THE CIRCULAR ECONOMY AS DEVELOPMENT OPPORTUNITY

Exploring circular economy opportunities across South Africa's economic sectors

Edited by
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Contents

Preface ……...……..…… ii
Linda Godfrey

Chapter 1: Driving economic growth in South Africa through a low carbon, sustainable and inclusive circular economy ……..…….. 1
Anton Nahman, Linda Godfrey, Suzan Oelofse and Douglas Trotter

Chapter 2: Placing the South African mining sector in the context of a circular economy transition ……...…… 9
Sumaya Khan, Zintle Nontso, Fleckson Magweregwede, Linda Godfrey and Busi Sereme

Chapter 3: Supporting food security and economic development through circular agriculture ……..……..…….. 18
Blessed Okole, Greg Gordon, Bernadette Brown, Boyse Pillay, Chanel Schoeman and Linda Godfrey

Chapter4: Supporting the development of a globally competitive manufacturing sector through a more circular economy ……..……...… 27
Shahed Fazluddin, Vincent Ojijo, Anton Nahman and Linda Godfrey

Chapter 5: Creating resilient, inclusive, thriving human settlements through a more circular economy ……...……...…… 36
Antony K Cooper, Tinus Kruger, Linda Godfrey and Mark Napier

Chapter 6: Facilitating sustainable economic development through circular mobility ……..……...…… 44
Refiloe Mokoena, Anton Steenkamp and Linda Godfrey

Chapter 7: Decoupling South Africa's development from energy demand through a more circular economy ……..…...……. 53
Xolile Msimanga, Linda Godfrey and Brian North

Chapter 8: Decoupling South Africa's development from water demand through a circular economy ……..……...…….. 61
Ashwin Seetal, Matlhodi Mathye and Linda Godfrey

Preface

The circular economy is not about waste management, but about sustainable resource management. With this as context, transitioning to a more circular economy becomes an imperative for every country, city or society in managing its development risks.

South Africa, a developing country facing very high levels of unemployment, poverty and inequality, has a very linear, resource extractive-based economy, with large throughputs of resources; export of resources for further international beneficiation; little resource 'investment' in local stocks; and even smaller resource returns into the economy. This places the country at risk in terms of resource depletion or over exploitation, with the potential to directly disrupt future development. At the same time, there is growing demand, and competition, by industrialized countries for access to finite resources, forcing resource-rich countries to re-evaluate their strategic approach to resource use.

South Africa's economy is carbon-intensive. More than 70% of South Africa's primary energy comes from the burning of coal. With high energy demands in industry (52% of total national energy demand) the knock-on effect is a carbon (and resource) intensive manufacturing sector. The transport sector draws 19% of the national energy demand, with the majority (98%) of the transport sector's energy supplied through petroleum products. With 77% of land freight still transported via road in South Africa, this makes the movement of goods and people highly carbon-intensive. Not surprising, South Africa's energy sector is the largest contributor to national greenhouse gas (GHG) emissions (80% in 2017) (excl. FOLU) and was responsible for 97% of the GHG increase over the period 2000-2017. In 2020, South Africa's CO_2 emissions were the 12th highest in the world, accounting for 1.3% of total global emissions. Despite this, rolling blackouts since 2008, continue to plague the country. The opportunities for decarbonising South Africa's economy, and driving greater energy security through circular economy interventions cannot be underestimated.

As a water scarce country, South Africa faces significant challenges around future water security. National water demand is expected to exceed supply by 17% by 2030, effectively capping South Africa's development, unless measures can be rapidly implemented and scaled, to decouple development from water consumption. This is particularly relevant in the agriculture sector (with 61% of South Africa's water allocations), and in our cities and towns (with around ~30% of water allocations). Inefficiencies in water use across economic sectors, combined with water leakage through deteriorating infrastructure, means that circular interventions within agriculture, human settlements and manufacturing are urgently needed. These challenges are further exacerbated by the legacy of spatial planning and current approaches to urban development.

The circular economy is recognised globally, as an opportunity to reframe economic development, unlock new economic and socio-economic opportunities, and achieve global climate and sustainable development commitments.

Transitioning to a more circular economy calls for a system change, and while it has largely been interpreted as an environmental concept, it is ultimately an economic issue, requiring collaboration and cooperation across all national government departments. With both systems and multisectoral expertise, the Council for Scientific and Industrial Research (CSIR) is well positioned to explore the complexities and opportunities of a circular economy transition in a relatively resource-rich, developing country such as South Africa, through the lens of science, technology and innovation.

The intention of this book is to present the CSIR's position and interpretation of the circular economy, and to use it to drive discussions on where immediate circular economy opportunities are achievable in South Africa. Opportunities that can be harnessed by business, government and civil society. These circular economy opportunities are framed in this book within the context of the current challenges facing various economic sectors. The CSIR has selected seven, resource intensive sectors – mining, agriculture, manufacturing, human settlements, mobility, energy and water – for further assessment. Many of these economic sectors have seen significant declines over the past years, with agriculture, manufacturing, transport and construction all showing negative growth pre-COVID. These are all sectors under economic stress and in need of regeneration. South Africa stands on the threshold of profound choices regarding its future development path. Transitioning to a more circular economy provides the country with the opportunity to address many national priorities including manufacturing competitiveness, food security; sustainable, resilient and liveable cities; efficient transport and logistics systems; and energy and water security, while at the same time decarbonising the economy. The transition to a circular economy provides the country with an opportunity for green and inclusive development to be the cornerstone of a post-COVID economic recovery.

The message is clear. Transitioning to a more circular South African economy is no longer an option or a 'nice-to-have'. As a country already feeling the impact of resource constraints, sustainable resource use is critical to South Africa's future development.

Linda Godfrey
Editor

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Abbreviations

ACEA	African Circular Economy Alliance
ACEN	African Circular Economy Network
BECCS	Bioenergy with carbon capture and storage
BIDF	Biorefinery Industry Development Facility
BNG	Breaking New Ground
BRICS	Brazil, Russia, India, China, South Africa
CAGR	Compound Annual Growth Rate
CCUS	Carbon capture use and storage
CDM	Clean Development Mechanism
CO_2	Carbon Dioxide
CRM	Critical Raw Material
DALRRD	Department of Agriculture, Land Reform and Rural Development
DFFE	Department of Forestry, Fisheries and Environment
DHS	Department of Human Settlements
DMRE	Department of Mineral Resources and Energy
DoT	Department of Transport
DSI	Department of Science and Innovation
Dtic	Department of Trade, Industry and Competition
DWS	Department of Water and Sanitation
CGCSA	Consumer Goods Council of South Africa
CSIR	Council for Scientific and Industrial Research
EI4WS	Ecological Infrastructure for Water Security
EoL	End-of-life
EPR	Extended Producer Responsibility
EU	European Union
EV	Electric vehicle
FCEV	Fuel cell electric vehicle
GACERE	Global Alliance on Circular Economy and Resource Efficiency
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse Gas
GWh	Gigawatt hours
HV	Hydrogen vehicle
IAIP	Integrated agro-industrial parks
IAP	Invasive alien plants
IC	Internal combustion
ICEV	Internal combustion engine vehicle
ICT	Information Communication Technology
IEP	Integrated Energy Plan

IoT	Internet-of-Things
IRP	International Resources Panel
IRP	Integrated Resource Plan
IS	Industrial Symbiosis
IUDF	Integrated Urban Development Framework
LIB	Lithium-ion battery
LCA	Life Cycle Analysis
LED	Light emitting diode
LPI	Logistics Performance Index
NATMAP	National Transport Master Plan
NCPC	National Cleaner Production Centre
NDC	Nationally Determined Contribution
NDP	National Development Plan
NMT	Non-motorised transport
NWMS	National Waste Management Strategy
OEM	Original Equipment Manufacturer
PBS	Performance-Based Standards
PGM	Platinum Group Metals
PPA	Power purchase agreement
PV	Photovoltaic
R&D	Research and Development
RE	Renewable energy
REI4P	Renewable Energy Independent Power Producer Procurement Programme
RTMS	Road Transport Management System
SANBI	South African National Biodiversity Institute
SDG	Sustainable Development Goals
SEZ	Special Economic Zones
STI	Science Technology and Innovation
TOD	Transport-oriented development
TWh	Terawatt-hour
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organisation
VRP	Value Retention Processes
WCDoA	Western Cape Department of Agriculture
WCEF	World Circular Economy Forum
WEEE	Waste electrical and electronic equipment

1

Driving economic growth in South Africa through a low carbon, sustainable and inclusive circular economy

Anton Nahman, Linda Godfrey, Suzan Oelofse and Douglas Trotter

The circular economy is gaining traction as a new model for sustained and resilient economic growth and job creation[1]. It provides the means to meet international climate commitments, and to achieve the Sustainable Development Goals. A shift to a circular economy in South Africa provides opportunities for low-carbon, sustainable and resilient economic growth; and to address the triple challenges of inequality, poverty, and unemployment.

1.1 From crisis to opportunity

South Africa's economy is plagued by stagnant GDP growth, significant unemployment, and persistent poverty and inequality. The COVID-19 pandemic has led to a further deepening of the economic crisis; and highlights the urgency for a new development model to drive economic recovery. Furthermore, there is a need to place South Africa's growth path, as outlined in the National Development Plan[2], within the context of the country's resource base.

As a developing country rich in natural resources, South Africa is characterized by an extractive-based economy; with large throughputs of resources, much of which ends up as waste (solid, liquid and gaseous); and limited productive return of resources into the economy (Figure 1.1). A large proportion (20%) of the domestically extracted resources are exported for further beneficiation off-shore, while there is limited use of resources for building up local 'stocks' of infrastructure such as buildings, roads and rail[3].

This reliance on raw material extraction and exports puts our future development prospects at risk, in terms of over-exploitation and depletion of resources, and predicted declines in demand for our exports. Further, while this model has led to economic growth in the past, the gains in prosperity have not been shared equally among the population, further entrenching social inequality. The South African economy therefore bears the environmental, social and economic burden of providing resources for the global market.

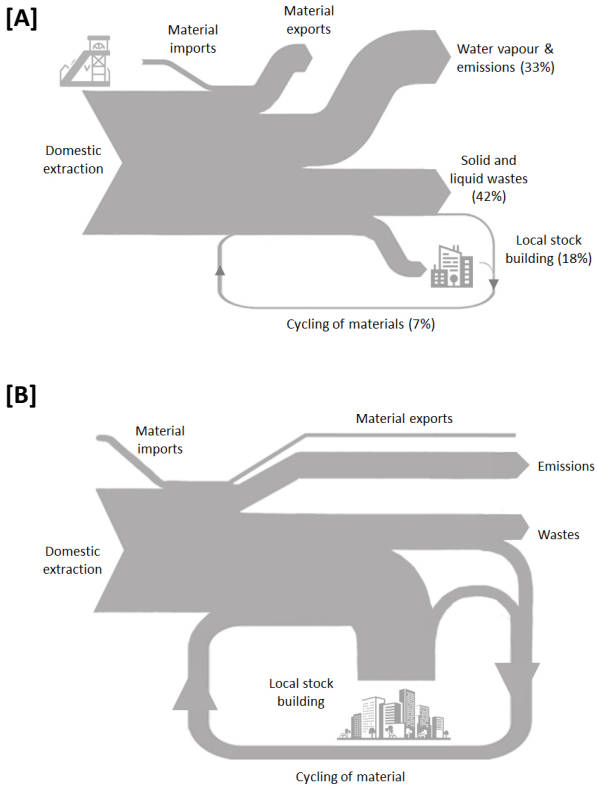

Figure 1.1. [A] Flows of materials through the South Africa economy in 2017 (adapted from von Blottnitz *et al.*[3]); compared to material flows in a more circular economy **[B]**

This raises the question as to whether South Africa is using its resources in the best interests of its people, and of its development priorities. The need to "build back better" following the pandemic[4] provides an opportunity to rethink how we are using and managing our resources. Could using our resources in a more efficient and productive way, in which they are retained in the economy for as long as possible, and with a greater emphasis on local value adding and stock building, help to unlock development and employment opportunities?

1.2 From linear to circular

The prevailing economic development paradigm, both locally and globally, can be described as a linear 'take-make-dispose' or 'take-make-waste' economic model. Resources are extracted from the natural environment and used to make products, which are often used for only a short period of time, before being discarded back into the environment[5,6]. Throughout this process, vast amounts of material and energy are used; while significant emissions and waste are generated.

The linear economic model is incredibly wasteful, inefficient, and costly. In addition to significant losses in economic value in the form of wasted raw materials and energy, underutilised assets, and disposal costs[5]; the linear model has contributed significantly to natural resource depletion; degradation of land and soils; biodiversity loss; air and water pollution; waste; and climate change[4,5]. For example, according to the International Resource Panel[7], resource extraction and processing is responsible for approximately 50% of climate impacts, 90% of water stress, and 90% of biodiversity loss due to land use.

South Africa is characterized by a particularly linear economy. Material cycling in South Africa is estimated at 7% (Figure 1.1)[3], of which 5% is the result of ecological cycling of biomass and organic waste. The socio-economic cycling rate (recycling and reuse of materials within the economy) is only 2%. There is increasing evidence that this linear model is no longer sustainable, and presents a risk to South Africa's future growth.

1.3 What is a circular economy?

The circular economy is recognized globally as an opportunity to reframe economic development and unlock new opportunities for growth and employment; while achieving global commitments relating to climate change and sustainable development, and reducing the negative impacts associated with both resource extraction and waste.

In contrast to the linear economic model, a circular economy "*entails keeping materials and products in circulation for as long as possible through practices such as reuse of products, sharing of underused assets, repairing, recycling and remanufacturing*"[8].

A circular economy therefore minimises the need for extraction of primary resources, while also reducing waste. It provides opportunities for improved resource efficiency and resource security, reduced energy and materials consumption, and reduced climate impacts; while offering new sources of economic growth and job creation. In short, it supports improved socio-economic development and well-being, while reducing associated environmental and human health impacts.

The circular economy is based on three principles: Design out waste and pollution; keep products and materials in use; and regenerate natural systems[9].

Contrary to how the concept is often perceived, a circular economy is about far more than simply improved waste management and recycling. It instead involves a systemic shift away from the traditional linear 'take-make-waste' economy; and encompasses a radical transformation of the ways in which resources are used and products are designed, and of the relationship between producers and consumers.

It therefore challenges us to change the way we think about product ownership, with a greater emphasis on product sharing, renting, repair, refurbishment, upgrading, recycling and reuse. It calls for a complete paradigm shift, creating opportunities for entirely new business models based on resource sharing, product-as-service, and access-over-ownership; facilitated through advances in digital technology.

1.4 Benefits of a circular economy for developing countries

International studies show that a transition to a more circular economy can create direct socio-economic benefits, including GDP growth; new sources of job creation; more robust employment; increased profits (through both cost savings and increased revenue from new business services); reduced reliance on increasingly scarce raw materials; increased disposable income for individuals; enhanced utility and convenience; and improved living conditions and health[5,9]. In addition, a circular economy creates direct environmental benefits, including reduced use of virgin resources; reduced waste and pollution; the regeneration of natural systems; and a significant contribution to meeting climate targets[4,5].

The circular economy is increasingly recognized as a key driver of a post-pandemic economic recovery, and a new source of more sustained and resilient economic growth, particularly in developing countries. Other BRICS countries, particularly China and India, have taken the lead in exploring the significant opportunities associated with the transition to a more circular economy[10,11]. It provides an opportunity for emerging economies to "leapfrog" the development models of the Global North, through innovation and early adoption of more sustainable and inclusive growth paths. It also provides an opportunity to build more resilient, sustainable economies that are better able to withstand future shocks – not only pandemics; but climate-induced natural disasters such as droughts and floods, and resource shortages, all of which are predicted to increase in both frequency and intensity in future.

South Africa has already felt the impact of resource constraints, particularly relating to water and energy. Decoupling growth from resource use, e.g. through enhanced circularity, creates an opportunity to better manage risks in terms of future resource constraints, and to build resilience. In addition, the current heavy reliance on raw material exports puts the economy at risk – as other countries transition toward circularity, their demand for our resources will decline. South Africa stands to lose €8.4 billion in raw material exports (equivalent to 2.7% of GDP) if the European Union moves to a fully circular economy[12]. It is therefore essential that we rethink the way in which we utilize our resources, in order to safeguard our future development.

