CIRCULAR ECONOMY SCIENCE TECHNOLOGY AND INNOVATION STRATEGY

A strategy to produce and use Science, Technology and Innovation to support an inclusive, just, climate resilient circular economy transition in South Africa

science, technology & innovation
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CONTENTS

ACRONYMS

3D	Three Dimensional
4IR	Fourth Industrial Revolution
AAMP	Agriculture and Agro-processing Master Plan
ABIPP	Agricultural Bioeconomy Innovation Partnership Programme
ACEN F	African Circular Economy Network Foundation
ARC	Agricultural Research Council
BIDF	Biorefinery Industry Development Facility
CE	Circular Economy
CISA	Circular Innovation South Africa
CO_2	Carbon Dioxide
CRM	Critical Raw Materials
CSIR	Council for Scientific and Industrial Research
CTCN	Climate Technology Centre and Network
CTFL	Clothing, Textiles, Footwear and Leather
DFFE	Department of Forestry, Fisheries and Environment
DHET	Department of Higher Education and Training
DHS	Department of Human Settlements
DMRE	Department of Mineral Resources and Energy
DoT	Department of Transport
DPME	Department of Planning, Monitoring and Evaluation
DSBD	Department of Small Business Development
DSTI	Department of Science, Technology and Innovation
dtic	Department of Trade, Industry and Competition
DWS	Department of Water and Sanitation
EPR	Extended Producer Responsibility
EU	European Union
GDP	Gross domestic product
GHG	Green House Gas
GIZ	German Development Cooperation
H2	Hydrogen
HCD	Human Capacity Development
HEI	Higher education institutions
HESTIIL	Higher Education, Science, Technology and Innovation Institutional Landscape
HSRC	Human Sciences Research Council
ICT	Information & Communication Technologies
IMC	Inter-Ministerial Committee
IP	Intellectual Property
IPCC	Intergovernmental Panel on Climate Change
IRP	International Resources Panel
LCA	Life Cycle Assessment
M&E	Monitoring and Evaluation
MaaS	Material-as-a-Service
MEL	Monitoring, Evaluation and Learning
MFA	Material Flow Analysis
MMP	Mandela Mining Project
NACI	National Advisory Council for Innovation
NDC	Nationally Determined Contributions
NDP	The National Development Plan
NSI	National System of Innovation
PMU	Project/Portfolio Management Unit
R&D	Research & Development
RDI	Research, Development and Innovation
REE	Rare Earth Elements
SA	South Africa
SAMERDI	South African Mining Extraction Research, Development and Innovation
SANEDI	The South African National Energy Development Institute
SARChI	South African Research Chairs Initiative
SDGs	Sustainable Development Goals
SHS	Sustainable Human Settlements
SMME	Small, Medium and Micro Enterprises
STEM	Science, technology, engineering and mathematics
STI	Science, Technology and Innovation
STI4CE	Science, Technology and Innovation for a Circular Economy
TIA	Technology Innovation Agency
UNIDO	United Nations Industrial Development Organization
WEEE	Waste electrical and electronic equipment

FOREWORD

The 2019 Science, Technology and Innovation (STI) White Paper sets the policy intent for a vibrant, inclusive, coherent and optimally coordinated National System of Innovation (NSI) that optimally contributes to South Africa's socio-economic and environmental priorities, and to a capable state. It is the goal of the Department of Science, Technology, and Innovation (DSTI) to boost socio-economic development in South Africa through research and innovation.

In 2022 the Department of Science and Innovation (DSI) published the Decadal Plan (2022-2032), which is premised on advancing the implementation of the STI White paper. It is the intention of the Decadal Plan to optimise synergies among STI-intensive government departments and the rest of government through joint programming and co-funding for STI priorities, and hence to ensure policy certainty to maximise the contributions of business, civil society and academia to STI initiatives and investments. The Decadal Plan identified the circular economy as a new source of growth for South Africa. A circular economy approach offers numerous opportunities for socio-economic growth and environmental protection. Scientific evidence indicates that the circular economy can contribute to GDP, provide new sources of employment, increase profit margins at firm level, and maximise resource utilisation efficiency. For a developing country such as South Africa faced with multiple socio-economic challenges, the circular economy can reduce reliance on increasingly scarce raw materials, increase disposable income for individuals, enhance utility and convenience, and improve living conditions and health.

