by the Water Research Commission which seek to assist organisations with commercialising their water innovations and bring these to market. In addition, given the opportunity noted in the literature review to form private public partnerships (Tahulela & Ballard, 2019) the role of the state in de-risking water projects and in developing these partnerships with the private sector particularly for the empowerment of entrepreneurs should not be discounted. The support and financing of innovation and entrepreneurship determines the extent and directionality of the TEP (Mazzucato & Perez, 2015). Finally although not addressed in this research, the potential for entrepreneurship across multiple sectors should also be considered as the WEF nexus continues to build (Liu et al., 2018). This will assist in not only addressing the challenge of water, but of food and energy and may result in a faster emergence of the green TEP. The entrepreneurship criteria for a TEP is therefore not fully observed.

5.3.4 Pervasiveness of technology

In order to determine the pervasiveness of innovation the assessment criteria were based on innovation take-up, the extent to which innovation is core or enabling to a business, the policy environment which either promotes or detracts innovation, the selection criteria for innovation and finally the relationships for knowledge sharing.

5.3.4.1 Innovation take-up

From an innovation take-up perspective, the innovation trajectory follows a well observed pattern which includes a slow uptake when introduced to the market introduction to market, accelerated uptake as market growth occurs and a flattening of uptake as the market matures. This is the traditional “S-curve” noted in the literature more than five decades ago (Vernon, 1966) and has been found to still be relevant and observable in innovation patterns by current scholars (Sood & Tellis, 2005) and is considered an important tool for the understanding of the innovation cycle (Brown, 1991). From a TEP perspective, it is the combination of multiple technologies at varying stages within their S-curves which cluster together to form a technological revolution and the subsequent TEP (Perez, 2010). The TEP emerges once technologies reach the maturation stage. Currently the take-up of water technologies in South African SEZs is noted as being slow (16 interviewees). This notion is only contrasted in those SEZs where water scarcity and drought have sped up the adoption of new technologies, particularly in the case of water meters which assist in reducing losses. The slow take-up of technologies required to advance the TEP was observed in the literature (Amankwah-Amoah, 2019; Stewart, 2021). A notable delay in the adoption of technology is the notion that the cost of using potable water, at present, is cheaper than the cost to install new technologies *(interviewees SEZ 2.2, WRE1, GOV2)* a notion that finds resonance in the literature wherein it was noted that switching and adoption costs are considered a challenge to water innovation (Habiyaremye, 2020). The slow take-up of technologies is an indication that the technological revolution is not at the maturation stage required for the TEP to emerge.

5.3.4.2 Extent to which innovation is core or enabling

From the perspective of the innovation centrality to business operations where water technology has been adopted the innovation is considered core to the business and businesses would not be able to function independently from the technologies. This is an indicator of the extent to which the organisational change and new business practices that occur as a result of the TEP is evident (Perez, 2010). In this study, it is noted that although technological take-up is slow, new technologies adopted are now considered core to the functionality of the business and are driving business practice changes. This is an indication that water technologies have the potential for market pervasiveness in instances where they create a cost, productivity or competitive advantage.

5.3.4.3 Polices

From a TEP perspective, organisational change is a characteristic of a new TEP. This is evidenced by behavioural changes and societal changes which include policies. In addition, paradigms cannot be created without involvement by policy makers who make the choices for the directionality of the paradigm (Perez, 2016). Policies in South Africa do exist for the purpose of accelerating innovation and technological diffusion such as the White Paper on Science Technology and innovation (DST, 2019). However, it would appear that this innovation focus has not been observed as being incorporated into the policies which govern the use and treatment of water and wastewater in South Africa (DEFF, 2014).