1.5 The policy context for a circular economy in South Africa

The transition to a circular economy is well aligned with South Africa's developmental priorities as articulated in the National Development Plan[2] and the Sustainable Development Goals (SDGs); and with the country's climate commitments as outlined in our Nationally Determined Contribution (NDC) (as updated). The circular economy is also seen as a key driver of a post-COVID economic recovery, and is enjoying growing political support[13,14]. An important focus is on the need for a 'just transition'; and for an *inclusive* circular economy, that is, a circular economy that benefits the economically marginalized members of society, through employment creation and small business development[15].

While the South African policy landscape in relation to the circular economy is currently very fragmented, cutting across many line departments (including DMRE, the dtic, DFFE, DWS, DALRRD, DHS, DoT, DSI); a policy context is starting to emerge, in the form of, for example:

- the White Paper on Science, Technology and Innovation[16], and the Decadal Plan[1], which identify the circular economy as a key new source of economic growth;
- the updated National Waste Management Strategy (NWMS)[17], in which the circular economy is a central concept;
- the Extended Producer Responsibility (EPR) Regulations[18];
- as well as the broader policy framework relating to the green economy[15].

South Africa is also playing a leading role in advancing the circular economy across Africa, as co-chair of the African Circular Economy Alliance (ACEA), and co-founder of the African Circular Economy Network (ACEN). It is also active in the international landscape, as a member of the Global Alliance on Circular Economy and Resource Efficiency (GACERE), and as an active participant in the World Circular Economy Forum (WCEF).

1.6 Unlocking South African opportunities: The need for a sectoral focus, and a systems view

South Africa has been driving elements of a circular economy for decades, through return water flows, renewable energy and waste recycling, for example. However, these activities have not (yet) reached a scale where they can meaningfully transform the economy and decouple growth from resource consumption and environmental impact[14].

Furthermore, the circular economy has often been narrowly interpreted in South Africa as a 'waste' issue; i.e., as synonymous with recycling or with the waste hierarchy. Circulating waste back into the economy as secondary resources is indeed an immediate 'low-hanging' opportunity. However, international studies, including in other BRICS countries[10,11], have shown that the greatest opportunities for driving circularity and improved resource productivity lie in resource-intensive sectors of the economy, such as agriculture and manufacturing; as well as those that directly affect human well-being, particularly in the context of rapid urbanization, such as human settlements and mobility.

The circular economy is a systems concept, that cuts across all economic sectors. To understand the opportunity that it provides for South Africa, it is necessary to adopt both a sectoral focus, and a broad systems approach. In other words, there is a need to identify specific opportunities within key sectors of the South African economy, while also piecing these together into a systems view of the collective opportunity.

The transition to a circular economy must also be driven by evidence and supported through innovation. As a leading scientific and technology research

organization, with both sector-specific and integrative expertise, the CSIR is well positioned to inform the national circular economy discourse, and to identify circular economy opportunities for South Africa.

Drawing lessons from circular economy strategies in other developing countries[10,11,19], and adapting these to the South African context (taking into account the contribution of each sector to GDP and employment in South Africa, as well as those that are inherently resource-intensive, and where potential exists for value-adding processes to be localised); the CSIR has identified the following five sectors as having significant potential for circular economic development (Figure 1.2):

- Mining
- Agriculture
- Manufacturing
- Human settlements
- Mobility

In addition, two cross-cutting thematic areas have been identified, representing key resources and infrastructure for all economic activity in South Africa, and which are currently facing significant constraints in being able to meet increasing demands; and where there is therefore an urgent need for innovation in terms of resource efficiency and sustainability:

- Energy
- Water

The CSIR is undertaking studies aimed at identifying and unlocking specific circular economy opportunities within all seven of the above-mentioned economic sectors and cross-cutting thematic areas (Figure 1.2).

1.7 Conclusion

South Africa stands on the threshold of profound choices regarding its future development path. In following the global trend for green and inclusive development to be the cornerstone of a post-COVID economic recovery, the President has called for a recovery that is transformative, inclusive, digital, green and sustainable[20]. A circular economy transition is core to the South African development pathway; with the President affirming that "*we cannot afford to be out of step with international moves towards green growth and green development*"[21].

While the circular economy is gaining traction internationally, increased circularity in the Global North will inevitably have consequences for extractive-based economies such as South Africa. Implementing a circular economy domestically provides opportunities for safeguarding our economy against future resource constraints and volatility in international markets, while unlocking the socio-economic benefits (particularly job creation) associated with economic

growth. It also provides opportunities to develop local value-adding industries; and to compete in export markets that are placing increasingly stringent environmental requirements on products.

Figure 1.2. Identifying circular economy opportunities for South Africa through a cross-sectoral approach

International literature and best practice suggest that the circular economy is not just about waste and recycling, but about sustainable resource management. In a developing country context, it is about managing risks to economic development, and unlocking new opportunities for growth and job creation. In the South African context, the greatest opportunities are likely to lie in resource-intensive sectors, such as mining, agriculture, and manufacturing; and in those that directly affect human well-being, such as human settlements and mobility; as well as in energy and water, as two key resources underpinning the economy. There is a clear need to identify appropriate circular economy opportunities and interventions for South Africa. The CSIR is well positioned to inform South Africa's choices in transitioning to a more circular economy, and to help unlock these opportunities through science, technology and innovation.

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2

Placing the South African mining sector in the context of a circular economy transition

Sumaya Khan, Zintle Nontso, Fleckson Magweregwede, Linda Godfrey and Busi Sereme

The mining and metals industry has a significant role to play in a circular economy as it provides the primary materials for consumer-use. Many South African mines already adopt elements of a circular economy with the potential to grow their initiatives to a larger scale for a subsequent meaningful impact on the economy.

2.1 Introduction

South Africa is richly endowed with mineral resources. The Minerals-Energy-Complex is an important feature of the South African economy – not only in the provision of minerals and metals into the domestic market, but also the global economy. It is a resource intensive sector, both in the provision of resources, but also as a major consumer of resources such as energy, water and chemicals. However, the contribution of the mining sector to the development of the country is gradually diminishing due to declining productivity; increasing operating costs; fluctuating exchange rates and commodity prices; declining ore grades; increasing mining depth; and health, safety, social and environmental challenges[1].

The circular economy is positioned as a framework from which to grow prosperity, jobs, and resilience while reducing greenhouse gas (GHG) emissions, waste, and pollution. However, the circular economy has traditionally been seen as a threat to the mining sector, based on a philosophy of reducing primary resource extraction in favour of the collection and reprocessing of secondary resources or "wastes"[2]. Early concepts of the circular economy placed mining outside of the circular economy (Figure 2.1), however recent studies show that the circular economy has a lot to offer the mining sector through sustainable resource use.

The CSIR recognises the role of the mining sector in South Africa's transition to a more circular economy. Firstly, in the role that the sector plays in providing minerals and metals into downstream economic sectors such as manufacturing, human settlements and mobility. Secondly, the circular economy creates an opportunity for the mining sector to become more competitive and innovative through the adoption of circular economy principles by designing out waste, closing resource loops; and regenerating natural systems: [3,4,5]

- **Design out waste**, e.g., redesign mining processes and value chains to be more resource efficient
- **Keep materials in use**, e.g., reduce, reuse and recycle various waste streams, including end-of-life equipment
- **Regenerate natural systems**, e.g., renewable energy, restoring mining landscapes

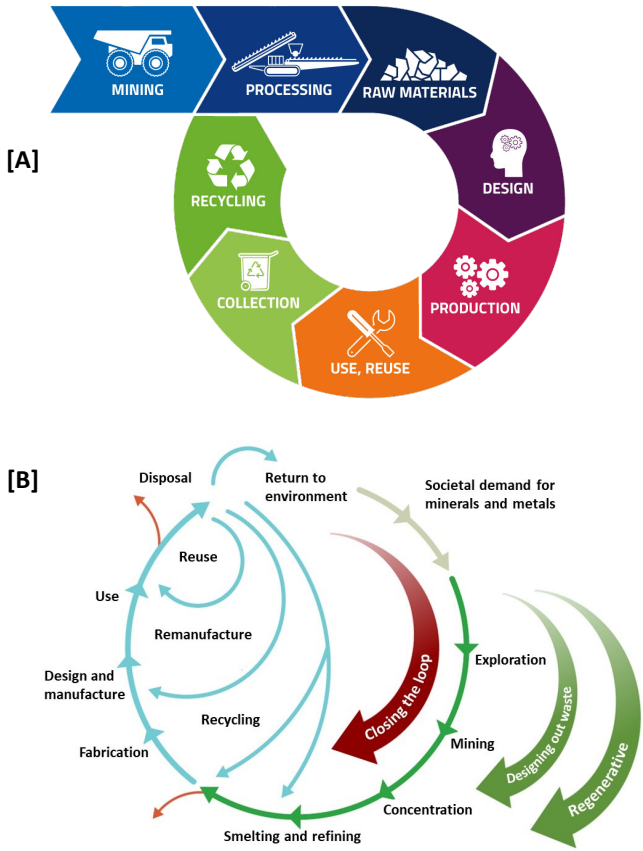

Figure 2.1. Integrating the main life cycle stages for minerals and metals into the circular economy (adapted from **[A]** EIT[29]; and **[B]** ICMM[5])

The circular economy also has the potential to unlock new growth areas for the South African mining sector. Transitioning to a low-carbon future, as called for in the National Development Plan (NDP, 2030), will require more and different minerals and metals, not less[6]. And despite growing innovation in closing resource-loops, primary demand for minerals and metals is unlikely to be fulfilled by secondary resource supplies alone, given the limitations in the quantity, quality and accessibility of waste materials[7]. Urban mining also provides an opportunity for

mining houses to diversify their access to minerals and metals, at higher grades and lower costs.

Globally, 50% of climate impacts, 90% of water stress, and 90% of biodiversity loss is a result of resource extraction and processing[8]. Changing the way we produce and consume resources is critical to addressing a number of global societal threats. The COVID-19 pandemic has also highlighted the need for more resilient and sustainable supply chains, including those for minerals and metals, which are facing their own set of challenges.

The reliance of the South African economy on minerals and metals raises the questions: Is resource scarcity and resource security the driver behind South Africa's circular economy transition, as seen in many countries? And is there an understanding of the resources needed to achieve South Africa's development objectives as outlined in the NDP?

2.2 The current state of mining in South Africa

The mining sector has always played a pivotal role in the South African economy with national gross domestic product (GDP) contributions in excess of 20% in the 1970s[9]. Over the years, the GDP contribution has steadily declined, with current contributions reported to be at 8%[10]. In 2020, mining directly contributed R371.9 billion to the GDP, a decrease from R376.4 billion in 2019[11]. The sector employed 452,866 people in 2020, a decline from 462,039 in 2019[11].

South Africa has the world's largest resources of platinum group metals (PGM), manganese, chromium, and gold[12]. Other economically important resources include coal, iron ore and diamonds. In 2019, mineral resource exports alone accounted for 39% of the GDP while imports accounted for 15%. Mineral exports included PGMs, iron-ore, coal, gold, manganese, petroleum (when overproduction occurs), and chromium. Imports primarily comprised petroleum and bauxite[13].

South Africa has a rich policy landscape governing the mining sector. The Department of Mineral Resources and Energy (DMRE) promotes and administers the regulations of the mining and minerals sector. Their goal is to promote economic growth, social prosperity and environmental sustainability through the mineral resources and energy sectors[14]. The sector is regulated by the Mineral and Petroleum Resources Development Act (2002) (as amended). The Mining Charter is a regulatory instrument that details specific measurable targets for the industry and aims to facilitate transformation, sustainable development, and growth of the industry[15]. Regarding environmental management, Regulation 5 of the 2015 Financial Provisioning Regulations published under Government Notice R1147 requires every mining company to set aside rehabilitation funds that can be used for the management, remediation and rehabilitation of all environmental impacts arising from mining activities. The regulation falls under the National Environmental Management Act (107 of 1998) administered by the Department of Forestry, Fisheries and Environment (DFFE). While the circular economy is not yet recognized in South African mining policy, the mining sector's existing policy framework can serve the sector as it transitions to a more circular model.

However, legislation alone is not enough to ensure the transition to a low-carbon, sustainable and inclusive mining sector. The mining sector faces a number of growing challenges. Amongst the adverse socio-economic and environmental impacts is its contribution to climate change, over-exploitation of resources, pollution, and a rapidly growing carbon footprint[3]. A recent material flow analysis for South Africa shows that our economy is dominated by the extraction of resources supporting export markets with little local stock building; large throughputs of gaseous, liquid and solid wastes; and very little productive return of resources back into the South African economy[16]. While other countries benefit from our minerals and metals, South Africa is left with the legacy of growing volumes of mining waste, and associated soil and water pollution.

Reducing carbon emissions is a key environmental challenge facing South Africa. Coal-generated electricity is the primary energy source for mining companies[17]. Coal mining and associated power utilities play a dominant role in the generation of GHG emissions. South Africa is ranked as the 12th largest contributor to global GHG emissions, accounting for 1% of global emissions[18], with 15% of South Africa's GHG emissions originating from the mining sector[19]. Apart from environmental consequences, the country faces the risk of lack of investment if we lag in our transition to carbon-neutrality. This could in turn have a direct impact on employment rates in the mining sector. These issues are further complicated by a sector now chasing complex ore bodies, mined at greater depths, with aging infrastructure, resulting in increasing operating costs, and severe health and safety concerns[20]. There is an increased demand for access to reliable energy, better quality of resources, and transitioning to carbon neutrality[21]. Development and implementation of policies and incentives to promote circularity in the mining sector is required to stimulate economic growth and create alternative employment opportunities.

2.3 The South African mining sector in a circular economy

The following section explores the circular economy in the context of the mining sector – as a driver of a circular economy transition, but also as an opportunity for the sector.

1. Resource scarcity and security as driver

For many countries, resource scarcity and security has been the driver to a circular economy transition. These countries face limited access to the primary resources needed to support their development. The European Union, for example, has tracked this in terms of Critical Raw Materials (CRM) since 2008[22]. CRMs are those raw materials that have high economic importance, high supply shortage risk, and are difficult to substitute[23]. It is currently unclear as to whether South Africa has an understanding of the resources needed to achieve its development objectives, including the remaining years of economically viable mineral resources, and the local and global demand for these resources. This information is considered critical to mitigating the risks to South Africa's development.

Another factor affecting South Africa's mining sector, is the transition by other countries to a circular economy. If the European Union, for example, were to shift to a fully circular economy, the demand for South Africa's resources is expected to decline, with a resultant impact on local GDP. This would further exacerbate the unemployment rate in the country, but could present an opportunity for greater local beneficiation.

2. Circular economy opportunities in the mining sector

Transitioning to a circular economy also provides opportunities for the mining sector, aligned with the three circular economy principles –

Design out waste and pollution

New and emerging technologies are being explored for increased precision and efficiency in ore extraction, with minimal energy usage; reduced water and capital intensity; and less waste production. For example, coarse particle recovery, bulk sorting, ultrafine recovery, and *in situ* mining[24]. Efficient extraction involves a more complete extraction of the ore, extending the life of mining operations, and increasing the range of mineral recovery. This reduces the need to open new greenfield mines (minimising the environmental footprint) and provides diversified opportunities for economic return.

Reducing dependence on fresh water in mining operations can contribute positively to ecological systems. Possible innovative technologies for water recovery and recycling include dry processing; evaporation management; novel leaching; and dry stacking. This will also eliminate the need for wet tailings storage facilities and instead create stable, dry, and sustainable land. Substitution of raw materials, where possible, could potentially minimise the overall production of waste, reduce health and environmental impacts, and reduce carbon emissions from excessive mining operations, for example, the use of thiosulphate leaching as an alternative to cyanide in gold processing.

Keep products and materials in use

Closing resource loops is focused on keeping resources circulating within the economy through reuse, repair, refurbishment and recycling. While there is still much to be done here, this concept is already adopted by some South African mines at a site-level. Opportunities include the re-purposing of waste rock; making bricks from clay-rich tailings; zero-waste-to-landfill strategies; using scrap metal in combination with primary concentrates to produce metals; producing fly ash geopolymers; secondary smelting of electronic scrap to recover valuable metals such as gold, silver, copper and palladium; and optimising the recovery of co-products, e.g., a nickel mining company can increase the recovery of co-products such as PGM, cobalt and copper[5]. Additionally, re-mining of tailings has the potential to revive economic opportunities for mining companies.

Given the growing stress on South Africa's water resources, further compounded by changing climates, closing the loop on wastewater, and the recovery of potable water from e.g. acid mine drainage, create immediate opportunities for mines.