The Decadal Plan frames the STI for circular economy priorities from a broader sustainable resource management perspective, aimed at an overarching resource productivity improvement in the targeted resource-intensive sectors. Adoption of circular economy principles requires a systems approach that considers sound evidence in the development and implementation of policy and in public- and private-sector decision-making. It requires the adoption of appropriate social and technological innovations that decouple South Africa's development from resource consumption, social impact and environmental degradation. It is recognised that to ensure a successful transition to a circular economy in South Africa, cooperation and partnerships between key actors, including government, private sector, and civil society is essential.

It is with great pleasure that I introduce the Circular Economy Science, Technology and Innovation Strategy. This strategy is an initiative of government aimed at supporting South Africa's transition

Dr B Nzimande
Minister of Science, Technology and Innovation

to a more sustainable, low-carbon and circular economy through science, technology and innovation. It aims to guide government in its strategic direction and investment in circular economy activities and encourage coordination and collaboration between the public and private sectors, and the NSI over the period 2024 to 2034. In line with the Decadal Plan the strategy focuses on three economic sectors – mining, agriculture and manufacturing – in need of an innovation-led response to their modernisation. The principle of a circular economy provides an opportunity to modernise these sectors through low carbon, sustainable and circular practices that will boost sector productivity and ultimately economic development of the country.

It is the ultimate goal of the Circular Economy STI Strategy to create a more sustainable and resilient economy for all South Africans.

EXECUTIVE SUMMARY

"Producing and using science, technology and innovation to support an inclusive, just, and climate resilient circular economy transition in South Africa"

The circular economy is a system where products, components and materials are kept in circulation within the economy at their highest utility and value, through processes such as maintenance, repair, remanufacture, refurbishment and recycling, and where nature is regenerated. Instead of depleting natural resources, natural capital is enhanced through regenerative practices; practices that enable soil restoration and enhance biodiversity, returning biological materials to the earth. Underpinned by a transition to renewable energy and materials, the circular economy is a resilient system that is good for business, people, and planet.[1]

Transitioning to a more circular economy provides an opportunity to address many of the planetary crises facing us this century – climate change, biodiversity loss, water stress, and pollution – by decoupling economic activity from the consumption of finite resources. The circular economy is based on three principles, driven by design – eliminate waste and pollution; circulate products and materials; and regenerate nature.[1]

Over the past decade, the circular economy has found considerable attention and traction, in both developed and developing countries. The transition to more circular economies, globally, has been fuelled by four big drivers: (1) growing resource scarcity in response to increasing resource demand, (2) impending global environmental threats such as climate change, biodiversity loss and water stress; the urgent need for (3) economic recovery, especially post the global pandemic, and (4) socio-economic development and improved quality of life for all.[1][8]

Circular economy as a national priority

The South African economy is at present predominantly linear, overwhelmingly characterised by export-orientated extraction of minerals and supported by an energy system dominated by fossil fuels.[2] In 2017, 19% of extracted materials were exported, 38% were used for energy, 35% became waste and only 15% were used to build local stock, which is considered low in comparison to other countries.[2] The evidence shows that continuing down a highly linear development path creates risks for the South African economy:

- **Risk of over-exploiting and depleting critical, finite resources:** For example, it is estimated that five of South Africa's 18 critical or strategic minerals have less than 50 years of economically viable mining remaining, assuming no new deposits are found.[3]
- **Risk in service provisioning and ensuring well-being for all:** South Africa's allocation of resources into domestic, societal stocks such as buildings, infrastructure and machinery, necessary for the provisioning of services to society, is insufficient. The rate of local stock building is three times lower than the EU average, for example.[4]
- **Risk to agriculture and food security:** Growing water insecurity, with national demand expected to exceed supply by 17% by 2030.
- **Risk to business and industry:** The ongoing crisis in the country's energy sector, which is 80% dependent on coal, characterized by regular power outages, significantly impacts all sectors and industries and reduces domestic productivity and exports.

South Africa's economy is highly carbon intensive. The CSIR has shown that adopting circular economy practices can assist in decarbonizing economic activities and improving energy security. Conservative, high-level modelling for South Africa shows that circular economy measures can reduce greenhouse gas (GHG) emissions in 2050 by 34%, keeping levels to below 2019 values.[5]

> *The South African government has recognised the potential of the circular economy in addressing growing resource challenges; achieving national climate and sustainability commitments; and creating new socio-economic opportunities through greening existing sectors and unlocking new circular businesses and business models.*[6]

The South African government has recognised the potential of the circular economy in addressing growing resource challenges; achieving national climate and sustainability commitments; and creating new socio-economic opportunities through greening existing sectors and unlocking new circular businesses and business models.[6] The principles of a circular economy align with the intentions of the National Development Plan (NDP) and several national industrial, developmental and environmental policies, including Government's Science, Technology and Innovation (STI) White Paper[7] and STI Decadal Plan (2022-2032),[8] which recognise the catalytic role of STI in a circular economy transition.