The literature notes the considerable spend by the South African government in developing water-related R&D for innovation with a further R330bn gap noted for water security in the next 10 years (Nepfumbada & Seetal, 2020). The need for supporting governance policies and incentives for innovation (Habiyaremye, 2020) is also noted. According to Mazzucato (2011) the state is also a policy maker who decides which long term innovation projects to develop . In South Africa, however, the state has long been seen as a detractor of innovation and inefficient (Muller, 2008; Soyapi, 2007) with existing state initiatives deemed insufficient to address the expected 2030 water scarcity challenges (Habiyaremye, 2020). The government is seen as important but not dependable (Stewart, 2021). This study corroborates this notion with eight interviewees identifying current policies for water and circularity as insufficient to either promote or deter the adoption of watertech. In addition six interviewees saw current water policies as an innovation deterrent because of a lack of incentives, a notion concurred in the literature (Habiyaremye, 2020). Interviewees note that policies do exist which are meant to provide guidance on circularity, wastewater management and innovation, but the enforcement of these policies is noted as lacking and businesses are not incentivised to innovate. Policies are also considered unclear and insufficient to address new technologies creating uncertainty (Nepfumbada & Seetal, 2020). These policy gaps amplify the culture of risk aversion noted in this research which sees companies favouring existing technologies over more efficient, but unknown, new technologies. A policy innovation is required which creates incentives for digitisation and technological adoption while penalising businesses that stick to inefficient technologies which may have a long term detrimental environmental and socio-economic impact.

However, SEZs do not have to wait for national policy guidance and can to work with businesses and municipalities within their zone on collaborative policies (Mativenga, Ejon, et al., 2017; Roberts & Schöer, 2021) for innovation and technological diffusion. Currently, this process of self-governance for water innovation is performed currently in a small scale with five interviewees noting that SEZ rules and not government policies promoted watertech adoption within the zone. This is further corroborated by the conclusion on the opportunities for innovation which show that the SEZs have been able to align their innovation opportunities for circularity with international guidelines despite the lack of dedicated circular guidelines for water in South Africa. There is therefore room to scale this process to the other SEZs.

The outcome of a new TEP is a change in the social and economic system through new organisational design, new behaviours and policies (Perez, 2010). This organisational change from a policy perspective is seen on a small scale at the SEZ level where innovation policies are adopted to drive behavioural change. However, this practice is not widespread.

5.3.4.4 Selection

The selection of technologies plays an important role in determining the type of innovation which is most prevalent in South African SEZs watertech. Where technologies are primarily selected from local suppliers and entrepreneurs this is an indication that primary innovation may be adopted by the SEZ. If technology is purchased from foreign suppliers, then potential exists for secondary innovation through assimilation, structural, functional and conceptual understanding of a foreign technology (Wu et al., 2009). In addition, technologies imported from foreign suppliers although not novel and only adopted and adapted to the local context will require support from financing, marketing and information technology systems perspectives, with innovative business and management capabilities required in order to achieve scale (Soumonni & Ojah, 2022). This would therefore qualify as tertiary innovation wherein organisational innovation is used to create adoption of technological innovation in South Africa. The highest number of interviewees (eight) noted that technologies are selected within the SEZ based on the extent to which they create efficiency for the business. This is linked to the water related challenge the business is trying to solve (e.g. the challenge of reducing leakages as opposed to the challenge of water treatment). From this response alone it is difficult to glean the extent to which innovations which are deployed in the SEZ are original (i.e. based on R&D or completely new to the world in their nature), secondary (i.e. imported technologies which are assembled and tailored locally) or tertiary (i.e. non-water specific technologies which enable faster deployment of water tech and the associated business, delivery and marketing models). However seven of the interviewees noted that selected is biased towards international suppliers given low levels of trust for South African technologies *(interviewees: GOV 3 and WII3)* and the plentiful supply of foreign technologies for deployment - a notion reiterated in the literature (Stewart, 2021). These technologies, however, are not always suited for the South African context given the differences in water quality from a biodiversity and pharmaceutical perspective such as high levels of anti-retrovirals in their water when compared to other countries (Horn et al., 2022). Technologies purchased from foreign suppliers therefore require adaptation for the local context in order to sustain longevity.

This creates an opportunity for secondary innovation particularly through partnerships between local and foreign technology suppliers. The SEZ context is primed for secondary innovation given the focus of SEZs on FDI (Nel & Rogerson, 2014) and the potential to use the SEZ as a mechanism to import novel technologies (Zeng, 2021). In addition, where technologies are purchased from foreign (and local) suppliers there may be a need for non-water related technologies and knowledge based services to introduce these technologies within the zone for widescale adoption. Technologies such as the digital data integration platforms, cloud based data storage technologies and automated sensors and associated organisational innovations, new management models and shared service models, may present potential for tertiary innovation. An example would be wastewater technologies managed through a shared service business model which includes knowledge sharing and integrated information technology systems for use by all companies within the SEZ to treat their water.