Regenerate natural systems

The impact of coal-powered electricity generation remains a crucial issue that needs to be urgently addressed if the country is to achieve its low-carbon goals. The transition to renewable energy, through a green industrialisation strategy, is critical to a circular economy transition. This could be utilised to power mining haulage fleets, machinery, and equipment, amongst other uses. The integration of renewable energy such as solar, wind, hydrogen (green energy) to power mining operations will reduce energy consumption, costs and carbon footprint. For example, Gold Field's Westonaria mine plans to move towards 20% solar powered operations by 2022 to partially mitigate the impacts of Eskom's unreliable supply[25].

Green hydrogen mining has huge economic potential for South Africa, which would consequently result in increasing demands for PGMs (platinum is used as a catalyst in fuel cells)[26]. The advent of hydrogen mining may lead to the adoption of fuel cell technologies in the country, used in electric vehicles (EVs). Mining companies such as Anglo American and Impala Platinum have already adopted the use of fuel cell electric vehicles (FCEV) at South African operations. The production of green hydrogen requires renewable energy (solar and wind power), both of which are vast in South Africa. This creates opportunities to decarbonize the South African economy while creating new markets through the export of green energy[26].

While the concept of a circular economy is relatively new to the South African mining sector, it is clear that many of the underlying principles are already being applied in the sector, although perhaps not yet at the scale for meaningful impact. These initiatives, however, have mainly been driven from a waste management and eco-efficiency context and not from a circular economy context. And while reducing, re-using, and recycling materials are highly feasible to adopt, the 'high impact' principles of regeneration of natural systems and designing out waste require large investments, often making them difficult and slow to adopt[4].

2.4 The benefits of a circular mining sector

According to ACEA[4], the adoption of circular economy principles may benefit the mining sector, by:

- Reducing operating costs and increasing efficiency, through optimised use of resources;
- Increasing access to capital by meeting investor requirements on climate change and social issues;
- Staying ahead of regulatory requirements, by adopting comprehensive sustainable measures;
- Adapting to the global shift in consumer demand for environmentally-friendly products, and hence the changing demand for materials supplied by the sector; and
- Mitigating growing internal and external reporting pressure from global mining institutions.

Several opportunities discussed in the previous sections either have been or are in the process of being implemented at some South African mines. This suggests that these initiatives are not unrealistic in a South African context. A significant overall positive impact could be achieved if a larger proportion of mines, or even better, the mining sector, were to adopt these practices.

The fact that minerals and metals are finite resources is undeniable. This raises many questions with regards to South Africa's future security: What are the implications to our economy, and to society, if our resources were depleted or inaccessible? If South Africa's global trading partners were to adopt more circular models of their own, where does that leave South Africa as a major exporter of raw materials? These questions lend themselves to the need for South Africa to diversify its economic activities while decoupling economic development from primary resource consumption. One such intervention would be to add value to raw materials through greater local beneficiation. Apart from beneficiation, the potential for other downstream (and upstream) interventions across the mining value chain need to be assessed if the country is to meaningfully benefit from its resources in the long-term[27].

Embedding the mining sector in South Africa's transition to a more circular economy, has the potential to create new jobs, while also reskilling and upskilling existing mine employees. This would consequently increase the demand for training facilities and change management specialists, thereby further enhancing the country's socio-economic position.

Placing the mining sector within the circular economy also creates synergies with other sectors. Young[28] for example, suggests that there could be significant socio-economic value through partnerships between mining companies and more circular sectors, such as automotive and technology companies.

2.5 Conclusion

Although South Africa is richly endowed in mineral resources (now), future socio-economic development may be jeopardized by continuing with a traditional, resource-intensive, linear, take-make-dispose approach. Government and industry must understand the role of the mining sector within a resource-secure growth path.

The current challenges facing the mining industry need to be addressed, including, national objectives of a just transition to a low-carbon economy. The circular economy provides us with a model to address some of these challenges. Considering emerging technological innovation, there is a need to understand what South Africa's critical raw materials are, and if resource scarcity is a driver for South Africa to transition to a more circular economy. South Africa is well positioned to take advantage of these circular opportunities.

Many mining companies have already adopted some of the principles of a circular economy, implying that there is potential to scale their application to achieve meaningful impact. If strategically addressed, the circular economy should not be considered a threat, but rather a model with potential to unlock new opportunities for the mining sector. Global investment into the mining sector could accelerate the drive towards economic growth, carbon neutrality and social well-

being through the circular economy. Further studies will provide a means to explore the circular economy opportunities for the South African mining sector in more detail.

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3

Supporting food security and economic development through circular agriculture

Blessed Okole, Greg Gordon, Bernadette Brown, Boyse Pillay, Chanel Schoeman and Linda Godfrey

"Circularity in agriculture has to be reachable and it has to be tangible. It needs to be a thing that people will embrace because they can afford it, and because they see its value". (Footprint Africa)[26]

3.1 Introduction

The agriculture sector relies heavily on resources and natural cycles as its primary inputs. Resources such as water, energy, soil, and nutrients underpin the functioning of the ecosystem in which the sector operates. However, these resources are finite and are already facing constraints in South Africa. Growing food demand and environmental challenges such as climate change, land degradation, biodiversity loss, and resource scarcity are increasingly pressurizing the agricultural system, impacting food security. The sector currently faces numerous challenges. Climate change is directly affecting agricultural productivity in South Africa through changes in precipitation and temperature patterns; surface water runoff; crop and animal breeds; new pests and diseases; and fertilization programs[1].

Changing agricultural practices, such as monocropping, which has replaced traditional methods of growing multiple crops on a piece of land, results in a loss in soil productivity and resultant soil degradation. This is enhanced through the increased use of chemical inputs, facilitating a vicious cycle whereby with each harvest, more chemical fertilizers and synthetic pesticides are required. South Africa already faces declining soil quality and generally, low organic matter levels[2]. Small-scale and household farmers are constrained by poor infrastructure and logistics. Opportunities to address these challenges are often constrained by the lack of access to modern technologies that can cheaply and easily revolutionize the sector. These include technologies like precision-farming, mobile or digital platforms, vertical farming, anaerobic bio-digesters or agri-processing options.

Food losses and waste in South Africa are a growing reality, estimated to be in the order of 10.3 million tonnes in 2021, or 34.3% of local production. In 2013, the cost of food losses and waste to society was already R61.5 billion, equivalent to 2.1% of national GDP[3].

Continuing to follow a resource intensive, linear path, focused on short-term efficiency gains, will ultimately risk national food security. On the other hand, a systemic approach based on circular economy principles can build a value-preserving model that would be regenerative, resilient, non-wasteful and healthier[4]. When applied to the agriculture sector, the circular economy principles of designing out waste, closing resource loops; and regenerating natural systems, provide a framework for South Africa to address food security[5]:

- **Design out waste**, e.g., precision farming; peri-urban and urban farming (bringing food production and consumption closer); the sharing economy
- **Keep materials in use**, e.g., returning nutrients to the agricultural system; biorefinery; value-add of waste products
- **Regenerate natural systems**, e.g., crop rotation; intercropping; mixed farming, reduced or zero till

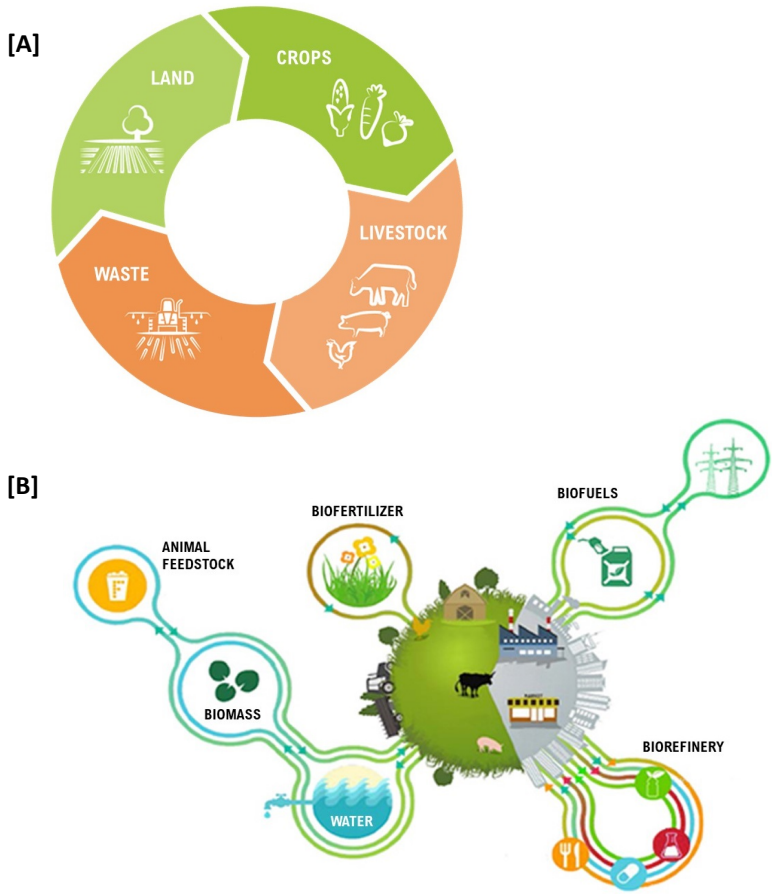

Figure 3.1. Circular agriculture and the valorization of waste from the agri-food sector (adapted from **[A]** WUR[6] and **[B]** AgrocCycle[7])

'Circular agriculture' centres on a regenerative system, with the production of agricultural commodities using a minimal amount of external inputs; decoupling production and processing from resource utilization; closing nutrient loops; restoring soil fertility; and reducing discharges to the environment. The circular economy has the potential to make businesses more economically viable, competitive and sustainable in the long-term, reducing risks linked to external inputs and commodity prices; reducing the pressure on natural resources; and opening new revenue streams through innovation, new technologies and collaboration between sectors and industry. If practiced on a wide scale, circular agriculture can reduce resource requirements (e.g. water, energy), land-use, chemical fertilizers, synthetic pesticides, GHG emissions, and ultimately the ecological footprint of agriculture.

3.2 The South African agricultural sector

South Africa is a major producer and exporter of agricultural products. The diversified agricultural sector produces a wide variety of agricultural commodities and is driven by both large-scale commercial farmers with sophisticated harvesting, storage and processing systems, and small-scale family farms practicing subsistence farming. Food production and retail is dominated by large corporations and large supermarket chains respectively[8]. The sector contributes 3% to South Africa's GDP. In 2019, the total income earned in agriculture and related services was R351,4 billion, with animals and animal products' generating the largest sales (R153,1 billion), followed by 'horticultural crops and products' (R86,3 billion) and 'field crops' (R61,9 billion)[9]. In 2021, the agricultural sector rebounded sharply (6.2% vs -0.1%) due to increased production of field crops, horticulture and animal products. The sector is projected to register a Compound Annual Growth Rate (CAGR) of 4.2% during the period, 2021-2026[10]. In 2019, the sector employed 5.0% of South Africa's working population which equates to 768,171 workers[9]. While the sector is a labour intensive one, employment in agriculture has declined every decade since the 1970s[11].

Land used for commercial agriculture is 46,4 million hectares, which represents 37,9% of the total land area of South Africa[12]. The sector is resource intense on water, energy, inorganic fertilizers, and synthetic pesticides to improve yields. Agriculture accounts for 61% of South Africa's water allocation (*See Chapter 8*) with all large irrigation schemes supplied from storage dams. As a result of high conveyance losses, a significant proportion of this water does not reach farmers[13]. Consequently, there is a need to improve crop water requirements and associated irrigation scheduling in order to improve water productivity in the sector[14]. Energy drives agricultural activities, with agriculture accounting for 6% of South Africa's energy demand in 2016 (*See Chapter 7*). The agriculture sector has a high demand for liquid fuels, accounting for 87% of its energy demand, followed by electricity at 13%[15]. The energy needs are mostly in farming machinery, and the transportation of agricultural raw materials, feeds, intermediary and finished products from farms to various markets. In 2018, chemical fertilizer consumption for South Africa was 72.8 kg/hectare compared to a sub-Saharan average of 17 kg/hectare[16].

South Africa has a rich policy landscape applicable to agriculture and agro-processsing. The Agricultural Policy of 1998, Section 4 focusses on the conservation of agricultural resources. A number of other policies, including waste policies, have potential relevance in driving a more circular agriculture sector. The White Paper on Science, Technology and Innovation recognizes the circular economy as a new growth area for South Africa, with the need to modernize and strengthen productive sectors such as agriculture. The dtic and line departments are developing several sector master plans to support South Africa's industrialisation efforts. Relevant plans have been developed for agriculture and agro-processing, and the forestry, poultry, and sugar sub-sectors. While these plans focus on economic development, many already hint to circular economy principles.

3.3 Opportunities for greater circularity in agricultural systems

Circular economy opportunities in the agriculture sector are briefly highlighted, aligned with the three circular economy principles:

Design out waste and pollution

Precision farming has shown good potential in increasing the efficiency of conventional agricultural systems when combined with regenerative practices. The use of agricultural IT, remote sensing and real-time environmental data can optimise crop yields, increasing farmer income, while reducing environmental externalities. Precision agriculture provides enhanced control over inputs like energy, water, fertilisers and agrochemicals by delivering the right amount, at the right time, and at the right place, using geo-spatial variability in soils, micro-climate and other relevant husbandry parameters. Precision farming promotes good stewardship of the land for future generations and preserves its potential for multiple uses. An example is *Fruitlook*[17], where the Western Cape Department of Agriculture (WCDoA) is offering a state-of-the-art information technology that helps deciduous fruit and grape farmers to be water efficient and climate smart. *FruitLook* allows these farmers to improve their water use efficiency using information from spatial data derived from remote sensing, which provides semi-real-time information on crop growth, evapo-transpiration deficits, and nitrogen status for irrigation blocks. This technology is currently limited to orchards and vineyards in the Western Cape's key growing areas.

Agricultural mechanization is a key driver of efficient farming systems. Business models for mechanisation hire services through the sharing economy, can facilitate greater access to advanced equipment, supporting improved productivity – particularly for small-scale farmers. Globally, the agricultural sector is seeing a shift from an owner-focused value proposition to a customer-centered one, through product-as-service. This has now extended to farmer group service providers. In this model, a group of farmers pool their resources and increase access to agricultural mechanization services. Services cover all operations in the agricultural value chain, from tillage to post-harvest activities, processing, and transport. The benefit is that the machinery is available to the farmer at lower prices; with optimization of heavy machinery (e.g., tractor) use; machinery is driven or

controlled by an expert; timely access to the equipment; access by vulnerable groups including women; and flexibility for payment.

Emerging technology innovations have the potential to enable greater circularity in South Africa's food systems, for example by increasing supply chain efficiency, boosting farm productivity, and improving citizen's nutrition. Examples include:

- Chemical leasing which is centred around a unit of payment which is no longer related to the chemical itself, but to the benefits of the chemical. The focus shifts from increasing the sales volume of chemicals to a value-added approach.
- Mobile or digital platforms that create better connections between producers and consumers.
- Digitally enabled business models to facilitate equipment sharing or on-demand services.
- Packaging technologies and agro-processing technologies to reduce post-harvest and food losses.

Keep products and materials in use

There are substantial food losses and wastes in supply chains, from farm to table. This is largely due to the lack of required market infrastructure; lack of safe transport; improper handling and packaging; lack of standardization and grading; under-developed cold chains; and improper processing. South Africa has committed to halve per capita food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses by 2030, in line with the Sustainable Development Goals. The Consumer Goods Council of South Africa (CGCSA) has given effect to this through a food loss and waste voluntary agreement[18].

Where food losses and waste cannot be prevented, they can be productively recycled back into the economy through various technology routes, including composting to organic manure, or anaerobic digestion to produce bio-energy. South Africa's chemical fertiliser consumption is more than three times higher than the sub-Saharan average[19]. An opportunity exists to increase the use of organic fertilisers, so that nutrient loops are closed and the need for mineral fertilisers is reduced. The application of organic fertilisers will also help to rebuild the topsoil and soil holding capacity of agricultural lands. For centuries, animal waste from livestock farming has been used as a source of fertilisers and soil improvers for agriculture. Rich in macro-nutrients like nitrogen, phosphorus and potassium, they enrich the soil and improve its aesthetics.

Organic waste streams can also be used to recover high-value materials through biorefinery technologies, including various platform chemicals[20]. The Biorefinery Industry Development Facility (BIDF), hosted by the CSIR, is working with several industries across the agriculture and agro-processing sectors to find appropriate, high-value solutions for various organic waste streams traditionally destined for disposal to land[21]. When optimally implemented, these pathways can result in full value chain processing of waste biomass. This obviates the need to dispose of waste

through landfilling, burning, stockpiling, or discharge to sea, and with it mitigating the generation of GHG emissions.