As an initiative of the Department of Science, Technology and Innovation (DSTI), this Circular Economy STI Strategy aims to support South Africa's transition to a more circular economy through science, technology and innovation. While there is not yet an overarching national circular economy policy or strategy, South African policy and practice has been increasingly referencing circular economy as a development paradigm; recognising that the policy landscape remains largely siloed by sector and line department. This strategy aims to guide government in its strategic direction and investment in circular economy STI activities, and to encourage coordination and collaboration between the public and private sectors and the National System of Innovation (NSI) over the period 2024 to 2034. Furthermore, the strategy proposes tangible routes for ensuring that a circular economy transition is well evidenced and de-risked.

Priority economic sectors

Circular economy practices have been taken up within and across various sectors of the South African economy, and at varying scales of implementation. The DSTI, in consultation with relevant stakeholders, has identified three priority economic sectors – mining, agriculture and manufacturing – in need of an innovation-led response to their modernisation. Alignment with the principles of a circular economy, identified as a cross-cutting issue in Government's STI Decadal Plan, provides an opportunity to modernise these sectors through low carbon, sustainable and circular practices that will boost sector productivity and ultimately economic development of the country. Engagement with the sectors confirmed that considerable opportunity exists for strengthening sector-based circular economy related STI.

MINING

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. However, it is a resource intensive sector, both in the extraction of resources, and as a major consumer of resources such as energy, water and chemicals. 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.[9,10]

The Circular Economy STI Strategy's objective with regards to modernising mining is to evidence South Africa's minerals and metals resource base in support of national resource security, with a special emphasis on critical raw materials; reduce the demand for resources in mining; reduce the generation of mining waste; and strengthen alternative, local sources of minerals and metals through, for example, urban mining.

AGRICULTURE

The South African 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.[11,12]

The Circular Economy STI Strategy's objective with regards to modernising agriculture is to enable improved food security by supporting greater resource efficiency through decoupling food and feed production from resource consumption; mainstreaming regenerative agricultural practices; ensuring sustainable practices in agro-processing; and unlocking high-value product recovery through biorefinery approaches to residual organic waste.

MANUFACTURING

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.[13]

The Circular Economy STI Strategy's objective with regards to modernising manufacturing is to support a more efficient and globally competitive manufacturing sector through the mainstreaming of cleaner production and resource efficiency; circular product design; advanced manufacturing; and remanufacturing.

EXECUTIVE SUMMARY

STI Clusters

Based on the current understanding of the circular economy, the opportunities and constraints to adoption, and the mandate of the DSTI, five strategic clusters (focus areas) which frame the Circular Economy STI Strategy (2024-2034), and which will guide STI and associated investment, have been identified (Figure i). These include:

- Strategic Planning
- Technology solutions
- Resources and the Environment
- Society

Ensuring that a circular economy transition in South Africa is based on sound evidence, the above Clusters are supported by a cross-cutting cluster:

- Modelling & Analytics

An Action Plan composed of five high-level enabling measures is outlined to support government's implementation of the strategy. These include:

- Enhancing inter-governmental, inter-sectoral and multi-stakeholder collaboration
- Directing finance flows towards circular economy STI activities
- Integrating circular economy into higher education and training
- Building and using an evidence base for the circular economy
- Enabling implementation of the circular economy through business support, capacity building, and demonstration.

The DSTI, as the lead agent of this strategy, will continue to engage with line departments to promote cooperation, facilitate the strategy's broad implementation, and ensure synergy, alignment and better coordination of activities.

The strategy elaborates on effective means of implementation through good governance, supported by adequate financing, and a consistent, robust monitoring and evaluation system to track impact.

The nature of this strategy shall not be prescriptive but can be seen as a fluid or dynamic document, that allows adjustment and further sharpening by the DSTI in its implementation.