Four interviewees noted a preference for local suppliers based on localisation drives at the provincial and SEZ level. In these instances, local suppliers are favoured over international suppliers for water technology requirements. For SEZs the literature notes that sourcing local inputs remains a challenge globally (Frick & Pose, 2021) and the development of local supply chains in China (Zeng, 2021) is a differentiator for SEZs which adds to their success. Therefore localisation drives may be indicative of primary innovation being adopted within the SEZ and one of the SEZs has already chosen to adopt technologies piloted within their science park *(interviewee: SEZ5)*. Scaling up the localisation drives and the protection of industries in the short term (Stewart, 2021) may encourage new innovators who then form a cluster of innovation thus driving water technology into the new green TEP.

The bias for technological selection towards the procurement officer's or selection committees' preferences is closely linked to a lack of information on new technologies as well as legislative restrictions which prevent the selection of new technologies. Many SEZs are subject to the Public Finance Management Act which is specific on the tendering process and the number of quotes required. This process may exclude new and novel technologies from the selection process given a lack of comparison to similar technologies, thus stifling innovation (Bolton, 2016) .

Strengthening the selection process in order to promote innovation take-up is an opportunity to further the TEP with a focus on building primary, secondary and tertiary innovation activity through procurement within the SEZ.

5.3.4.5 Formal relationships for knowledge sharing

A TEP is described as a collectively shared logic, a new common sense that is developed as public institutions and non-profit organisations adopt the changes noted in the business world (Perez, 2010). This implies that knowledge sharing is required to advance the TEP. This information and knowledge transfer can be performed through a strong national system of innovation (NSI). The NSI includes relationships between institutions and organisations where innovation and technical skills are built through learning and sharing. (Lundvall, 2007). Through the NSI knowledge sharing and interactive learning occurs where private and public entities can import and diffuse new technologies and create, transfer and store knowledge (DST, 2019). A strong NSI for knowledge sharing is therefore an enabler of the TEP. Innovation hubs and science parks are examples of mechanisms used for knowledge sharing (Comins & Kraemer-Mbula, 2016). From this research it was noted that relationships for knowledge sharing occur in innovation hubs and science parks for 10 interviewees. However, most knowledge sharing noted by 12 interviewees occurs through other forums (e.g. the SEZ CEO forums and seminars and reference groups). Aligned to this is the lack of relationships with universities with only three interviewees reporting a working relationship for knowledge sharing on water despite universities being a key contributor to research and development (DST, 2019). This limited interaction with universities as well as low usage of innovation hubs for knowledge sharing and development represents a gap in the NIS. Low levels of knowledge sharing slow down the emergence of the TEP and therefore represent an untapped opportunity.

5.3.4.6 Time

Technological revolutions follow the Kondratiev cycles pattern which lasts 50-60 years (Drechsler et al., 2009) and the emergence of the TEP associated with a technological revolution takes 20-30 years to fully emerge (Perez, 2010). This TEP emerges at the deployment phase of the revolution. From a literature perspective it is difficult to estimate exactly when the green TEP will be evident (Conceição, 2004; Perez, 2016) given the multiple recessions in 2000 and 2008 (Perez, 2013) as well as the impact of Covid-19 in

South Africa (Stewart, 2021). Although not specifically explored in this research, many of the interviewees were of the opinion that it would take between five years to more than 10 years before the watertech discussed in the interviews have been adopted at scale. This is aligned with the information from the previous questions which highlight that the technology has not become pervasive at present.

5.4 Summary of data analysis

5.4.1 Impact of water circular economy innovation on economic development

It has been noted in this chapter that, based on the data analysis there are many different definitions of a circular economy , this is aligned to criticisms of the CE on its lack of a single understanding (Ghisellini et al., 2016; Kirchherr et al., 2017). However, the definitions used by SEZs are inherently aligned to the differing definitions are still aligned to the themes noted in the seminal Ellen McArthur foundation definition. These themes are designing pollution and waste out of a system, maintaining the use of materials and restoration of natural systems (Kirchherr et al., 2017) although restoration of natural systems was not a predominant theme identified in this study.