South Africa already faces challenges in terms of food security; water scarcity; a decrease in arable land; high population growth and rapid urbanisation. The adoption, in urban and peri-urban settings, of sustainable farming systems, such as vertical agriculture, hydroponics, aquaculture, aquafeed from agricultural waste, and aquaponics, could result in several advantages and benefits:

- The production of fresh, healthy, nutritious, and pest-free food all year-round – where production is not dependent on the weather.
- Significant reduction in the use of water – vertical farming uses 96% less water and recycles the water.
- The use of renewable energy.
- Efficient use of land and production can take place in urban, industrial, and rural settings close to consumers and market thus reducing transport costs, and consequently carbon emissions.
- Higher yields per cultivated hectare and no loss of harvest because of adverse weather conditions, drought, or pests.
- Longer shelf life of produce and reduction in input costs.

The use of treated wastewater, rain water harvesting and return-flow systems where drainage and surplus irrigation are channeled back, are integral elements of circular agriculture.

Industrial symbiosis also provides opportunities for keeping materials in use. Through the intentional clustering of mutually beneficial resource-converting industries, by-products and waste materials from one company can be used as input into another. UNIDO is supporting the establishment of integrated agro-industrial parks (IAIP) throughout Africa. The objectives of IAIPs are to create a better environment for increased investment in agro-food and allied sectors; drive the structural transformation of the economy; and reduce rural poverty. Based on the agri-business value chain concept, a rigorous base of specialized services are deployed targeting the weaker links of the chain including: agricultural mechanization, modern processing technologies, packaging of perishable products, the promotion of food safety in the processing and regulatory environment; and interventions to improve competitiveness and productivity. The IAIP is a geographic cluster of independent companies grouped together to provide economies-of-scale and add value to the output of the agricultural sector, thereby improving competitiveness and productivity. This includes providing shared services for the reuse and beneficiation of waste[22].

Regenerate natural systems

Regenerative agriculture, such as indigenous knowledge-based agriculture, is not new in South Africa. Regenerative agriculture aims to preserve the integrity of the natural system. Traditional practices such as crop rotation; inter-cropping; mixed farming (combining livestock and crop production to create additional nutrient

loops); minimum tillage; agroforestry (tree planting in combination with crops or pastures), ecological aquaculture; food waste application in gardens; and cover cropping can support circular economy goals towards an optimised agricultural system. This approach can facilitate a wide set of long-term benefits including nutrition; preservation of genetic biodiversity; carbon capture, soil protection; water conservation; lowering external inputs and improving the larger ecosystem as a whole. This is in stark contrast to linear agriculture's narrow focus on short-term productivity and yield gains through intensive farming practices and synthetic inputs – at the expense of long-term farm health and the environment. Effective regenerative agriculture approaches need to encompass aspects such as: embracing crop biodiversity, leveraging traditional agro-ecological knowledge, as well as appropriate technology and scientific knowledge on eco-systems, soil health, nutrition and resilience – whilst being adaptive to the context and geography[23].

It is clear that the principles of a circular economy are not new to the South African agriculture sector. Transitioning the sector from a linear to a circular one is a necessity to support food security and to unlock new economic opportunities. However, the sector requires the development and application of new knowledge, leading to innovative, technological, and sustainable processes, products, and services[24]. The circular economy has the potential to be scaled and fast-tracked through a number of global trends[25], many of which have direct bearing on the agriculture sector –

- Smart farming
- Sensor technology
- Information technology
- 3D and 4D printing
- Smart materials
- Robotics
- Autonomous micro-robots
- Bioinformatics
- Renewable energy
- Biorefinery and biofuels
- Genetics
- Synthetic biology
- Protein transition
- Food design
- Aquaculture
- Vertical agriculture
- Conservation technology
- Transport technology

3.4 Conclusions

Agriculture is a highly resource intensive sector, with a demand on South Africa's energy and water systems for land preparation, seeding, irrigation and harvesting, amongst others. The water-energy-food nexus is fundamental to South Africa's economy, and any increase in demand in any one sector has knock-on effects on the others. Transitioning to a more circular agricultural system creates very real social, economic and environmental benefits for South Africa. These include improved food security; resilience; global competitiveness; economic development; job creation; decarbonising the sector; sustainable resource utilization; and sustainable food systems.

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4

Supporting the development of a globally competitive manufacturing sector through a more circular economy

Shahed Fazluddin, Vincent Ojijo, Anton Nahman and Linda Godfrey

"The lesson for South Africa is to build greater economic resilience – at firm and economy level – and pursue 'strategic autonomy' goals, which in the South African context demands greater levels of innovation and industrialisation". Minister of Trade and Industry

4.1 Introduction

The South African manufacturing sector has suffered from de-industrialization over the past two decades, mimicking global trends. However, the local manufacturing sector continues to operate on the linear 'take-make-dispose' economic model, plagued by excessive resource demand, unsustainable production and consumption patterns, and high levels of wastage. There is a need for systemic shifts in production and consumption patterns to enable effective resource utilization to achieve sustainable economic growth, preserving natural capital and improving socio-economic wellbeing.

Various policy and economic drivers have resulted in a declining demand from South Africa's main export markets, which has seen the sector's GDP contribution fall from over 20% in 1993 to 13% in 2020[1]. The South African manufacturing sector, despite its decline, remains a sizeable contributor to national greenhouse gas (GHG) emissions, largely through the sector's fossil-based energy use, and liquid fuel demand[2]. The heavy economic dependence on resource extraction in favour of exports is well recognized (*See Chapter 2*). Despite massive inputs of natural resources, productivity within the manufacturing sector remains low, while significant volumes of waste and pollution are generated[3].

The application of circular economy principles of designing out waste, closing resource loops; and regenerating natural systems offers a systemic approach to addressing these challenges and achieving resilience of the local manufacturing economy[4] as outlined below:

- **Design out waste**: redesign manufacturing processes and products to enhance resource efficiency, coupled with sharing economy business models.
- **Keep materials in use:** remanufacture, refurbish, repair and recycle materials and products across value chains.

- **Regenerate natural systems:** transition to green energy (solar, wind, hydrogen) and decouple resource utilization.

The implementation of circular economy thinking can enhance sectoral innovation and competitiveness[5]. This is evident from global trends. The newly adopted EU Circular Economy Action plan forms one of the main anchors for the region's sustainable growth agenda - the European Green Deal[6]. The plan focuses on *design* and *production* for a circular economy ensuring that resources are continuously recirculated within the economy.

Circular solutions can similarly be leveraged locally to fulfil national development objectives, climate obligations and Sustainable Development Goals, with emphasis on economic growth, poverty alleviation, infrastructure development and job creation[7]. The CSIR recognises the pivotal role of the manufacturing sector in driving re-industrialization and the transition to a circular economy. Indeed, the manufacturing sector, in close collaboration with other economic sectors, is centrally placed to design and implement the circularity of resources, with positive impacts on the economy, society and the environment. Manufactured products, chemicals, plastics and industrial machinery play a key role in the productivity and growth of both upstream and downstream economic sectors, such as agriculture, mining, energy, and water. Applying circular principles in the design of products, manufacturing companies can influence the production process, and indeed the entire product life cycle, including usage and end-of-life scenarios (Figure 4.1)[7].

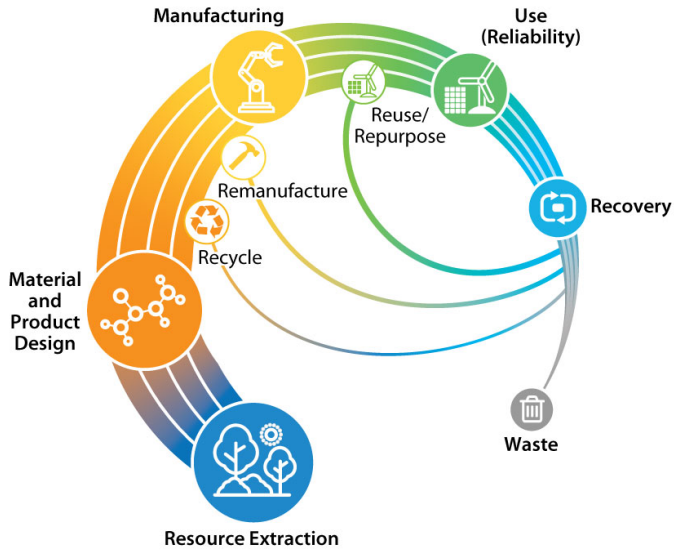

Figure 4.1. Integration of circular economy into manufacturing (from NREL[8]).

4.2 Overview of the South African manufacturing sector

The manufacturing sector ranks fourth in GDP contribution, embodying a diverse list of sub-sectors, each demanding a broad range of resources, processed materials and finished products. The main sub-sectors by contribution (%) are as follows: food and beverages (26%), petroleum and chemical products (including plastics and plastic products) (24%), basic iron and steel (19%), wood products, paper and printing (11%), motor vehicles, parts and accessories (7%), glass and non-metallic mineral products (4%), textiles and clothing (3%), furniture and other manufactured products (3%), and electrical machinery (2%)[9]. The three largest sub-sectors account for over two thirds of manufacturing activity[1]. Despite the sectoral GDP doubling since 1994, its contribution to national GDP has declined, forcing labour migration towards the services industry[10].

The manufacturing sector has high resource demands, relying strongly on primary and secondary processing of extracted resources (e.g. base metals) and other feedstocks. These finite resources face increasing risk from over-exploitation. Moreover, the country mostly exports un-beneficiated ores and unwrought base metals, apart from motor vehicles, and associated spares and accessories. Lack of local beneficiation is exacerbated by high levels of manufactured imports (>80% in 2020), comprising: motor vehicles, parts and accessories (13.6%); machinery and equipment (11.9%); chemical products (8.9%); and basic chemicals (5%)[1]. In addition, the sector draws 52% of national energy demand (*See Chapter 7*) and 3% of the national water allocation (*See Chapter 8*). Electricity costs have outpaced inflation for over a decade, exceeding R9Bn by Q3 2019 for the iron and steel subsector alone[11]. Blackouts lead to production losses, rising costs, reduced competitiveness and investment. Over 80% of sectoral energy is sourced from coal-fired utilities, a major GHG source[12].

Currently, industrialization driven by localization, import substitution, beneficiation, and embracing of both green and hydrogen economies are key thematic areas of the policy landscape, which if leveraged could pave the way for socio-economic recovery based on circular economy models. The 10th Industrial Policy Action Plan tackles the decline in manufacturing, having to date boosted the automotive and textiles industries, designating specific products for preferential procurement (rail stock, transformers, etc)[13]. Special Economic Zones designated by the SEZ Act, 2014 also present opportunities for promoting circularity in local manufacturing[14]. The OR Tambo SEZ recently launched for fuel cell manufacture, Platinum Valley SEZ for auto-catalyst production and PGM recycling, and Tshwane Automotive SEZ exemplify policy driven revival of the sector.

The **dtic** industry Master Plans afford further opportunities for growth and transition toward a more circular South African economy. Localization driven by preferential procurement and the secure supply of raw materials, chemicals and equipment are key underlying strategies. The Steel Industry Master Plan mandates the use of locally manufactured steel for key infrastructure programs, and value-chain development for capital and transport equipment. Export of steel scrap is restricted via ITAC controls and export taxes, given its economic value[15]. Cross-border carbon taxes will penalize local manufacturers, hence the 2050 Master Plan

targets on carbon neutrality for local industry. Power-intensive steel mills, foundries, and smelters reliant on fossil-fuels are highlighted as opportunity areas for renewable energy and gas, water conservation and waste reduction.

The waste sector is recognised by Government as an important industry in which technology and innovation have a crucial role to play in creating a secondary resources economy and driving greater circularity as envisaged in the 2020 National Waste Management Strategy (NWMS)[16]. Despite policy-driven changes aimed at overcoming sector challenges, a detailed stock-take and gap analysis are needed to frame a more coherent approach to circularity.

4.3 Circular economy opportunities in the manufacturing sector

Potential opportunities in the manufacturing sector, as aligned to these circular economy principles, are highlighted here:

Design out waste and pollution

Circular business models have come to the fore in recent years, e.g. product-as-service, product sharing, remanufacturing and circular supplies. Changing usage patterns via the sharing economy and product-as-service models can realize significant economic and environmental gains. Tata Steel and the Indian Steel Authority set up *mjunction*, an e-market for steel waste, allowing traders transparent access. *mjunction* has evolved into the world's largest e-market for steel, with trade volumes increasing from $13.8m in 2002 to $9.45Bn in 2016[17].

By selling product functionality or services rather than products *per se*, companies can manage an entire product life cycle, and associated costs, by developing closed material flow loops[4]. Renault, for example extends and optimizes the EV battery lifecycle by selling it as a service. Since starting, battery leasing is now preferred by over 90% of customers. Renault further extended its EV battery lifecycle by cascading to energy storage applications[17]. In the EU, the circular chemical leasing model shifts focus from increasing sales volumes to value-addition, where the client pays per functional unit, ensuring that both supplier and end-user achieve reductions in chemical use[18].

Manufacturing product design must consider optimising materials, durability, and repairability to design out waste. In the *textiles industry*, there is increased focus on design of more durable, re-usable and eco-friendly textiles. Natural fibre development can help avoid use of harmful chemicals in the textiles value chain, a global problem. Improved textile design would reduce the level of hazardous chemicals and micro-fibre waste entering ecosystems[19]. In the *plastics industry*, the South African Plastic Pact calls for zero waste by redesigning problem packaging such that 100% of plastics are reusable, recyclable, or compostable by 2025[20].

Improved resource efficiency in manufacturing is critical to the sectors global competitiveness. The National Cleaner Production Centre (NCPC-SA), tasked by the **dtic**, fulfils a vital role in helping reduce energy, water and materials use across various manufacturing sub-sectors. Over the period 2010-2020 the NCPC's industrial energy efficiency program has worked with 274 large companies and 180 manufacturing SMEs, saving over 6500 GWh in energy and R5.275 Bn in direct

costs[21]. The recent NCPC I-GO (Integrated Greening Operations) initiative, facilitated on behalf of UNEP aims to scale-up resource efficiency efforts of SMEs in Africa.

Keep products and materials in use

Circular economies aim to optimize resource yields by constantly circulating products, components, and materials at highest utility. Tight product cycles are a key circularity trait, circumventing a loss of embedded energy, resources and labour from simple recycling and disposal. The remanufacture of industrial equipment by Value Retention Processes (VRPs) can reduce virgin material usage by 80-98% and cost by 15-80% over Original Equipment Manufacturer (OEM) products[22].

Globally, remanufacturing is dominated by the automotive and aerospace sectors (*See Chapter 6*), as well as construction, electrical equipment, heavy machinery and medical devices. However, global uptake remains low due to lack of infrastructure, supply chains and investment in remanufacturing technologies[23]. Remanufacturing of internal combustion (IC) engines is a well-established industry within the local automotive sector. In contrast to simple reconditioning, local ICE remanufacturers adopt industry standards to guarantee used engines are returned to OEM approved specifications through an extensive and audited process. Remanufactured engines provide levels of performance, reliability and lifespan that equal, and, in many instances exceed the original[24].

Caterpillar, the global heavy machinery OEM has been remanufacturing components since 1973. Caterpillar's dedicated remanufacturing arm (CAT Reman) is now a leader in developing value recovery processes and technologies, profitably growing to nine locations worldwide (>3500 employees) based on its component recovery business model. Durable parts enjoy repeated remanufacturing, e.g. gearboxes, drivetrains and brakes[4]. The circular framework of designing for multiple remanufacturing cycles has been increasingly used by CAT, given that the major costs lie in materials (65%).

Local manufacturing features an established recycling industry across various sub-sectors, despite a need to improve recycling rates. The South African *metals sector* has established a mature scrap metal recycling industry, achieving a recycling rate of 80% in 2018[25]. Continued recycling is necessary to maintain steel scrap in a constant loop, and to supplement primary steel production, given the insufficiency to satisfy rising world demand. Almost half of EU steel originates from secondary process and end-of-life (EoL) scrap[26]. A strategic value chain with opportunity for closing resource loops is the primary processing of local platinum group metals (PGMs). The reliance on exports of unwrought PGM base metals mandates the need for local beneficiation. Dedicated SEZs for fuel cell and auto-catalyst manufacture present opportunities for refurbishment and recycling of components at EoL, enabling beneficiation and retention of extracted precious metals within the local economy.