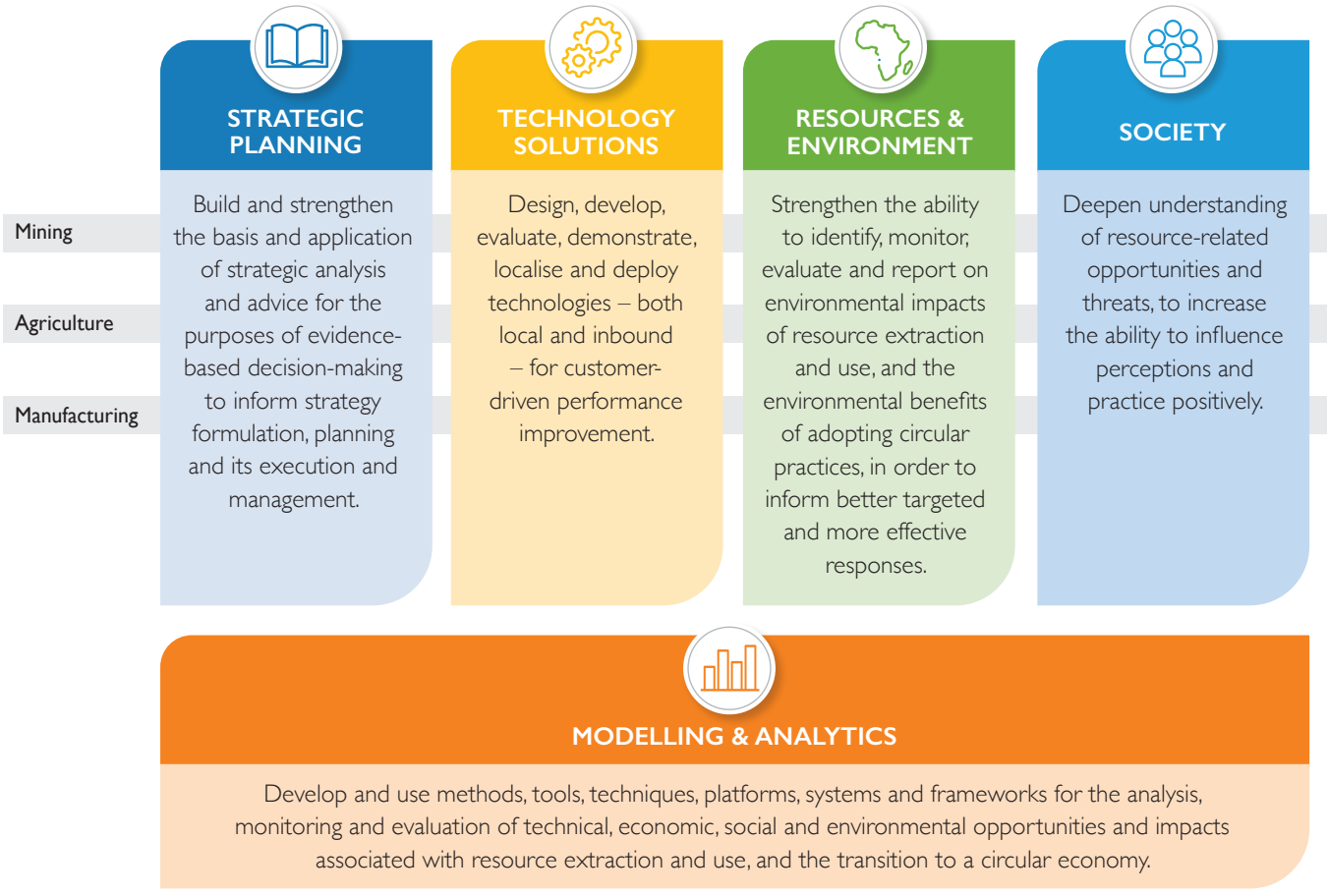

Figure i. Priority economic sectors and STI clusters framing the context of the Circular Economy STI Strategy

1 INTRODUCTION

The Circular Economy Science, Technology and Innovation (STI) Strategy is an initiative of the Department of Science, Technology and Innovation (DSTI) aimed at supporting South Africa's transition to a more sustainable, low-carbon and circular economy through STI. It aims to guide government in its strategic direction and investment in circular economy activities, and to encourage coordination and collaboration between the public and private sectors and the National System of Innovation (NSI), over the period 2024 to 2034.

1.1 THE CIRCULAR ECONOMY CONCEPT

The circular economy is an internationally recognised concept that provides an alternative model to our current linear 'take-make-waste' economy. It is restorative and regenerative, and aims to keep products, components and materials circulating, at their highest utility and value, through processes such as maintenance, reuse, refurbishment, remanufacture, and recycling. At end of product life, technical materials are reincorporated into new production, while organic materials are reintroduced into the biosphere to restore natural capital. In so doing, the circular economy provides opportunities to unlock new growth and employment, achieve global commitments related to climate change and sustainable development, and reduce negative impacts associated with resource extraction, use and waste.[14]

The circular economy concept is often, mistakenly, understood as being limited to waste management, and in particular, waste recycling. However, it spans a range of topics, including resource efficiency and sufficiency; regeneration of natural systems and a shift to renewable resources both for materials and energy; the sharing economy; and more. This broad systems approach to sustainable resource management is a clear strength of the circular economy.