Furthermore despite national guidelines related to water it appears that SEZs have identified opportunities for CE principles in water with a literature and best practice focus internationally being in the areas of design (Mativenga et al., 2017; Roberts & Schöer, 2021), wastewater treatment (Godfrey et al., 2021), greentech adoption (Godfrey et al., 2021) and government led initiatives (Tahulela & Ballard, 2019). Co-creation of policies (Mativenga, Ejon, et al., 2017; Roberts & Schöer, 2021), the decoupling of production from water demand (Godfrey et al., 2021) and the restoration of natural systems (EMF, 2018) are areas of opportunity that require investigation by the SEZs on their inclusion within the zones. The WEF nexus emerged as a cross cutting CE opportunity that can address both energy and water circularity at the same time (Naidoo, Nhamo, Mpandeli, et al., 2021; Nhamo et al., 2020).

Water innovation in the CE In addition when categorised against the 5R network is most prevalent in the “Reduce” and “Recover” categories and is primarily related to wastewater treatment and the harvesting of sludge for use in new value chains. These identified innovation activities across both product, process and service innovation as well as value creation are comparable to literature on CE innovation activities. However, wastewater pre-treatment and the monetisation of innovation are areas of exploration. Wastewater treatment prior to discharge into the water system may be an area for cost optimisation, process efficiency and regulatory compliance (Smol et al., 2020). Novel methods are required to adequately monetise CE water innovation and remains a national challenge (Habiyaremye, 2020). This study has also identified innovation for new water sources through desalination, atmospheric water generation and rainwater harvesting.

The impact of the water CE water innovation is both environmental and socio-economic. From an environmental perspective the reduction in water pollution and optimised use of water resources were primary effects of innovation. These address the historic and present challenges of pollution and water scarcity in South Africa (Soyapi, 2007). However, from an environmental perspective, innovation should be considered holistically particularly in areas such as desalination wherein potable water is produced from seawater, but may come at the cost of other natural resources such as energy or biodiversity (Lattemann & Höpner, 2008).

The primary impact of water CE innovation is industrialisation and job creation. Job creation is both direct through new jobs created from decentralised wastewater treatment and indirect through the new industries which are created from sludge harvesting and the use of offtakes. Green jobs (Sulich & Sołoducho-Pelc, 2022) and wastewater treatment jobs (Smol et al., 2020) were the most notable job creation opportunities in the literature. The full impact of innovation in the water CE is difficult to measure as both the environmental and socio-economic impacts are reinforcing with improved water quality impacting persons livelihoods and health and their ability to work. The major outcomes of decoupling environmental pressure from economic demand (Godfrey et al., 2021) have been observed in the SEZs with scope to improve water security from a preserving ecosystems and political stability (UN, 2013) perspective. **There is therefore a positive impact of water CE innovation on both the environment and socio-economic conditions.**

5.4.2 Extent to which water innovation is driving a green techno-economic paradigm

From a TEP perspective there are numerous ICT enabled technologies available to address water challenges across the value chain but primarily in wastewater treatment and reuse

(Habiyaremye, 2020; Smol et al., 2020). Water monitoring systems combined with robotic sensors and mobile applications are the most common in the SEZs. These technologies have the potential to form a cluster within this sector.

The cost of these monitoring technologies is decreasing and is expected to still decrease further as technology becomes more widescale. This is because of the improvement in telemetry costs over time (Ogudo & Ayodele, 2020). However, cost reductions have not been observed in all innovation as yet given high installation costs in some instances (Habiyaremye, 2020). **The first criteria for a new TEP (i.e. that of cost reduction) is still regarded as being met.**

From an entrepreneurship perspective, at first glance, it appears that there are many opportunities for entrepreneurship to address water challenges. However, these opportunities are not being taken up primarily because of a lack of market access, low levels of funding available and risk aversion to new technologies. Government intervention in addition to the existing market entry mechanisms is therefore required in order to de-risk technologies and increase entrepreneurship activities (Habiyaremye, 2020). This is directly linked to the concept of mission-oriented finance, where the government is seen to play a key role in investing in grand societal challenges (such as water scarcity) in order to foster innovation, stimulate entrepreneurship and create economic growth (Mazzucato & Penna, 2015). **The criterion for the TEP is therefore only partially met in that the opportunities exist but are not being taken up.**