The *electrotechnical sector* is one of the fastest growing sectors globally, with high resource demands and high levels of waste electrical and electronic equipment (WEEE). Since 2014, e-waste has grown by 9Mt globally. Currently, <10% of locally generated WEEE is recycled, mostly pre-processed with export for metal

recovery, resulting in the loss of resources. Increasing the local WEEE recycling rate would provide local job opportunities[25].

The South African *plastics sector*, despite implementing voluntary EPRs two decades ago, has only achieved a 43% collection rate (input), with much lower recycling (output) rates. Plastics recycling is an important local industry with opportunity for businesses to actualise the SA Plastic Pact target: all packaging to contain 30% recycled content with 70% of packaging effectively recycled by 2025[18]. Extended Producer Responsibility (EPR) regulations for paper and packaging, e-waste and lighting are expected to significantly scale up the collection, reuse, repair and recycling of these goods in line with mandated targets[27].

The *clothing and textiles sector* requires significant circular interventions given its impacts in terms of resource demand and resultant wastage. Currently, less than 20% of textiles are recycled globally, despite a massive environmental burden. As a developing country, end-of-life clothing in South Africa often finds reuse opportunities driven by high levels of poverty and unemployment. Locally, organisations such as *The Clothing Bank*, and *Rewoven*, have partnered with major local retailers to drive greater textile reuse of excess stock, customer returns, store damages, end-of-season and bulk rejections. The textile sector can phase out hazardous substances, enhance resource utilization, adopt renewable resources and inputs, and radically improve recycling along the value chain via circular interventions. Cascaded recycling allows re-use of textiles in lower value applications (insulation, cleaning materials, etc)[19]. NCPC-SA has partnered under the UNEP's InTEX project in developing Innovative Business Practices and Economic Models across the textiles value chain[21]. NCPC and GreenCape have championed industrial symbiosis (IS) to close resource loops, with opportunities to scale up and lower material input costs, whilst addressing resource scarcity and waste[28]. Over the period 2015-2020, NCPC assisted 80 companies through IS, diverting 215,000 tonnes of waste resources from landfill and saving R17.7m in landfill diversion[21].

Regenerate natural systems

In addition to the sector adopting more renewable energy solutions, the emerging green energy market (estimated at R30Bn) offers new circular manufacturing opportunities. NERSA's exemption on self-generation (up to 100MW) renders embedded generation via local solar panel, wind tower and turbine manufacture feasible. A 1GW/yr solar PV market is sufficient for five manufacturers to set up local facilities of 200MW each, providing opportunities for circular renewable energy products[11]. Policies call on national R&D organizations to assist in developing a green, circular industry[13]. Bio-based energy and materials, including bio-catalysis, can also help in moving away from fossil-based resources.

Circular impacts can be further achieved by adopting a suite of tools, such as Life Cycle Analysis (LCA), an important part of circular economy modelling and analysis. LCA quantifies resource inputs and outputs to air, water and soil over the product lifecycle, complementing circular economy models by testing model assumptions and exploring alternatives[29]. Mitigating resource use throughout

product lifecycles can help restore natural systems and reverse pollution damage, whilst enabling carbon footprint or climate change impact reductions.

It is clear that the application of circular economy principles is not new to the South African manufacturing sector, with activities being driven locally, regionally and internationally to decouple growth from resource consumption and transition to alternative circular economy business models. However, while many of the underlying principles are already being applied in the local manufacturing sector, more needs to be done in achieving the scale required for meaningful impact. Collaboration at all levels is vital, and companies can employ the ReSOLVE framework (regenerate, share, optimize, loop, virtualize, exchange) to navigate the complexities in transitioning to a circular economy[30].

Scaling circular manufacturing will require disruptive technologies, including digital technologies such as Internet-of-Things (IoT), big data, and blockchain, which allow for advanced tracking and monitoring of resource utilization and waste capacity. Additive manufacturing for instance, has disrupted traditional manufacturing processes (machining, casting, injection moulding) enabling reductions in development costs, resource utilization, waste and energy consumption. Its on-demand, digitally distributed manufacturing, allows for reduced physical inventories and more resilient supply chains.

4.4 Conclusions

South Africa needs to reverse pre-mature de-industrialisation trends of the past two decades in a more sustainable and inclusive manner, moving away from the linear economic 'take-make-dispose' model to a more resilient economic framework. The manufacturing sector is centrally placed to unlock circular opportunities, by designing and producing for circularity of resources, and adopting circular business models that minimise consumption.

The benefits of a circular economy include environmental gains, job creation, and improved competitiveness due to greater efficiencies and reduced manufacturing costs. New opportunities exist in designing out waste by enhancing resource efficiency, re-use, and remanufacture. New businesses can be created by closing resource loops using value retention processes, and existing circular initiatives can be scaled to achieve impact. Similarly, new circular manufacturing opportunities exist in the green energy market, and adoption of renewable materials for regeneration of natural capital.

Digital transformation driven by 4IR technologies allow for advanced monitoring of resource utilization and waste. Industry Master Plans afford further opportunities for growth and transition toward a more circular South African economy, providing a framework from which to drive circularity as part of re-industrialization. To aid in this transition, impact investment is required, as well as enhanced collaboration within the local manufacturing sector.

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5

Creating resilient, inclusive, thriving human settlements through a more circular economy

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Circularity in resource flows in cities can tackle the consumption of resources, such as energy, water, buildings and land. Systems integration, flexibility, intelligence, cooperative behaviour, localisation, recycling and renewable resources are the key concepts under-pinning the Circular City[20].

5.1 Introduction

Human settlements – whether cities, towns or villages – include the built environment (houses, engineering infrastructure etc.), the natural environment (vegetation, water bodies etc.), amenities (such as healthcare and recreation), and the residents (people)[1]. Given their composition and purpose, settlements are resource-intensive nodes consuming vast quantities of construction material, food, energy, water, and other resources. Similarly, settlements generate various types of waste, such as wastewater, greenhouse gas (GHG) emissions, and associated pollution.

Cities occupy 3% of the earth's land surface, but they are responsible for 60-80% of energy consumption, and more than 75% of the world's natural resource consumption[2]. It is estimated that cities contribute up to 75% of global carbon emissions, with transport and buildings being among the largest contributors[3]. This large footprint is primarily due to the vast extraction, transport and construction activities involved, as well as the energy used to light, heat and cool dwellings[4].

Due to the nature of South Africa's energy system (electricity and liquid fuels), many human settlements are energy- and carbon-intensive centres. A study that tracked the energy use of 20 of South Africa's most energy-intensive cities and towns revealed that they accounted for 38% of the country's total energy consumption in 2017 and were responsible for 29% of the country's emissions[5].

A large portion of South Africa's energy is consumed within human settlements. In 2019, 42% of the country's electricity was sold to redistributors, mainly municipalities. The distribution of electricity by sector in 2020 further underscores the extensive and inefficient use of electricity within settlements (*See Chapter 7*). Industry is the largest electricity consumer (52%), the residential sector consumes 8%, and the commerce and public services sector 14%. Activities linked to these sectors largely take place within human settlements[6]. In addition to electricity,

settlements also use significant amounts of water. Municipalities supply 27% of South Africa's water allocations to residential, commercial, and industrial users[7] (*See Chapter 8*).

Settlements do not function in isolation. They are interconnected and have symbiotic relationships with the regions within which they are located. There are various forms of links, or networks, within and between settlements to distribute goods, services, and people, such as roads, railways, and pipelines. For instance, various types of food are produced in rural areas and have to be transported to cities and towns. These networks contribute to the demands on energy and water, while they also increase pollution, carbon emissions and waste, including large quantities of food waste (*see Chapter 3*).

When applied to human settlements (Figure 5.1), circular economy principles – eliminating waste and pollution, closing resource loops, and regenerating natural systems – provide a promising framework for South Africa to transition to inclusive, resilient and sustainable cities[8]:

- **Design out waste**, e.g., green, energy-efficient buildings, more compact cities, pedestrian-friendly neighbourhoods.
- **Keep materials in use**, e.g., circular construction value chains, circular organics, waste management.
- **Regenerate natural systems**, e.g., urban agriculture, renewable energy, green roofs, green open spaces.

Figure 5.1. Circular and regenerative cities (adapted from UCL[9])

5.2 Human settlements in South Africa

About two thirds of South Africa's population lives in urban areas[10]. While urban areas may provide opportunities, the country's socio-economic context affects cities and towns. Poverty, unemployment, inequality, crime and violence impact on the sustainability and liveability of human settlements. Many characteristics of South Africa's human settlements result from planning principles and approaches influenced by the apartheid ideology and the modernist approach to urban planning. The legacy is still visible in spatial patterns and the form and structure of South African cities and towns, including sprawl, and low-density and mono-functional neighbourhoods. This results in inefficiencies and the wasteful use of scarce resources, especially land and infrastructure networks[11].

Despite well-intended policies and strategies, many parts of South African cities and towns still face challenges such as a lack of adequate infrastructure, facilities and amenities, low levels of service and few or undesirable public spaces. South Africa's public infrastructure was graded D+ overall in 2017, indicating deterioration[18]. A key framework guiding the future growth and management of urban areas is the Integrated Urban Development Framework (IUDF). Its purpose is to steer urban growth towards a sustainable growth model of compact, connected and coordinated cities and towns[11]. Another key document is the Comprehensive Plan for the Development of Sustainable Human Settlements (Breaking New Ground - BNG). It encourages higher densities, mixed land use, integrating land use and public transport planning and a more compact urban form to create more diverse and responsive environments and reduce travelling distances. The spirit of these, and other policies and strategies, clearly support the principles of the circular economy in developing and managing human settlements in South Africa – but they need to be implemented.

Prior to the BNG policy approach, government's housing subsidy programme has in the last 20 years contributed to the single-house-on-a-plot model of development, perpetuating sprawl. These developments are often located on the periphery of cities and towns, and therefore residents generally have to travel long distances between their homes and their workplaces, shops, amenities, and facilities. This increases pollution and results in inefficient use of resources[1]. Middle- to high-income lifestyle and security estates developed on the outskirts of cities and towns further contribute to the expansion of the urban edge with similar negative environmental consequences. This development model means that municipalities need more resources and infrastructure to render services such as water and electricity provision, and waste collection. It also requires more maintenance of infrastructure.

Informality manifests in South Africa's human settlements as informal settlements and the way income is generated. About 26% of urban dwellers live in informal settlements[12]. The government has targeted programmes to support informal settlement upgrading. The informal economy supports many households and contributes to poverty alleviation and economic growth.

Many municipalities struggle to execute their mandates effectively. Challenges they face include poor service delivery; low levels of payment for municipal services; ageing infrastructure; and inadequate maintenance (resulting, for instance, in substantial water losses due to leaks). In South Africa, most buildings, especially houses, are constructed using conventional "bricks and mortar". Despite stated support for alternative or innovative building technologies from various government departments, academics, researchers and practitioners, such technologies have not been widely adopted. Government entities such as Agrément South Africa are responsible for testing and certifying construction industry products and methodologies to ensure quality and durability. However, factors such as perceptions of users, municipal regulatory restrictions and procurement challenges still inhibit mainstreaming some products and building systems.

The construction industry in South Africa has been under pressure for some time. Public sector spending on infrastructure has declined steadily since 2017[13]. A recent material flow analysis found that relatively little of South Africa's materials consumption goes into local stock-building, i.e., infrastructure, buildings, etc.[14]. However, some interventions have been put in place to stimulate the industry. For instance, only locally produced cement, made from locally sourced raw materials, may now be used on any government-funded project[15]. Furthermore, the government has developed a post-COVID Infrastructure Investment Plan aimed at increasing spending on infrastructure projects[16]. This will increase demand for resources, but it also creates an opportunity to integrate circular economy principles into the construction industry and economic development due to the focused investment in construction.

5.3 Opportunities for greater circularity in urban systems

With the substantial contribution settlements make to consuming resources and generating waste, pollution, and carbon emissions, implementing the principles of the circular economy should make significant positive differences. The circular economy provides an opportunity to look at ways to decouple urban development from resource consumption, create circular cities, and contribute to improving the quality of life for all (Figure 5.1).

A "circular city" is more than just the sum of various circular economy interventions[19]. To create circular cities, the principles of the circular economy need to be focused on more than just buildings, building components, economic or production systems. The entire complex urban system should be considered, particularly systems for providing services and infrastructure across multiple sectors (rather than the system of production). At a settlement level, land and infrastructure are also critical resources (in addition to natural and other resources). Land is scarce, providing the space where circular activities could occur. It is also essential for regenerating the urban ecosystem. Infrastructure plays a key role in the provision and consumption of resources. It could also be reused and or recycled, thereby enhancing circularity[19].

The principles of circularity can be applied at various scales, including entire city-regions, municipal areas, cities or towns, neighbourhoods, and buildings (industrial, commercial, residential etc.). Opportunities for circular development are highlighted below according to the three interconnected principles. Many interventions could support more than one of the principles.

Design out waste and pollution

There are various ways in which human settlements could contribute to reducing waste and pollution (including carbon emissions). For instance, deficiencies in the construction, mobility, energy and water sectors could be addressed at settlement level to enhance circularity.

Because the construction industry consumes vast amounts of resources, it provides ample opportunities for circular economy interventions. Reducing construction waste involves more than re-using material – interventions should commence during the planning, design, specification and procurement stages of the manufacturing or building process to limit the generation of waste from the outset and reduce the use of virgin material. For instance, dimensional coordination and materials and components standardisation should reduce the waste generated. Standard sizes (steel and timber lengths, glass pane sizes, roof sheeting dimensions etc.) should be considered when specifying material, and quantities should be accurately calculated before materials are ordered. Other strategies include off-site construction, recovering unused materials from building sites, and re-using materials (e.g., concrete, bricks, roofing material), to extend the lifespan of materials. Furthermore, buildings could be designed to facilitate deconstruction, and to be flexible so they could be repurposed for different uses and functions to extend the lifespan of existing stock.

Building and infrastructure efficiency are fundamentally linked to their maintenance and management. Failing and poorly maintained infrastructure cause resource losses, in particular water wasted because of leaking pipes.

Waste and pollution could also be reduced through space sharing economy initiatives. This involves the sharing of underused physical spaces, e.g., as accommodation, kitchens, and coworking spaces. Business models of the sharing economy emphasise a shift from ownership of goods to using goods through services. This provides opportunities for job creation, and it provides those previously unable to afford them with access to quality goods and services. The disruption to traditional office workspace caused by the COVID-19 pandemic, presents an opportunity to fast-track the adoption of alternative work-space environments, including space-sharing[17].

Applying sound planning, design, and management principles at city, town and neighbourhood level should contribute substantially to reducing pollution and carbon emissions. For instance, accommodating and encouraging the use of non-motorised transport (NMT) reduces the need for using private motor vehicles. Strategies and interventions include transport-oriented development (TOD), creating cycle- and pedestrian-friendly neighbourhoods, and providing affordable, efficient, safe and reliable public transport (*See Chapter 6*).

Keep products and materials in use

One of the aims of the circular economy is to reduce the consumption and wastage of resources, by closing the loop and productively returning resources back into the economy for use, rather than disposal. The loops are the flows of resources, materials, parts, goods, by-products and so on, within cities and neighbourhoods, and between them. To manage these loops, they need to be mapped and understood, and to be measured, monitored and improved.

The circular economy aims to move from linear processes to circular value chains, such as by sharing, leasing, repairing, refurbishing, repurposing, reducing, remanufacturing, upcycling or recycling as opposed to the traditional take-make-consume-dispose process. This also includes just-in-time procurement (reducing the need for excessive warehousing and parts that go unused) and reverse logistics, where the manufacturer aims to take back as much as possible, the packaging used and at the end of their life, the used goods. The built environment needs to be considered as a whole, not segmented by zoning types, because opportunities are likely to loop through different parts of a city.

Examples of the circular construction chain are brokers who facilitate sharing expensive equipment or selling unused materials from one building site to another, so they don't become waste; informal businesses repairing discarded equipment or recovering resources from waste; buildings that can be assembled and disassembled rapidly, to be moved to where needed; and re-occupying abandoned buildings.

Other ways of closing the resource loop involve organic waste. For instance, food waste, garden waste, etc. can be cycled back into the economy, e.g., as compost for urban parks, gardens, urban food systems and agricultural activities surrounding cities and towns; bio-energy generation; or returned to biorefinery processes for the recovery of high-value products. In South Africa to a limited extent, sewerage is already being processed to return clean water to the water distribution network and to provide fertilizer for application within the agricultural sector. A further use of sewerage sludge is for energy, by producing biogas through anaerobic digestion or by burning dry sludge.