The circular economy is based on three principles, driven by design:

- **Eliminate waste and pollution**, by focusing on product design (more than 80% of a product's environmental footprint is determined during the design phase);[15] reducing energy, water and materials consumption; and creating more efficient and sustainable value chains.
- **Circulate products, components and materials** at their highest utility and value, by prolonging their life and keeping them in use for as long as possible through activities such as reuse, repair or refurbishment.
- **Regenerate nature** by moving from exploitative to regenerative practices, for instance, through the application of regenerative farming, focussing on growing renewable raw materials, and the transition to renewable energy sources.[16]

The transition towards a circular economy challenges governments, businesses, and consumers to rethink production and consumption patterns and redefine the term "growth" into one that captures benefits beyond economic profit alone. The circular economy requires decoupling economic activity from the consumption of natural resources, while designing negative externalities (waste and pollution) out of the system. This demands a holistic approach and lifecycle thinking and action across system and product design, raw material extraction and processing, manufacturing, transport, retail, delivery, consumption, (re)use, repair and end-of-life.[17]

1.2 THE CIRCULAR ECONOMY AS A NATIONAL PRIORITY

Over the past decade, the circular economy has found considerable attention and traction, in both developing and developed countries. The transition to a circular economy has been fuelled by four big drivers: (1) growing resource scarcity in response to increasing resource demand, (2) impending global environmental threats such as climate change, biodiversity loss and water stress; the urgent need for (3) economic recovery, especially post the global pandemic, and (4) socio-economic development and improved quality of life for all.[18]

As countries adopt green- and digital-technologies into their economies, there is a growing demand for resources, in particular critical raw materials (CRMs). According to the International Resources Panel (IRP),[19] 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. This highlights that if we are to solve the big planetary crises facing us this century, there is an urgent need to decouple economic development from resource extraction and consumption, with a greater reliance on regenerative and nature-based solutions.[20]

The global pandemic severely disrupted global supply chains and negatively impacted economies. The circular economy is recognised by many countries as an opportunity to 'build back better' through a green economic recovery, providing opportunities for new types of businesses and business models and the creation of much needed jobs.[21] The circular economy is also increasingly seen as a means

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to achieving critical socio-economic outcomes, in line with the Sustainable Development Goals (SDGs), such as the creation of decent jobs, social inclusion, and sustainable and healthy livelihoods.

Furthermore, current national climate commitments are estimated to achieve 40% of the required greenhouse gas (GHG) emissions reduction under the Paris Agreement.[22] A more integrated approach through a circular economy, which considers the efficient and sufficient use of resources, can address about half of the remaining gap (Figure 1). Transitioning to a more circular economy can address 45% of global GHG emissions.[23] However, approaches based on the decarbonisation of processes are not enough, and it is equally important to make more efficient and effective use of the materials and products already produced, which is heavily influenced at the design stage.

The South African government recognises the potential of the circular economy to address growing resource challenges; achieve national climate and sustainability commitments; and create new socio-economic opportunities through greening existing sectors, and unlocking new circular businesses and business models. The principles of a circular economy align with the goals of South Africa's National Development Plan (NDP) and a number of national industrial, developmental and environmental policies, including Government's STI Decadal Plan (2022-2032), which recognises the catalytic role of STI in the transition to a more circular economy. As outlined in the STI Decadal Plan:

> *"[the] circular economy approach offers numerous opportunities for socio-economic growth and environmental protection. Several scientific, foresight and policy reports have indicated that the circular economy can contribute to GDP, provide a new source of employment, increase profit margins at firm level and maximise resource utilisation efficiency. For developing countries, the circular economy can reduce reliance on increasingly scarce raw materials, increase disposable income for individuals, enhance utility and convenience, and improve living conditions and health. Consequently, intensifying the circularity of the economy provides a new model for sustained and resilient economic growth and job creation."*[25]

The South African economy was estimated to be only 6% circular in 2017,[26] significantly lower than the 9.1% circularity of the global economy.[27] The South African economy is predominantly linear, overwhelmingly characterised by export-orientated extraction of minerals (mainly coal, iron ore and other ores needed for steelmaking), and supported by an energy system dominated by fossil fuels.[28] According to a national (economy-wide) material flow analysis aimed at mapping the level of circularity of the South African economy,[28] 19% of extracted materials were exported, 38% were used for energy (technical energy, feed and food), 35% became solid and liquid waste which was returned to nature, and only 15% were used to build local societal stocks (e.g., infrastructure, buildings and machinery) (2017 figures). The net addition to stocks (NAS) of 2.0 tonnes per capita in South Africa is very low, above that of sub-