Finally, from a pervasiveness perspective, technological take-up is slow which may be an indication of South African SEZs being at the start of the technology lifecycle curve (Brown, 1991; Sood & Tellis, 2005; Vernon, 1966). Where technologies are being taken up, they are considered core to the business and are driving organisational change and indicator of future pervasiveness (Mathews, 2013). However, the policy environment does not foster technological take-up with policies seen as being inadequate, insufficient in terms of incentives, and as detractors of innovation. New policies are therefore required which promote technological take-up (Habiyaremye, 2020) and penalise the use of non-environmentally friendly processes and technologies which are supplemented by new forms of financing and government support. **Policy changes are expected with a new TEP, and the lack thereof may indicate the TEP is not fully emergent**.

From a selection perspective there is a bias towards foreign technology, but these technological imports can be used in conjunction with local partnerships (Frick & Pose, 2021) to create secondary innovation pathways within the SEZ (Wu et al., 2009). Furthermore the adoption of foreign technologies provides an opportunity for tertiary innovation for the widescale adoption and dissemination of technologies (Soumonni & Ojah, 2022). Localisation drives may assist in building a primary innovation (Zeng, 2021) environment while also increasing entrepreneurship. **The selection process may therefore be an enabler of the TEP and can be used to increase innovation which drives the technological revolution forward.**

A new TEP requires knowledge sharing for widespread adoption and societal change (Perez, 2010). Currently, the networks for sharing knowledge are primarily through forums. However the opportunity to build a strong NSI through the optimal utilisation of innovation hubs and stronger relationships with universities exists (Comins & Kraemer-Mbula, 2016). **The slow take-up of technologies, policy limitations, low levels of local innovation and limited NSI interactions all indicate a low level of technological pervasiveness and therefore, this criterion for the TEP is not met.**

As per this study it appears that the water sector ICT innovation is at present not driving a green TEP with only the criteria of cost being observed as met. There remains an opportunity to drive a green TEP through entrepreneurial support and local capacity building, knowledge sharing and mechanisms for incentivising the uptake of technologies. A failure to do so will see the continuation of inequality and low sustainability as opposed to the green TEP which will be characterised by an observable positive social and environmental change.

Chapter 6: Conclusions and Recommendations

6.1 Introduction

This chapter summarises the research findings and data analysis and provides a conclusion on SEZ innovation in the circular economy and the extent to which this innovation is ICT enabled and contributes to the emergence of the green TEP. Research implications for stakeholders are discussed along with recommendations for further studies.

6.2 Major findings

6.2.1 Interpretation of the CE

The interpretation of the CE is wide within the SEZ context and this broad interpretation is aligned with literary criticisms of the CE. However, within this study, definitions of the CE were found to be aligned to international best practice definitions (i.e. the Ellen MacArthur Foundation) and relate to the optimisation of resources and the application of the XR principles. In this study the component of the definition related to the "regeneration of natural systems" was the least observed interpretation of the CE.

6.2.2 Opportunities for circularity

Although having a broad definition of a CE is considered a criticism, this study has observed that broadness allows for the identification of varying opportunities for circularity. This is aligned to the World Bank view that CE principles should be adapted to suit the industrial or local needs (Delgado et al., 2021). This study identified 18 opportunity areas for the adoption of CE principles, the most predominant of these relates to circular design, decentralised wastewater treatment and greentech adoption. The need for government led interventions was also highlighted. These opportunities as noted in the literature related to co-creation of policy and decoupling production from water demand should be further investigated and enhanced in the SEZ context. There is a benefit in co-creating CE policies given the national guidelines for the water CE are yet to be developed and can be informed by actual implementable practices. This is the optimal state as it has been noted that more can be done by creating bespoke national CE guidelines than the separated and sporadic activities of multiple actors (Ghisellini et al., 2016). In the absence of these national guidelines, the co-creation of policy with government however may be circumvented in the short run if the SEZs policies are created along with tenants and municipalities and are sufficient to create water circularity within the zone. In addition the need to decouple production from water demand is a primary outcome of the CE (Ghisellini et al., 2016) and although decoupling activities have been observed in this study, specific focus by the SEZs on decoupling from a planning, execution and measurement of CE activity may be required.