Regenerate natural systems

Regenerating natural systems means more than merely protecting the natural environment. The concept of a regenerative settlement encompasses more than sustainability – it involves the active restoration of the natural environment and the regeneration of the natural resources it consumes. Regeneration incorporates the principles described above, namely the reduction of waste and the creation of closed loop systems that actively feed natural resources back into the ecosystem to improve the natural environment.

A key pillar of regenerative settlements is the need for a mutually beneficial relationship with the surrounding region. This means that cities and towns should source their resources locally and regionally (closing the loop) to create social, economic, and environmental value for the local communities. Similarly, local farmers could benefit from organic waste generated by settlements. Such waste could be a resource and could be used as compost or as livestock and poultry feed.

Regenerative initiatives could be implemented across various sectors such as energy, water, mobility, and waste. It could include interventions aimed at the generation of renewable energy, utilising rainwater and stormwater (e.g. by applying the principles of water-sensitive design[11]), and creating walkable neighbourhoods. Organic waste could be used to provide bioenergy or support decentralised energy systems in cities and towns; for growing algae, mushrooms and insects for food and feed; and for fibres, bioplastics and bio-aromatics. Well-considered greening initiatives could improve the quality of the atmosphere, reduce urban heat islands, and have a positive impact on the wellbeing of the people living in the city or town.

5.4 Conclusions

The terms "*circular economy*" and "*circular city*" may be relatively new in South Africa, but the principles behind these concepts have been promoted by human settlement researchers and practitioners for many years. Various policies, strategies and frameworks guiding human settlement development in South Africa support and encourage the development of sustainable, resource efficient, liveable, and resilient cities, towns and neighbourhoods. However, many parts of South African cities and towns still face challenges such as a lack of adequate infrastructure, facilities and amenities, low levels of service and inadequate public spaces.

Since many of the circular city concepts are emerging from developed countries, there is more to be done in understanding their relevance and appropriateness in developing countries, often facing their own unique social and economic challenges. When implementing circular economy initiatives in South Africa, the local context should be carefully considered. This includes factors such as poverty, unemployment, the role of the informal economy, inequality, crime and violence. Furthermore, challenges related to service delivery at municipal level and the lack of infrastructure maintenance could jeopardise initiatives aimed at creating circular cities and towns.

To guide local circular economy initiatives, a thorough understanding of the challenges and opportunities is needed. Reliable data and evidence are required to develop appropriate initiatives that create a net benefit. In addition, to enhance circularity in any settlement, attention needs to be paid to the interaction between the systems of provision and the lifestyles of the residents, and also to the effect lifestyles may have on the residents' willingness to adopt circular practices.

While much needs to be done to achieve circularity in human settlements in South Africa, the challenges are far from insurmountable. The concepts of circularity are starting to be included in the plans of some local governments and there are replicable projects that are already making a difference.

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6

Facilitating sustainable economic development through circular mobility

Refiloe Mokoena, Anton Steenkamp and Linda Godfrey

Circular mobility has strong themes of shared, integrated, smart, and sustainable mobility, geared towards economic development while reducing the dependance on finite resources and improving the quality of life for society. A circular mobility system is accessible, affordable, and effective; it is multi-modal in that it incorporates public transportation in combination with flexible last-mile solutions. "*Faster decarbonisation of the transport sector is key to achieve the 1.5°C Paris agreement.*"[1]

6.1 Introduction

Mobility is a key component of economic development and provides access between businesses and their respective markets, households, and communities. Traditional, linear approaches for managing mobility systems, operations and infrastructure have been shown to be unsustainable as they lead to increased greenhouse gas (GHG) emissions; depletion of finite resources; congestion; wasted time; decreased productivity; urban heat-island effects; and pollution[2].

The movement of goods and people is an energy and resource intensive activity. The transport sector accounts for 19% of South Africa's total energy demand (*See Chapter 7*), exacerbated by extensive travel distances. The majority (98%) of the transport sector's energy is supplied through petroleum products[3], 79% of which is used for road transportation and 13% for civil aviation[3]. As at 2019, both petrol and diesel consumption exceeded local refinery capacity production, resulting in a steady increase in imports of both petrol and diesel finished products into South Africa[3].

The transport sector accounted for 10.7% of national GHG emissions in 2017 (excl. Forestry and Other Land Uses), with road transport making up 95.7% of that. In comparison, domestic aviation and railway had smaller contributions at 2% and 0.9% respectively[4]. Emissions from transport have increased by 33.2% between 2000 and 2017, the major contributor being road transport, which increased by 37.8%, highlighting the high reliance of the South African transport sector on fossil fuels[4].

An estimated 77% of land freight is still transported via road in South Africa, which in addition to consuming significant quantities of fossil fuels, has a direct

bearing on national productivity and competitiveness. The heavy reliance on road transport also negatively impacts the condition and maintenance of the national road network[5]. While South Africa has a sophisticated logistics sector, ranking 33 out of 160 countries in 2018, in terms of the World Bank's Logistics Performance Index (LPI), it is plagued by numerous challenges including the lack of adequate infrastructure investment and maintenance, lack of skills, and high costs, all of which negatively impact system efficiency[5].

South Africa's resource intensive transport systems, provides the perfect impetus for transitioning South Africa to a more circular mobility system (Figure 6.1). Applying the circular economy principles of designing out waste, closing resource loops; and regenerating natural systems provide a framework for South Africa to improve the efficiency and competitiveness of mobility systems[6,7]. For mobility, this includes:

- **Design out waste**, e.g., shared, and multi-modal mobility; increased use of zero-emission mobility; encouraging remote and flexible working
- **Keep materials in use**, e.g., scaling up vehicle remanufacturing; recycling; vehicle and infrastructure design for circularity
- **Regenerate natural systems**, e.g., mobility systems based on renewable energy; climate resilient transport infrastructure

Figure 6.1. Mobility within a circular economy (adapted from SIFA[8])

Circular mobility requires a primary focus on designing for users and goods, instead of vehicles – such as planning transport networks that provide reduced travel distance and time per journey. Transitioning towards a circular mobility system creates opportunities for improved productivity, efficiency, and reduced costs, with

positive spillover effects for other sectors of the economy such as agriculture, manufacturing, and human settlements.

6.2 Overview of the mobility sector in South Africa

South Africa has an extensive transport infrastructure network, with approximately 750,000 km of roads, approximately 30,000 km rail tracks, eight commercial ports, and eleven principal airports[5]. South Africa's transport and storage sector accounts for ~10% of the country's GDP (excluding unaccounted for minibus taxi services), the fifth largest economic contributor to national GDP[9]. While labour intensive, the sector saw a decrease in the number of jobs from 1,025,000 in 2019 to a low of 878,000 in the 3rd quarter of 2020 (largely due to the economic disruption caused by the COVID-19 pandemic), which recovered to 969,000 by the 2nd quarter of 2021[10]. Furthermore, the sector was the highest contributor to national economic growth for the same quarter[11].

With 77.3% of freight transported via road, the proportion of logistics costs to GDP is relatively high. The approximate cost of logistics was R480 billion in 2018[5], with two of the major operational expenses associated with road transport being fuel and tyres[12].

The National Development Plan (NDP 2030) recognises that poor transport links and infrastructure networks, raises the cost of doing business in South Africa and negatively impacts the standard of living. It calls for the sector to invest in effective, safe, and affordable public transport as a means of facilitating mobility for low-income households. There is a need to consolidate and expand transport and logistics infrastructure and reduce associated costs. At the same time, the NDP recognises the urgent need to shift to a low-carbon economy and a more sustainable economic growth path.

With South Africa's road transportation being the largest contributor to GHG emissions in the transport sector, and the highest energy consumer, the sector has employed an Emission Reduction Strategy that aims to reduce the reliance on fossil fuels for transportation. One of the key drivers of the shift being the projected decline in global oil reserves and resultant increasing prices.

Implementation of the Green Transport Strategy, which aims to reduce the transport sector's GHG emissions, provides an ideal launch pad for a circular economy transition within South Africa's mobility sector. While it is acknowledged that effective implementation and sufficient funding are critical constraints to achieving the outlined objectives, the Department of Transport has committed to achieving sustainability through the development of regulatory instruments, particularly for vehicle emissions; restructuring taxes; and providing incentives to reduce costs where possible; prioritising infrastructure development; and education and awareness to accelerate behavioural change.

There is opportunity for collaborative governance with the relevant sectors towards a more circular mobility sector. The National Transport Master Plan (NATMAP) 2050, for example, has identified twelve strategic themes, in order to achieve "*An integrated, smart and efficient transport system*" capable of supporting national sustainable economic growth and development.

6.3 Circular economy opportunities in mobility

Possible circular economy opportunities in the mobility sector are briefly highlighted, aligned with the three circular economy principles:

Design out waste and pollution

Resource efficiency in transport systems, operations and infrastructure provides an immediate opportunity area for decoupling the sector from resource consumption. Transport logistics is the backbone of many economic activities. It is therefore important that this industry be productive and efficient. It is expected that by 2040 the emissions produced from material production for vehicles will account for 60% of life cycle emissions, versus the current figure of 18%.

There are numerous opportunities to design out waste in transport[1]. South Africa has piloted two schemes that show great promise for supporting the circular economy – the Road Transport Management System (RTMS) and Smart Truck initiatives. The RTMS is an industry-led, self-regulation scheme that encourages consignors, consignees, and road transport operators to implement a management-systems standard in order to improve fleet management and sustainability; and reduce logistics costs. By using properly considered Performance-Based Standards (PBS) through the Smart Truck pilot project, improved heavy vehicle safety and productivity can be achieved. The pilot project has shown substantial savings, with one in four heavy vehicle trips eliminated using PBS; fuel and emission savings of 20%; and road wear reduction of 12%. These initiatives can be scaled up to form a significant proportion of circular mobility.

Greater efficiency and productivity can be achieved through integrated and multi-modal mobility, although this is proving slow to implement in South Africa. In 2007, South Africa adopted the National Public Transport Strategy, aimed at increasing passenger transport network productivity; reducing vehicles on the road and the road space required for personal vehicles; alleviating road congestion; reducing system inefficiencies and associated costs; and reducing energy consumption per capita. The program has, however, experienced several delays[13]. The reinforcement of rail for long-haul transport, which then transitions onto road freight transport for final short-haul distribution, provides a significant opportunity for improved productivity and efficiency, while reducing energy and material demands, GHG emissions, and impact on national roads. There is growing interest and support for moving suitable freight and long-haul passenger transport back to rail, given that rail transport is the most efficient and cost-effective method for long-haul land-based transport. Circular economy principles can also be applied to the rail infrastructure and vehicles to reduce resource demands and overall costs.

South Africa is located on one of the busiest international sea routes, with contrarily some of the worst performing ports in the world according to the World Bank's Container Port Performance Index 2020 report[14]. Improving the efficiency of port operations through strategies like the development of dry ports and modernisation of port infrastructure can increase productivity, efficiency and overall performance.

A key aspect of circular mobility also includes the incorporation of sharing economy principles, which focus on maximising resource productivity through the sharing of temporally under-utilised assets. In Europe, for example, cars are estimated to park 92% of the time, and when in use only 1.5 out of the 5 seats are occupied on average[8]. South Africa experiences a similar situation. Globally, the mobility sector is seeing some shift away from an owner-focused value proposition to a customer-centered one, resulting in a move away from individually owned vehicles – whether for personal or business use. Mobility-as-a-Service (MaaS) focusses on ride-, car- or bike-sharing, taxi or car rental/lease, or a combination thereof. Utilising shared services in freight transport can also greatly reduce material consumption and waste in the sector. This includes initiatives such as *Empty Trips* which aims to utilize the traditional empty back-haul of heavy vehicles by offering this space to other logistics companies. Ride-sharing platforms in South Africa have shown promising outlook with growing competition in the market[15].

The heavy reliance on road transport and liquid fuels means that there is an urgent need to decarbonise the sector. This will require a shift to circular mobility solutions, including greater mobility sharing, while reduced personal mobility will shift to electric vehicles (EVs) supported through renewable energy. Many countries have moved to ban internal combustion engine vehicles (ICEV) in favour of EVs, with ambitious passenger-car and truck CO_2 reduction targets. South Africa, however, is lagging in the move to EVs, representing only 0.02% of domestic vehicle sales. Nonetheless, this creates an opportunity for South Africa, as 64% of locally manufactured vehicles are exported to global markets with South Africa already having experience with hybrid vehicle manufacturing[16]. Large-scale adoption of EVs or hydrogen vehicles (HVs) for public transport could be a game changer.

Reliable data is crucial for efficient and circular mobility systems. There are large international efforts to establish data sharing platforms and programs to unlock maximum value at every level of different value chains. There are already several integrated multimodal transport applications as well as private and public mobility providers that collaborate on making their service data accessible across platforms[1]. This is however severely lacking in South Africa.

Keep products and materials in use

The mobility sector has numerous opportunities to facilitate greater reuse, repair, remanufacturing and recycling of waste materials. These include, amongst others, end-of-life vehicles, waste batteries, and waste tyres. In addition, waste materials can be used to substitute virgin materials in transport infrastructure, for example, substituting natural aggregates with construction and demolition waste, which is currently mostly landfilled.

Waste tyres have numerous end-of-life solutions. If tyres cannot be re-treaded for reuse, they can be recycled to produce rubber crumb that has various applications in e.g. sports tracks, building materials, and road surfaces[17,18], or they can be converted to energy or liquid fuels through high temperature thermal processes such as pyrolysis or gasification. Several research and demonstration projects on the use of waste materials such as steel slag, waste glass, coal ash,

construction waste, waste plastic and tyres, as alternatives to traditional road materials, have been implemented in South Africa[19,20]. The benefits of introducing alternative materials into road construction include offsetting virgin material use; reducing natural land-use for quarrying; economic savings on virgin materials; creating jobs; while also producing better performing roads[21].

Lead-acid batteries have already achieved high levels of recycling in South Africa (around 90%)[22]. However, as vehicle manufacturers move towards EVs, an increase in waste lithium-ion batteries (LIBs) will occur[23]. With South Africa slow to adopt EVs, the impact of large volumes of LIBs entering the waste stream is only expected in the next 10-20 years. However, the very low levels of Li-ion battery collection from the consumer electronics and ICT equipment sectors in South Africa, has meant that e-waste recyclers have been reluctant to invest in local recycling infrastructure[23]. With the potential for growing Li-ion battery waste, it is important that a strategy be put in place to close the loop on this waste stream and recover valuable materials for the South African economy.

ICEVs are likely to be in use for some time in South Africa, and in many parts of the world. This creates an opportunity for South Africa to position itself as a global leader in the remanufacturing of IC engines. Remanufacturing of engines is already a well-established industry within the local automotive sector (*See Chapter 4*). End-of-life directives on vehicles, and other components such as vehicle remanufacturing, will be an important driver to achieve higher levels of waste reutilization within the sector[1].

Regenerate natural systems

Restorative and regenerative design is concerned with restoring social and ecological systems to a healthy state and enabling these systems to evolve[24]. Understanding current and future user needs and expected demands on mobility systems is therefore a critical component to regenerative and restorative design. The shift to alternative fuels, and EVs supported through renewable energy (as discussed above) presents an opportunity to reduce GHG emissions thus contributing to climate change mitigation strategies and international commitments.

Climate adaptation strategies include the planning, design and construction of climate resilient transport infrastructure which also has benefits of reduced repair and maintenance costs, as well as improved service life of assets. South Africa has experienced a 57% increase in recorded weather-related disasters over the past two decades compared to the previous two, resulting in an estimated R95 billion in economic damages[25]. The increase in city vehicle emissions as well as the use of heat trapping materials for construction can result in the occurrence of urban heat islands. Combined with more frequently occurring heatwaves, linked to climate change, heat stress is rapidly posing a major health risk for urban dwellers[26]. Research continues to show the importance of climate change adaptation through design of local transport infrastructure[27,28]. Restorative design can therefore be used as a strategy for climate adaptation and can assist in avoiding unnecessary social and economic costs associated with reactive and linear planning.

6.4 Crime and the circular economy

One of the biggest threats to transitioning South Africa to a more circular economy is the issue of crime. Increasing crime directly impacts the use of public transport and shared mobility. Examples include the local attacks on ride-hailing drivers and customers; vehicle theft; and hijacking. The concept of safety is a huge deterrent for many commuters who prefer to rather use their own vehicles. Furthermore, crime and corruption directly discourage investment and uptake in these circular solutions.