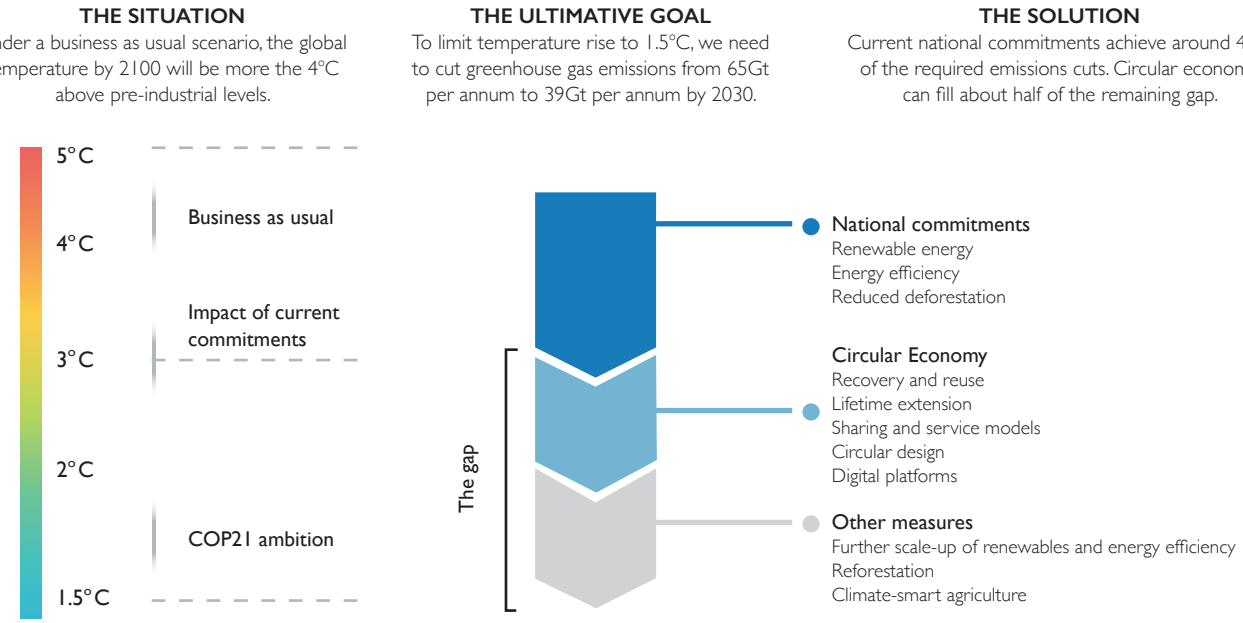

Figure 1. Contribution of circular economy towards meeting the temperature goal of the Paris Agreement 22

Saharan Africa, but significantly below international levels, making it difficult to provide services for the economy and its inhabitants, to create well-being for all.[29] These data reflect several key challenges currently facing the South African economy.

If the current extractive economic trajectory continues, the country will eventually deplete *critical, finite resources*. For example, available data suggests that five of South Africa's 18 critical and strategic minerals have less than 50 years of economically viable mining remaining, assuming no new deposits are found.[30] These minerals, however, are mostly exported, suggesting that South Africa may have little control over their downstream circularity at end of product life. This trend of impending resource depletion will severely undermine future inclusive economic development needed to address the country's high unemployment and stark inequalities in access to basic resources and services.[31]

The percentage of extracted materials going towards *domestic societal stocks* such as buildings, infrastructure and machinery necessary for the provisioning of services to society, is insufficient. The rate of local stock building is three times lower than the European Union (EU) average, for example. For further comparison, while the EU material consumption rate per capita is 10% higher than that of South Africa, the building and maintenance of domestic stocks is 300% higher.[32]

In addition, the country faces significant water insecurity, with national demand expected to exceed supply by 17% by 2030. Significant water shortages have already been experienced, such as the 2017-2018 Cape Town water crisis, the 2015-2020 drought in the Eastern Cape and more recent crises in the cities of Johannesburg, eThekwini and Tshwane. The main sources of water consumption are agriculture (61%), cities (30%) and manufacturing (3%).[33] It is crucial that these sectors become more efficient and circular in their water use and decouple economic development from water consumption to ensure that water does not become a constraint to national food security and future economic development.