6.2.3 Water innovation in the CE

Innovation in the CE is vast and includes product, process and service innovation as well as innovation in value creation. The existence of varying types and degrees of innovativeness are an indication that all categories of innovation activities are present (i.e. primary, secondary and tertiary). The most notable innovation from this study relates to the ways in which wastewater is treated both reused. Along with wastewater reuse are the novel ways in which minerals and chemicals are harvested using biotechnologies, evaporation technologies and new extraction techniques, in order to be used in new industries such as construction and agriculture were predominant. Additionally, new business models created around shared services and collaboration have been created within the SEZ in order to minimise the excessive use of water and other resources and to reduce cost and create business efficiencies. The need to consider new ways of wastewater treatment prior to discharge as effluent, which is linked to the principles of water restoration may be an area of untapped innovation where efficiencies and cost effectiveness can be created while still meeting regulatory requirements. Finally, the monetisation of water innovation remains a challenge both in the literature and in practice with the prevailing notion being that the cost of innovation exceeds the benefit to adopt CE innovation in some companies.

Overall, innovation activities have been classified into a CE framework, which sees the reduce and reuse innovation as being the most prevalent innovation types with innovation in business models and finance being cross cutting across the CE.

6.2.4 Environmental and socio-economic impact of the CE

Overall CE activities have been observed as having both a decoupling impact as well as an improvement in water security. From an environmental impact the primary outcome of the CE is a reduction in water pollution and the reduction of virgin resources. These impacts directly address the challenges of water scarcity and pollution observed in literature on water in South Africa (Godfrey et al., 2021; Habiyaremye, 2020). From a social and economic perspective, jobs are created from circularity with further opportunities for green job creation in the future expected as per the literature (Godfrey et al., 2021) and the new TEP will create new jobs for which upskilling is required. The creation of new industries in wastewater and from sludge offtakes also contributes to economic development. From a social perspective, there is an inherent health impact of having access to clean and unpolluted water. However, it is important to consider the negative impact of certain circular activities which may be critical to water circularity but have an adverse energy and biodiversity impact.

Overall, there is a further opportunity to merge the water CE with renewable energy and food and build the WEF nexus. This may address challenges associated with the depletion of one resource (i.e. energy) when trying to create a circular economy for another resource (i.e. water). Measurement of the impact of CE activities remains a challenge and adequate monitoring tools are required to determine the extent to which the environment, economy and societal well being impacted.

6.2.5 ICT technologies

From an innovation perspective, it is those ICT enabled innovation technologies which are expected to create the green TEP. The circular economy has been identified as an enabler of the TEP (Mazzucato & Perez, 2015). Therefore, the extent to which ICT enabled circular technologies are adopted and diffused in the SEZ will determine the nature and emergence of the TEP. Multiple ICT water innovations were identified, the primary of which were digital monitors and robotics. These innovations are examples of existing technologies (sensors and robots) which have been enhanced due to ICT in order to foster information intensity, decentralised data integration and collaboration (Perez, 2010). This is indicative of the instalment phase of the technological revolution (Stewart, 2021). Frugal innovation has emerged as a potential mechanism to increase innovation in a low cost and socially equitable manner in order to create the TEP. Finally, there is potential for water meters, remote sensors and mobile applications to form a cluster of technologies which is a requirement for the maturation of the technological revolution and TEP.

6.2.6 Cost

From a cost perspective, it would appear that costs for ICT technologies are either reduced or reducing. This is due to an improvement in telemetry costs which is aligned to the current ICT revolution. This criteria for a TEP is therefore met. However, the implementation of water technologies is still considered expensive when compared to the cost of using potable water in certain areas and this creates a barrier to technological adoption.

6.2.7 Entrepreneurship

From an entrepreneurship perspective there are observable market opportunities for water technology, but these are not being taken up primarily due to barriers in market entry. Entrepreneurship therefore requires external intervention in order to create market opportunities, to commercialise existing innovation and to de-risk early stage innovation. A mechanism to enable entrepreneurs is through mission-oriented financing which sees the State playing a determinant role in the trajectory and diffusion of innovation through funding and policies. Should the South African government designated water scarcity as a grand challenge which requires long term patient capital to develop innovation, then it would need to finance early stage innovation, incentivise take-up and de-risk private sector investment. This can be done through direct government funding or through development finance funding particularly for frugal innovation linked to entrepreneurship. In addition the role of entrepreneurs in water and sanitation should not be discounted at the policy level. The entrepreneurship criteria for a TEP are not fully met and require intervention.