6.5 Conclusions

It is clear that the principles of a circular economy are not new to the South African mobility sector. However, while many of the underlying circular economy principles are already being applied, more needs to be done to accelerate and scale-up action, to ensure meaningful impact. Possible reasons for the slow uptake include the fact that South Africa is spatially segregated with large financial disparity; lack of appropriate infrastructure, and investment; and high costs for some of the necessary technologies. Reliable data sharing networks and systemic design considerations for local conditions will need to be established for beneficial implementation.

The concept of circular mobility is a multi-disciplinary area and will require involvement from various stakeholders and participants through improved relationships, across various sectors of the economy. The benefits of transitioning to a circular mobility system include improved productivity and competitiveness for business; reduced cost of doing business, reduced congestion, and reduced GHG emissions. Government policies and strategies such as the Emission Reduction Strategy, the Green Transport Strategy and the NATMAP 2050 support most of the circular economy principles and provide a launch pad to promote greater circularity within the mobility sector.

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7

Decoupling South Africa's development from energy demand through a more circular economy

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"*Companies that traditionally have been heavily focused on hydrocarbons are using circularity principles as a basis for major strategic shifts in response to decarbonisation.*" [9]

7.1 Introduction

The South African energy sector is a resource intensive sector characterised by high levels of inefficiency. An estimated 71% of South Africa's primary energy consumption comes from the burning of coal[1], with 2% of South Africa's water directed to energy generation[2] (*See Chapter 8*). The sector is also a highly linear, wasteful one, generating large quantities of gaseous, liquid, and solid waste[3,4]. Fly ash and bottom ash from the electricity and petroleum sectors, were the largest hazardous waste streams generated in South Africa in 2017, making up 75% of total hazardous waste generation[4]. Eskom's 14 coal-fired power stations consumed 116 Mt of coal in 2017, producing 202,106 GWh of power and 32 Mt of ash – an average of 156 T of waste ash for every GWh of power produced[4]. This is compounded by high transmission and distribution losses, with approximately 20% of total primary energy entering the system lost due to power generation processes[5]. The energy sector is also the largest contributor to national GHG emissions (80% in 2017) (excl. Forestry and Other Land Uses) and was responsible for 97% of the GHG increase over the period 2000-2017[6]. In 2020, CO_2 emissions were the 12th highest in the world, accounting for 1.3% of total global emissions[1].

South Africa has experienced constraints on its electricity system since 2008, resulting in ongoing loadshedding. Electricity supply problems have placed severe pressure on South Africa's economic growth sectors, particularly manufacturing and human settlements (*See Chapters 4 and 5*). Facing growing energy insecurity, South Africa's high reliance on fossil fuels for energy and the resulting waste, provides the perfect impetus for transitioning to a circular energy system[7] (Figure 7.1).

When applied to the energy sector, the circular economy principles – eliminating waste and pollution; closing resource loops; and regenerating natural systems – provide a framework for South Africa to address energy security[7, 8, 9]:

- **Design out waste**, e.g., energy efficiency (demand management), waste and emissions prevention, reducing materials-use in manufacturing energy technologies, increasing energy technology lifespans
- **Keep materials in use**, e.g., waste gas and heat valorisation; carbon capture use and storage (CCUS); repair and recycling of energy technologies (repurposing), waste-to-energy; fly-ash to building materials;
- **Regenerate natural systems**, e.g., renewable energy (RE), green hydrogen

Applying these circular economy principles within the South African energy sector – both in the manufacturing of energy technologies as well as in energy utility – creates opportunities for more efficient and sustainable use of resources in transitioning to a low-carbon economy. It creates opportunities for decoupling economic activity from the consumption of energy, reducing costs, driving greater competitiveness, unlocking new business opportunities, and building resilience to local and global shocks.

The implementation of a circular economy strategy within the energy sector, also creates opportunities for decarbonising a range of sectors, including agriculture, manufacturing, mobility, and human settlements (*see Chapters 3, 4, 5 and 6*). As South Africa works towards a just energy transition, away from fossil fuels to cleaner energy, the circular economy provides the opportunity for greater inclusion of social dimensions by identifying socio-economic opportunities[10].

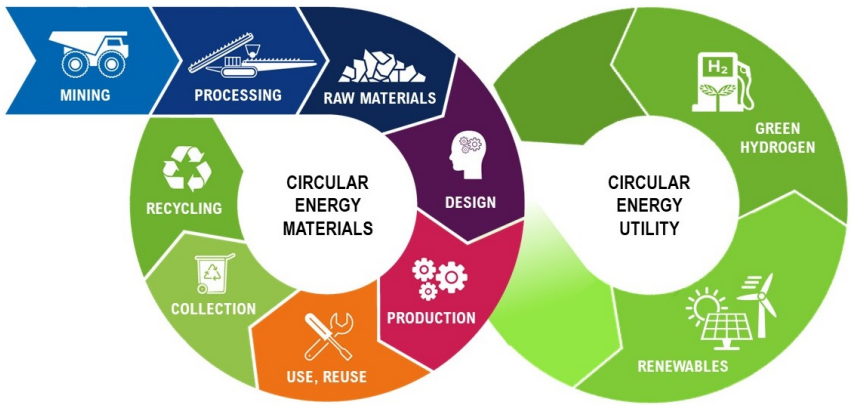

Figure 7.1. Circular materials and energy systems (adapted from EIT[30] and PwC[9])

7.2 The current state of energy in South Africa

The South African energy sector is heavily reliant on fossil fuels (95% of primary energy consumption)[1]. This dependence has resulted in South Africa being one of the most carbon intensive countries in the world. In 2020, coal accounted for 71% of South Africa's primary energy consumption, followed by oil (21%), nuclear and

renewable energy (5%), and natural gas (3%)[1]. The industrial sector is responsible for most of the final energy demand (52%), followed by transport (19%) (Figure 7.2)[11]. In terms of human settlements, the percentage of electrified households in South Africa was 85% in 2019[12].

South Africa's power utility, Eskom, is facing operational challenges due to its' ageing coal fleet (average age ~39 years) and the declining energy availability factor, and has had to intermittently implement rotational load shedding to meet demand. Despite this, South Africa has only progressed to ~10% installed renewable electricity as at 2020[13].

After the power sector, the South African transport sector is the most important to decarbonise as it is primarily dominated by internal combustion engine vehicles which rely on petroleum fuels for mobility. From an economic value perspective, the liquid fuels industry contributed R139 billion to GDP in 2019[14].

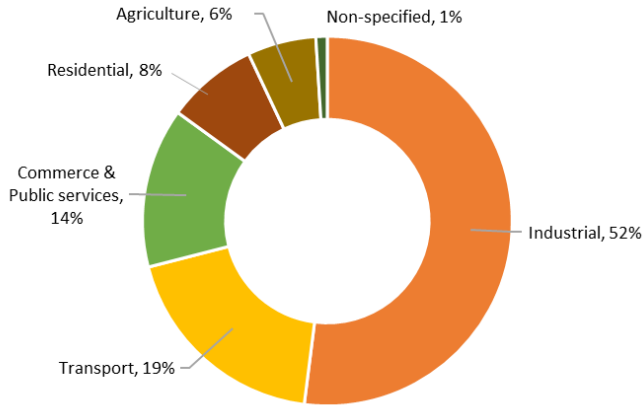

Figure 7.2. Energy demand in South Africa (adapted from DoE[11])

Due to the lack of exploitable oil resources, South Africa relies on imports for 95% of its' crude oil, most of which is processed at its refineries to produce liquid fuels[11]. Decarbonising the transport sector will require a shift to circular mobility solutions, including greater mobility sharing, while reduced personal mobility will shift to electric vehicles supported through renewable energy (*See Chapter 5*). This will also benefit South Africa's balance of trade, by reducing oil import demands. A transition from combustion engine vehicles to electric vehicles, without broader circular mobility solutions, will simply result in increased demand on the power sector[15].

The vision for the South Africa energy sector is clearly outlined in an array of national policies. These include the NDP 2030, which calls for a transition to an environmentally sustainable, climate resilient, low-carbon and just society. This is supported by the National Climate Change Response White paper 2014. Several flagship programmes outlined in the White Paper support a circular economy transition. These include the Renewable Energy Programme; Energy Efficiency and

Energy Demand Management Programme; and the Carbon Capture Storage and Use Programme[16]. In addition, South Africa has made official global commitments to decarbonization through the Paris Agreement (2015) under the UNFCCC. Most of the emission reductions will come from the energy sector, mainly the power sector – as the most carbon intensive and most affordable to mitigate considering the declining renewable energy costs[17]. In November 2021, at COP26, South Africa joined France, Germany, UK, US, and the EU in announcing a partnership to support a just transition to a low carbon economy and a climate resilient society. This will be supported by a commitment of USD131 billion to be mobilized over 5 years[18].

The Integrated Resource Plan (IRP) made allowance for renewable energy capacity additions of 17.8 GW by 2030, which paved the way for the establishment of the Renewable Energy Independent Power Producer Procurement Programme (REI4P). The Integrated Energy Plan (IEP), which aims to guide future energy infrastructure investments and policy, is anchored in the National Energy Act, 2008[19].

7.3 Circular economy opportunities in energy

While much of the focus of a circular energy transition has been on renewables, there are considerable opportunities in energy efficiency and energy productivity; and in the manufacturing and decommissioning of energy technologies. Possible circular economy opportunities in the energy sector are briefly highlighted here, aligned with the circular economy principles:

1. Circular economy for energy materials

As highlighted in the CSIR's mining sector response to a circular economy (*See Chapter 2*), the uptake of renewable energy technologies and the transition to a low-carbon economy, as called for in the NDP 2030, will require more (and different) minerals and metals, with ever larger material footprints. While this resource demand has the potential to unlock new growth areas for the South African mining sector, it also has the potential to erode national resource security, with widespread environmental impacts. It is therefore important that the principles of a circular economy are applied to the sustainable use of resources – including critical raw materials – in the development and deployment of clean energy technologies, including battery technologies, in South Africa (Figure 7.1). This includes –

- Improved design of energy technologies to ensure greater repair, refurbishment, or recycling at end-of-life
- Designing energy technology manufacturing processes with reduced material and energy use
- Increasing energy technology lifetimes (greater resource productivity)

2. Circular economy in energy generation and use

Design out waste and pollution

The National Energy Efficiency Strategy was gazetted in 2005 and set an economy wide reduction target in energy intensity of 12% by 2015. The target was achieved and exceeded, reaching 23.7% by 2012. Programmes such as the Industrial Energy Efficiency Programme, funded by GEF and implemented by NCPC-SA in partnership with UNIDO has since 2011, assisted more than 450 industries to save 6.5 TWh of energy, resulting in cumulative cost savings of R5.3 billion. Energy efficiency projects have also extended into the building industry, with new building installations of solar panels, LED lighting, motion sensing automated lighting; and centralised heating and cooling. There is an opportunity for new infrastructure development to make use of low-carbon, high-thermal efficient building materials to reduce energy demand in the built environment. (*See Chapter 5*). The wind energy sector has the potential to increase resource efficiency by narrowing loops in the design and manufacturing of rare earth magnets[21].

Keep products and materials in use

Waste materials provide the opportunity to generate energy, through various waste-to-energy technology solutions, including low temperature landfill gas recovery; and bio-energy generation from organic and biomass waste streams. eThekwini Municipality's waste-to-electricity landfill gas project, a CDM project, had avoided 2.5 $MTCO_2$ equivalent emissions as at 2017[22]. An increased focus has been placed on diverting organic waste from landfills through composting and energy recovery through the production of biogas[23]. DRAX power station, the largest and most efficient coal-fired power station, based in the UK, converted half of its units to run on biomass. By deploying bioenergy with carbon capture and storage (BECCS), Drax will have minimal emissions. SAPPI has a 25MW biomass power plant in Mpumalanga which uses the biomass waste from its production processes to produce electricity, they could close the loop through CCUS technology. Biorefinery of various organic waste streams, creates opportunities to recover high-value resources. The concept is already being applied in the pulp and paper, and sugar sectors in South Africa. Biomass, or captured "unavoidable" CO_2, can also be used as the carbon source in the production of synthetic liquid and gaseous fuels and chemicals. The destruction of resources through high-temperature processes such as incineration, pyrolysis, gasification, while potentially generating energy is typically considered to fall outside of the circular economy, due to the loss of resources through burning.

Fly ash from the burning of coal is used in the production of aluminosilicate-based cement replacement geopolymers, with some South African companies already doing this[24]. Waste heat recovery systems are used by companies to recycle the waste heat from its' processes back to produce electricity. Anglo Platinum established a project to produce 5MW of electricity from its Waterval smelter complex in Rustenburg, which was to feed 4.3 MW power back to the grid[25]. Battery energy storage systems (BESS), solar panels, and wind turbines will all require sustainable end-of-engineered life solutions to recover valuable resources.

Although South Africa is undergoing an energy transition, fossil fuels may still be a part of its' future for the foreseeable future – considering government has highlighted the importance of developing CCUS technology to minimise the impact from harmful CO_2 emissions. This was supported by the establishment of the South African Centre for Carbon Capture and Storage (SACCCS), a division of the Council for Geoscience. The DMRE sees CCUS technology as one of the avenues for continuing to take advantage of coal. In 2019, the government launched the Coal CO_2-to-X programme, which focuses on the production of green chemicals such as green ammonia and green hydrogen from flue gas[26].

Regenerate natural systems

The REI4P was introduced in 2011 as the official procurement mechanism for renewable energy in South Africa. The programme managed to procure 6,327 GW of renewable energy through four bidding rounds. The IRP released in 2019 makes provision for 14,4 GW of wind power and 6 GW of solar PV power by 2030[27], resulting in an ambition for an additional 20,4 GW of renewable energy by 2030. This will result in the share of installed renewable energy increasing to ~33%. It also makes allowance for the decommissioning of several Eskom coal power stations equalling 11.7 GW by 2030. In 2021, the DMRE announced that the threshold on embedded generation without licensing requirements would be increased to 100MW[28]. Effectively, allowing private power generation power purchase agreements (PPAs) for larger facilities from renewable energy resources. Eskom plans to repurpose decommissioned coal-fired power plants using renewable energy, battery storage, gas conversion and agri-voltaics – the symbiotic use of solar energy and crops, resulting in energy for agricultural processes and reduced water consumption[29]. A pilot is already underway, and the plan is to start repurposing Komati Power Station in 2022 once it is fully decommissioned. Other repurposing options could be establishing green manufacturing facilities at the power plant sites to supply renewable energy components.

"*Green hydrogen could play a pivotal role in a sector-coupled circular economy, offering a solution for decarbonising a range of sectors, including transportation, heating, chemicals, and iron and steel.*"[9]. Green hydrogen production is a major component of the government's strategy to decarbonise. The development of the hydrogen economy increases the business case for renewable energy. Establishing electric vehicle (EV) infrastructure and increasing penetration, complimented by electricity sourced from renewable energy resources instead of fossil fuel-based energy, provides an opportunity for green mobility (*See Chapter 6*). Conversion of trucks to EV fuel cell technology will reduce consumption of diesel significantly and establish further demand for hydrogen. Furthermore, biofuels and synthetic green fuels can also be pursued. Sustainable aviation fuel is being explored to further reduce the emissions from the transport sector.

Solar PV and wind mini-grids in unelectrified communities reduces the use of burning charcoal, wood and other substances for cooking, heating and lighting. It also has the potential to create new businesses and jobs in communities, especially if the model gives them some form of ownership of the mini-grids.

The principles of a circular economy are not new to the South African energy sector. Many activities are underway to transition the sector. However, given the magnitude of the impact of the South African energy sector, and the current high levels of energy insecurity which negatively impact on all sectors, this is a sector that does not have the luxury of time to achieve scale and impact of circular energy interventions.

7.4 Conclusion

The legacy of the energy sector in South Africa has gone against the principles of a circular economy and remains highly resource intensive and wasteful, with a continued overreliance on fossil fuels. However, there have been several projects and ongoing efforts to reduce this wastage and recycle waste for alternative energy use or high-value product recovery. Furthermore, energy efficiency has been prioritized to reduce energy consumption, while reducing GHG emissions. As South Africa grapples with securing energy, it must decarbonize simultaneously. Energy is required in all economic sectors and circular economy solutions in this sector positively impacts other sectors e.g., a more sustainable and globally competitive manufacturing sector; improved transportation and living conditions for all citizens. Undoubtedly, as South Africa embarks on the energy transition, the circular economy also provides the opportunity for positive socio-economic impacts such as improved health and job creation. The energy sector has a long way to go to achieve circularity, however the actions that are being taken and promoted by government and industry signal a need to achieve greater resource-security in support of socio-economic development, through sustainable resource utilisation.