The ongoing crisis in the country's energy sector, which is 80% dependent on coal,[34] characterized by regular power outages, significantly impacts all sectors and industries, and reduces domestic productivity and exports. Combined with this, the transportation sector's 98% reliance on increasingly finite and costly imported fossil fuels,[35] and widespread pollution from manufacturing, serve as increasingly urgent indicators for a need to rapidly shift from a linear, carbon-intensive economy to a more circular South African economy.

Although the current economy is vastly *carbon-intensive*, opportunities exist for decarbonization and improved energy security through circular interventions to improve energy infrastructure and diversify sources. If implemented in a just and inclusive way, the circular economy can help address many of the country's resource-related development challenges. The CSIR has shown that given the carbon intensity of our energy and resource use in South Africa (e.g., in transportation, manufacturing, and agriculture), adopting circular interventions in a few strategic economic sectors can lead to significant decarbonisation.[36] Conservative, high-level modelling for South Africa shows that circular economy measures can reduce GHG emissions in 2050 by 34%, keeping levels to below 2019 values. Sizable contributions to mitigation are achieved through ambitious changes to the use of energy resources in the manufacturing, mining, construction, mobility and agriculture sectors.[36]

In summary, international and national research confirms that resource scarcity, climate mitigation, economic recovery, and socio-economic development are as important in driving South Africa's transition to a more circular economy, as they are to other countries.

1.3 REALISING A CIRCULAR ECONOMY TRANSITION

Realising the circular economy in South Africa requires a fundamental shift that reshapes how the country's economy operates; specifically, how it (i) derives value from resources, assets and labour, (ii) provides value and opportunity to citizens, and (iii) situates itself in a broader global trade system.[37] This is a shift that our institutions are not yet fully designed nor equipped to lead, and a shift which must engage social and cultural norms related to resource access and use.

The Circular Economy STI Strategy, while promoting and supporting a vision for a paradigmatic shift in our economy, recognizes that this vision needs to be articulated across other strategies and actions relating to both government and societal actors. It recognizes that a circular economy transition requires further evidence, advocacy and demonstration that can showcase the benefits of a circular economy, and that provides evidence of the types of institutional structures, governance processes, and social-cultural interventions that are needed to drive such paradigm shifts.

Therefore, this strategy is scoped around one of the key enablers of the transition to circular economy: the provision and uptake of robust STI, which can evidence why a circular economy transition is important, what interventions could be most impactful, and what processes and institutional structures may best enable the realisation of a circular economy. As such, the strategy should be seen as contributing to the development of a broader South African Circular Economy Strategy, but is itself specifically focussing on, and scoped to, STI.

1.4 ALIGNMENT WITH NATIONAL POLICY

1.4.1 Sectoral policy

It is acknowledged that this Circular Economy STI Strategy, which aims to give effect to the STI White Paper[38] and STI Decadal Plan (2022-2032), has been developed in the absence of a national Circular Economy Strategy or Policy. Despite the lack of such a national strategy, South African policy and practice has been increasingly referencing a circular economy as a development paradigm. However, the policy landscape is largely siloed by sector and by line department. There are several sector policies and regulations which align with the principles of a circular economy, and that can support South Africa's transition to a more circular economy. These include, but are not limited to the National Environmental Management Act;[39] the National Environmental Management Waste Act;[40] the National Water Act;[41] the Mineral and Petroleum Resources Development Act;[42] the Carbon Tax Act;[43] Agricultural Policy;[44] the Extended Producer Responsibility (EPR) Regulations;[45] the National Waste Management Strategy;[46] the National Water and Sanitation Master Plan,[47] the Integrated Resource Plan;[48] various industry masterplans of the Department of Trade Industry and Competition (dtic), including the Steel; Automotive; Clothing, Textile, Footwear and Leather sectors (CTFL); agriculture and agro-processing; sugar; and forestry masterplans;[49] the Green Transport Strategy;[50] the Comprehensive Housing Plan for the Development of Integrated Sustainable Human Settlements (Breaking New Ground);[51] and various strategies of the DSTI, including the Bio-economy Strategy,[52] and the Water[53] and Waste Research, Development and Innovation (RDI) Roadmaps.[54]

The country has made progress particularly in sectors such as waste management, water reuse, and renewable energy. However, various opportunities remain to be exploited, including the urgent need to scale circular interventions, particularly within the resource intensive sectors of the South African economy.

The investment in STI provides an opportunity to better understand and unlock the opportunities of a circular economy, including the development of a robust and appropriate Circular Economy Strategy for South Africa.