6.2.8 Pervasiveness

From a pervasiveness perspective it would appear that adoption of water technologies and innovation is slow which is consistent with findings in literature given the risk aversion and negative profitability assumptions around watertech. These barriers therefore need to be overcome in order for the TEP to emerge. In contrast to the slow take-up, is the observation that where water technologies are adopted, they have become core to the functionality of organisations. There may therefore be scope to start new showcases and scale up existing showcases which highlight the value of these technologies using existing SEZ case studies in order to increase the pace of technological adoption.

From a policy perspective, this study has noted that current policies are insufficient to stimulate innovation and act as a deterrent in certain instances. Linked to the principles of mission-oriented finance is the need for policies which foster technological take-up and particular for water incentivise take-up and penalise the use of environmentally damaging water technologies. Policy change is also an outcome of the TEP as a result of changes in organisational and societal behaviour and the role of the government in driving this change particularly in the South Africa context of inequality and economic development cannot be discounted. The observation that these policies are not sufficient indicates the TEP has not emerged and may be stifled by existing policies. Although government policies reference future planning for water security, short term changes policy changes can be adopted to expedite this long term goal.

Linked to policies is the selection process for water innovation which is mostly biased towards off the shelf foreign technologies. However, in the SEZ the use of FDI to import foreign technologies may provide opportunities for secondary innovation wherein technologies are not merely adopted but assimilated and modified based on an increasing structural, functional and conceptual understanding. In addition, this would improve South Africa's ability to leapfrog other countries by using its latecomer advantage to improve on international water technologies and hasten the TEP. Localisation drives which see partnerships with foreign entities may foster both primary and secondary innovation. Tertiary innovation potential is exemplified in the use of non-water related technologies (i.e. big data analytics and cloud computing) in order to increase adoption of water technologies and eventually, build technical capabilities.

Finally, increased networks for knowledge sharing are required as part of the TEP but were observed as being limited in this study in related to the national system of innovation. Innovation hubs within the zones may be used to pilot and incubate innovation as well as used as ways to increase technological expertise and share information on new technologies.

6.3 Key conclusions of the study

6.3.1 What are the characteristics of water innovation within the circular economy that have a positive impact on economic development?

A decoupling of water demand from industrial production has been observed as an impact of the water CE in SEZs. This is evidenced by the increase in industrial activity and job creation with a reduction in water usage and pollution and increased water reuse.

6.3.2 Does water innovation drive the green techno-economic paradigm in South Africa? If so to what extent?

From a TEP perspective it would appear that water sector innovation is not driving the green techno-economic paradigm. Only the criterion of cost reduction is being observed and not that of increased entrepreneurship and organisational change (pervasiveness). This is in contrast to the findings of Mathews (2013) wherein it was determined that renewable energy is driving a green TEP.

6.4 Recommendations

6.4.1 For special economic zones:

- Inclusion of regeneration of natural systems as a focus area of CE activities.
- Include stakeholders in co-creation of CE policies and create mechanisms to actively plan for, execute and monitor the extent to which CE activity creates a decoupling of water demand from production.
- Consider innovation in wastewater treatment prior to effluent discharge to create process efficiency, cost reduction and water restoration activities.
- Consider the CE catalogue developed in this study in order to identify innovation opportunities and as a framework for comparing existing activities in order to determine gaps.
- Take a holistic approach to circularity planning in order to prevent unintended consequences on energy and biodiversity.
- Create monitoring and measurement tools which can assess the extent of environmental, social and economic impact.
- Look for frugal water technologies, which can be adopted and diffused as well as for the adoption of clusters of innovation in order to expedite the technological revolution.
- Continue to showcase the positive applications of water technologies in order to increase technological take-up.
- Use foreign direct investment to build secondary innovation capabilities and localisation opportunities.
- Use the vast services sector to as a mechanism for tertiary innovation for the adoption of new technologies and increase their pervasiveness.
- Develop new costing models which show the positive cost implications of water technologies particularly as the 2030 deadline for water scarcity approaches.