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8

Decoupling South Africa's development from water demand through a circular economy

Ashwin Seetal, Matlhodi Mathye and Linda Godfrey

"*Water is our country's most critical natural resource. Water security is fundamental to the lives and health of our people, to the stability of our society and to the growth and sustainability of our economy.*" H.E. President Cyril Ramaphosa, 5 August 2021[1].

8.1 Introduction

Water is essential for life, it drives socio-economic development and supports healthy ecosystems. Without access to reliable sources of water, the economy will stall. This is already evident in South Africa, where recent droughts in the Eastern and Western Cape Provinces, fuelled by changing climates, has negatively impacted local agriculture, manufacturing, tourism, food prices, and exports, resulting in job losses and the diversion of much needed government funds away from national development priorities towards disaster relief[2].

South Africa is a water-scarce country, one of the thirty driest countries in the world with an average annual rainfall of approximately 460 mm, less than half the world average [3]. It is a semi-arid country with a climate characterised by cycles of wet or dry spells, with droughts and floods regarded as natural hazards. Climate variability and projected climate changes are regarded as key risk factors to national water security, particularly to South Africa's economic development and industrialisation strategies. Currently, South Africa is using 98% of its available water supply[4]. Most of this water comes from surface water (68%) and return flows that support surface water (13%). Based on growth projections and current water use efficiency levels, the demand for water in South Africa is expected to exceed supply by 17% by 2030 (Figure 8.1). If left unchecked, this will constrain South Africa's future growth.

A more sustainable and efficient approach in the use of our very limited water resources is needed. The CSIR recognises the opportunity a circular economy transition provides South Africa in decoupling growth from water consumption, thereby addressing national resource-security in support of socio-economic development, through sustainable water resource use.

When applied to water resources, the circular economy principles of eliminating waste and pollution; closing resource loops; and regenerating natural systems, provide a framework for South Africa to address water security[5, 6] (Figure 8.2).

- **Design out waste**, e.g., reducing water use and wastewater generation, improved water use efficiency, better water use practices;
- **Keep materials in use**, e.g., reuse and recycling of wastewater (return flows), reclamation and recovery of resources from water-based waste;
- **Regenerate natural systems**, e.g., improving water flow and quality through the restoration of land by controlling invasive alien plants (IAP) and rehabilitating and protecting wetlands and riparian systems.

These principles are not novel in the South African water sector and have been practiced since the 1980's, with examples in different sectors that demonstrate these principles. Given our economic growth and development ambitions and associated strategies, as well as many of our prevailing circumstances, it may be opportune to consider how a mainstreamed circular economy paradigm in the water sector can contribute to national water security and socio-economic prosperity.

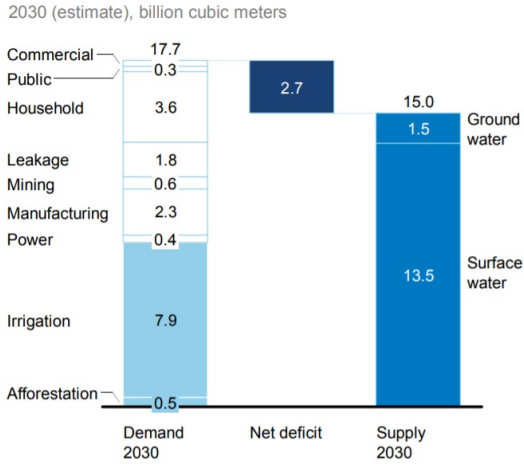

Figure 8.1. SA water demand versus supply projections for 2030 (from WRG[7])

8.2 The current state of water in South Africa

Water is critical to the South African economy. It is an important input in industrial sectors, particularly agriculture, agro-processing, manufacturing, energy production, mining and forestry[10]. As highlighted by the State President in his Cabinet announcement on 5 August 2021, "… *water is a far broader issue, impacting not only on human settlements, but also on agriculture, industry, mining and environmental management. Water is our country's most critical natural resource. Water security is fundamental to the lives and health of our people, to the stability of our society and to the growth and*

sustainability of our economy." This highest level of government commitment is a reminder of the importance of water in our country and reinforces the criticality of water in supporting socio-economic prosperity.

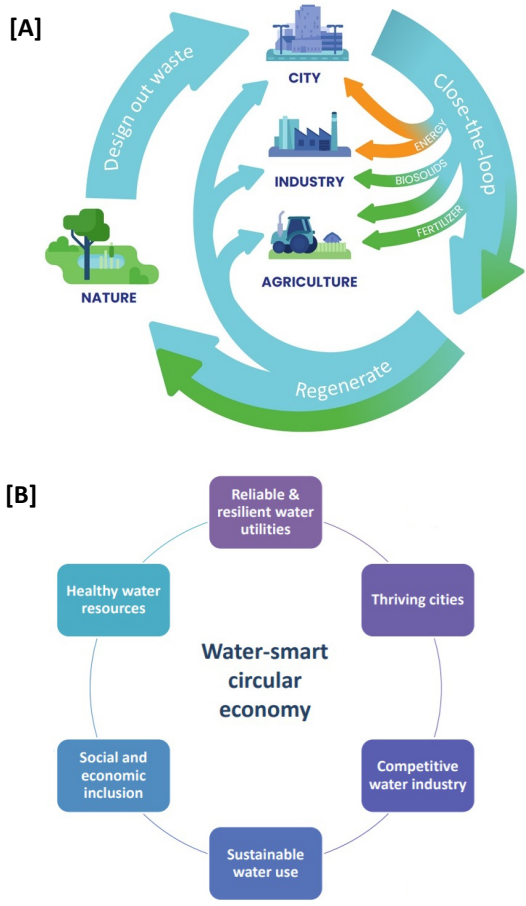

Figure 8.2. Circular water systems (adapted from **[A]** Delgado *et al.*[8] and **[B]** Zvimba[9])

The water sector has a strong influence on all economic sectors. The sectoral allocations (Figure 8.3) show the largest demand for water in the agricultural sector (61%) followed by human settlements (27%). However, the financial value of water sales (Figure 8.4) highlights the discrepancy between the largest water user sectors and the financial returns on their respective water sales. Given the importance of agriculture to the South African economy[11], decoupling agricultural production from water demand, must be prioritised.

According to the World Bank, some regions of the world, including Africa, could see a decline in economic growth rates of as much as 6% as a result of water-related losses, with South Africa's projected economic growth declining by at least

1%[12]. In South Africa, the situation is further complicated by the fact that many of our critical industries are located inland, where access to water, and in particular good quality water, remains a risk. With 98% of water already allocated, any additional economic growth requires re-allocation from existing water supplies or the generation of "new" water through alternate sources. The increase in demand for, and supply of water will result in an increase in wastewater and pollutants, particularly in the inland economic regions. Water supply and water quality are interconnected.

The South African water sector directly contributed approximately R6.4bn or 0.4% to the country's Gross Domestic Product (GDP) in 2016. The private sector's involvement in water is largely confined to the provision of supplies and professional services. While there is much to be done in addressing the state of water in South Africa, government also recognises the opportunities that exist in the export of water technology solutions, knowledge and skills diffusion, and the transfer of water-linked products like chemicals, industrial components, and ICT systems[10].

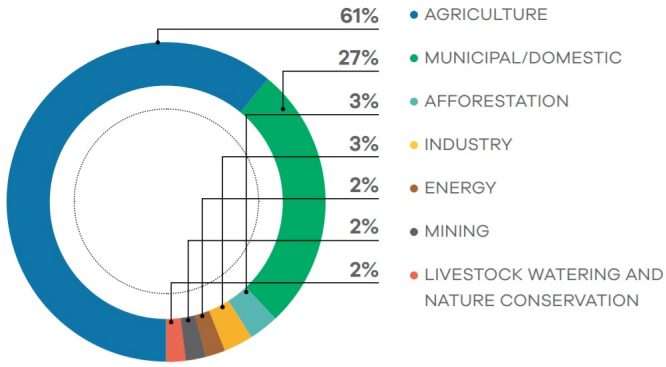

Figure 8.3. Water allocations in South Africa (GreenCape[4])

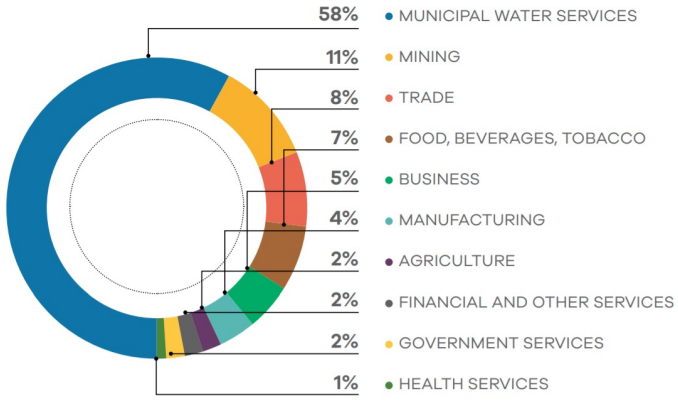

Figure 8.4. Financial value of water sales per sector in South Africa (GreenCape[4])

A large proportion of South Africa's GDP and jobs are directly dependent on water through its use in the agriculture and forestry, manufacturing, energy, and mining sectors[11]. Growth projections[13] show that water demand leading up to 2030, will increase in the following three key sectors: municipal by 1.3 Mm^3, agriculture by 0.5 Mm^3, and industry by 0.5 Mm^3. The substantial projected increase in municipal water use means that cities of the future must be water-circular, with more sustainable use of water within our urban systems[14]. With increasing pressure on our water supplies, South Africa's water security is at risk. Additional threats are posed by climate change, land-use changes, declining water quality and catchment degradation.

The South African water sector is replete with policies, strategies and plans that embrace different aspects of the circular economy. Although these interventions are differently described, their intention and impact are the same as the circular economy, and are aligned to South Africa's Constitution (1996). Relevant policies include the National Water Act (No.36 of 1998) and the National Water Resources Strategy (2004 and 2013). Other non-statutory policies include an overarching national, and various sectoral, Water Conservation and Demand Management Strategies (developed since 1999), a National Strategy for Water Re-Use (2011), the National Water and Sanitation Sector Masterplan (2018) and Industrial Policy Action Plan (2018) and most recently, the National Water Security Framework for South Africa (2020).

While the circular economy is not specifically recognised in South African water policy, the existing policy framework will serve the sector as it transitions to a more circular model.

8.3 Circular economy opportunities in the water sector

Potential circular economy opportunities in the water sector are briefly highlighted, with broad strategic interventions in several priority domains and aligned with the three circular economy principles described below. These priorities include:

- *Decoupling agricultural production from water demand.* This includes primary agriculture and associated downstream agricultural value chains;
- *Decreasing wastage and increasing water use efficiency in the urban and industrial water use sectors.* Reducing water losses, water sensitive design, geographic location of critical and strategic industries;
- *Increasing on-site wastewater treatment and re-use* to minimise pollution impacts on the receiving environment and extending water circularity; and,
- *Strengthening public-private sector partnerships* through greater inclusion of the private sector in innovative circular economy interventions.

Design out waste and pollution

In order to address a looming crisis and close the gap between water supply and demand, a strong focus must be placed on water conservation and demand management. Addressing conservation and demand management at a municipal

and industry level, by reducing leakages, has the potential to realize about 58 Mm^3 of water per year[7]. Results from the National Cleaner Production Centre (NCPC-SA), under the National Industrial Water Efficiency Programme (2015-2019), yielded 862,795m^3 in industrial water savings across 80 businesses[15].

In the irrigated agricultural sector, South Africa's largest water user, the South African Irrigation Institute supports the sector to optimise irrigation practices and achieve related environmental goals. Its mission is the saving of water through technical interventions and members include designers, engineers, soil scientists, crop experts, entrepreneurs, economists and irrigation farmers. Its initiatives include irrigation enhancement and water knowledge training via its *IrrigationWise Academy*. One of its recently completed programmes was on "Efficient irrigation water use by Water User Associations and Water Users". This was funded by the DWS Fetwater Network and presented on behalf of the Directorate Water Use Efficiency at Jacobsdal, Koffiefontein, Pongola, and Vredendal.

Keep products and materials in use

Transitioning to a circular economy goes beyond waste prevention and minimisation. It is about the sustainable use of water; where maximum value is extracted from water resources while in use. This includes diversifying the water mix to include the reuse of water and wastewater.

Globally, wastewater recycling facilities are finding application in industry, e.g., zero discharge effluent treatment facility (Qatar); water resource exchange between industries (South Korea). These applications result in, amongst others, the reduced discharge of wastewater to sewerage, reduced costs, reduced water consumption, and reduced CO_2 emissions[16,17]. The use of treated wastewater for irrigation in agriculture has been practiced for many years, thereby replacing water use in agriculture and releasing freshwater for alternative use. At the same time, additional resources can be recovered from the wastewater, including biogas, biosolids and nutrients. At a household level, rainwater and domestic greywater have been reused within the home, or for watering green spaces, where water of drinking quality standard is not required[18].

While the discharge of wastewater has largely been seen as a burden and cost, growing water scarcity in many parts of South Africa has resulted in a recognition of the importance of wastewater collection, treatment and reuse. Currently, South Africa only treats about 54% of municipal wastewater and about 13% of water is directly reused [11, 13]. Mine water is being treated in South Africa for reuse, e.g., Anglo American's eMalahleni water reclamation project, where treated mine water is piped directly to the eMalahleni Local Municipality's reservoirs supplying 12% of the city's daily water needs. Extra water is sent to other Anglo American operations. This reuse prevents polluted mine water from impacting the environment; recovers additional water for municipal use; and reduces the need for freshwater extraction. Industrial wastewater is being reused in the Nestlé Mossel Bay dairy factor, where treated, evaporated water is used for other applications within the facility such as cooling, garden watering and cleaning[19]. This approach eliminates the need for municipal water intake, and the reduction of wastewater from the factory frees up

capacity at the municipality's wastewater treatment plant. A number of new wastewater reuse facilities are planned across South Africa[20].

Regenerate natural systems

South Africa's water strategy has largely been around the investment in engineered water infrastructure, such as dams and canals. We can no longer manage our water security risks only through this approach. The rehabilitation and regeneration of our natural systems, which supply water, are an integral part of our economy [21].

Examples of regenerative systems include:

- the Working-for-Water programme, which has been regenerating natural systems since 1995, with the aim of improving the integrity of natural resources and restoring the productive potential of land; improving water security; and promoting sustainable use of natural resources. The programme has resulted in improved water security; enhancing streamflow; improving water quality; supporting secondary industries where biomass from clearing operations is utilized; minimising potential negative impacts such as fire damage; and creating new jobs
- the SANBI Ecological Infrastructure for Water Security (EI4WS) Project, which links with the Water RDI Roadmap Living Catchments intervention to address transformative innovation in catchment governance. These relate to nature-based solutions that address sustainable livelihoods, well-being of people and water resources. It also complements the earlier declaration of the uKhahlamba-Drakensberg Park as a World Heritage site in 2000 which recognised its significance as a critical source of South Africa's water.

The circular economy concept is not new to the South African water sector. The country has a track record dating back to the mid-1990's in addressing water supply-demand concerns. Several of these have endured and matured as scalable solutions in other parts of the country. However, more needs to be done to achieve the scale required for meaningful impact. The public and private sectors will need to invest in the replication of current successful initiatives; the localisation of international examples to local settings; and the identification of new opportunities through ongoing science, technology and innovation.

Key economic sectors for water innovation opportunities, given their water resources demands and impacts, are the agricultural, mining and municipal sectors.

8.4 Conclusion

Increasing water demands and deteriorating water quality are severely impacting South Africa's economic development. Constraints in water supply are increasingly compromising water security. Traditional options to supplement our water supply are also becoming unavailable and unaffordable. Together with the economic growth plans and climate change projections, our water security picture looks bleak.

However, current and long-standing examples in practice of the three circular economy principles provide tangible evidence (financial and water security) of the benefits of the circular economy to water users in our different economic sectors (industries, mines, municipalities and agriculture).

Under these circumstances, the circular economy becomes our "no option solution" and wastewater our "new gold". There are almost boundless intervention opportunities, if sought out. As a forward-focused intervention, the mainstreaming of a water circular economy paradigm in South Africa provides opportunities to support and fortify our current and future economy against the projected changes. Most importantly, the circular economy will provide us with the means to build improved resilience to potential future shocks.

8.5 References

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