- Participate in formal and informal knowledge sharing through the national system of innovation to address biases towards existing technologies and foster technological take-up.

6.4.2 For governments and state-owned entities (policy recommendations):

- Consider using actual best practice activities when developing national guidelines for water circularity.
- Anticipate and invest in skills for green jobs to be created (from an innovation capabilities perspective) through the circular economy.
- Consider ways to build a circular WEF nexus which addresses scarcity in three areas rather than only one resource at a time.
- Rethink water scarcity in the context of a grand societal mission which requires government investment in the long term in order to create market adoption and diffusion of technologies through patient capital.
- Develop and co-create policies that are enforced for water innovation, and which incentivise adoption and penalise the use of inefficient technologies using data collected through water meters. Create mechanisms to monetise water innovation in a country where water is considered a basic human right and not a profitable market venture.
- Develop mechanisms that seek to outline and increase secondary and tertiary innovation in water in order to promote and foster original innovation in South Africa.

6.5 Suggestions for future research

This is a narrow study focused on circular activities within the SEZ and water. There is scope to either narrow the study further to specific industries or companies (e.g. agro-processing or mining) in order to perform in depth holistic case studies on water circularity and the environmental and social and economic impact. Alternatively, the scope of the study can be broadened to the macro-level industrial activities and their impact on the CE and TEP from a water perspective. A comparative study of the South African TEP to countries in Europe or others in the BRICS or the Global South more broadly, where the TEP can be identified more accurately is also a potential area of investigation. The impact of government policies on the TEP is the final notable area for further research.

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Appendix One – Research instrument

The purpose of this interview is to answer research questions for the research project *"Water innovation and the circular economy for special economic zones in South Africa"* with a special focus on the circular economy and driving a green paradigm.

Introductory questions

1. What is your current role and what do you do in that capacity as it relates to water?
2. Which of the SEZs in South Africa have you worked with or have familiarity with?

Circular economy related questions

3. What does the notion of the circular economy mean to you and how if at all does it inform the work that you do?
4. In your experience, in which areas do you believe present an opportunity to apply the principles of reduction, reuse and recovery for water within the SEZ context?

General innovation related questions: Circular economy

5. Could you share with me any information on new and notable ways in which firms within the SEZ address the principles of reduction, reuse and recovery through new through new products, services, or processes?
6. Could you share with me any information on the novel ways in which firms create value using an economic model that incorporates such principles as reduction, reuse and recovery into business activities that promote viable products and services? Are you seeing behavioural changes?
7. To what extent would you consider the above-mentioned ecologically-sensitive business activities as having an impact on the environment in the vicinity of the SEZ?
8. In your experience, what has been the socio-economic impact of such initiatives, if any? (e.g. job creation, poverty and inequality reduction, increased economic output etc.)

Techno-economic paradigm related questions:

Focusing in on the technology aspect, I wanted to understand the broader water related technologies used in the SEZ.

9. Which ICT enabled technologies used within the SEZ to address water challenges are you aware of?
10. Have you noted any changes to technologies adopted recently, or are technologies relatively stable? What are the challenges to take-up. Are the technologies becoming generic.

11. To what extent are the new technologies part of core water treatment or remediation functions, or part of the enabling functions for their effective implementation?
12. In your experience, how do existing policies and strategies encourage and are specific kinds of innovation (e.g. digital versus non-digital) encouraged over others.
13. To what extent have these technologies reduced overall costs? Could you share an example of such a policy?
14. What new opportunities for entrepreneurship in the water value chain due to these technologies do you see? (e.g. new ventures created from new technologies or a scaling up of these by existing firms in the SEZ).
15. How are these technologies selected? To what extent are digital solutions preferred over non-digital. To what extent are local solutions selected versus non-local.
16. Nanotechnology, for instance, is an emerging technology that is widely reported to have numerous applications in the water industry. Can you share with me the nature of the interactions with research bodies as it relates to such emerging water technologies either through the SEZ or at the firm level?

Closure

17. What are your closing comments? Could you kindly suggest any other persons who might have different perspectives, to possibly interview?

Thank you for your time, input, and for granting this interview at short notice.