1.4.2 STI policy

The South African STI policy landscape includes implementation strategies, administered across multiple Government Departments and affiliates. The policy landscape journey leading up to the development of this Circular Economy STI Strategy started in 1996 with the promulgation of the White Paper on Science and Technology. Developments over the last 27 years have included numerous science and technology driven outputs and developments to address challenges such as poverty, food security and energy, and to create an enabling environment for a circular economy.

Figure 2 provides a broad overview of the policy landscape journey leading up to this Circular Economy STI Strategy. It references the key documents that have been developed between 1996 and 2024. From 2019 onwards, the circular economy has become an

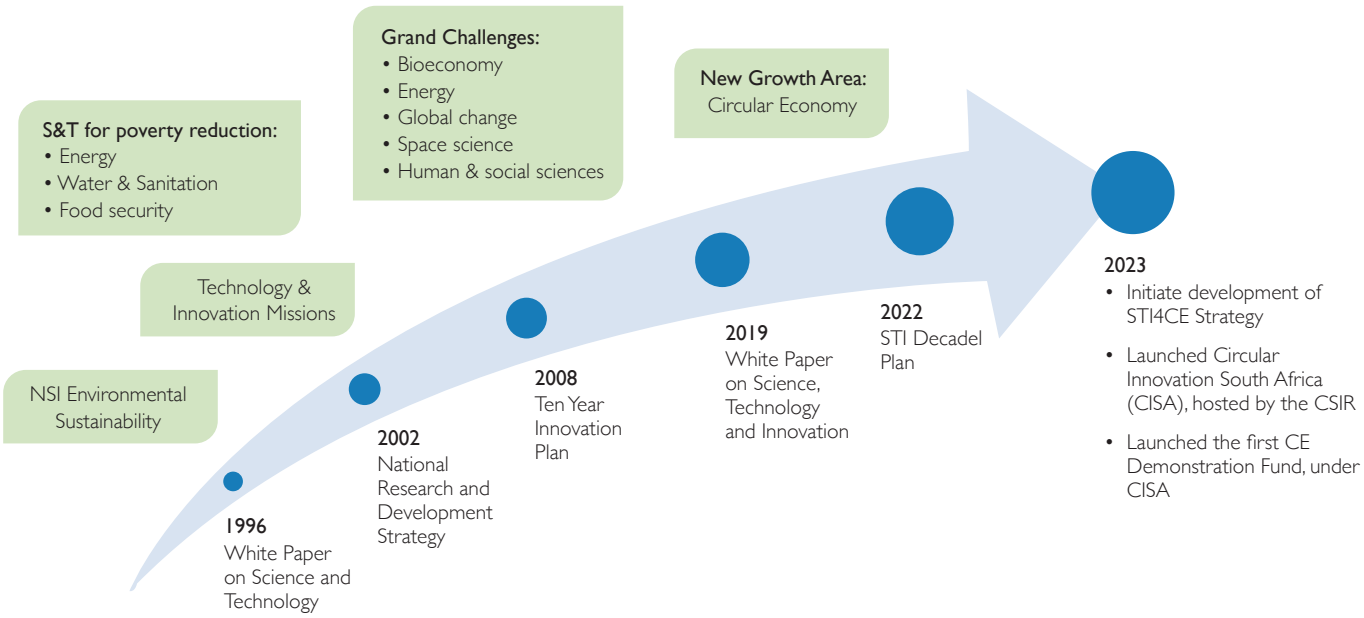

FIGURE 2. Policy development leading up to the Circular Economy STI Strategy (Roman, 2023)

integrated means to improve socio-economic development and environmental preservation.

The adoption of the STI White Paper in 2019 led to the introduction of an innovation mandate across government. There are a number of STI policies, strategies and roadmaps that have paved the way for the development of this strategy. The long-term goal of the STI Decadal Plan is to create a productive NSI, which will contribute to the goals identified in the STI White Paper:[55]

- Goal 1: An inclusive and coherent NSI
- Goal 2: An expanded and transformed research system
- Goal 3: Increased and future-proof human capabilities
- Goal 4: An enabling innovation environment, and
- Goal 5: Significantly increased funding for the NSI

These goals are supported by:

- Increased and strategically targeted STI internationalisation, and
- Monitoring, evaluation & learning framework for the NSI

With this context in mind, this Circular Economy STI Strategy proposes tangible routes for ensuring that a circular economy transition in South Africa is well evidenced, de-risked, and supported by a relevant and capable NSI.

There are several sector policies and regulations which align with the principles of a circular economy, and that can support South Africa's transition to a more circular economy.

2 METHODOLOGY AND ASSUMPTIONS

2.1 THE STRATEGY PROCESS

The Circular Economy STI Strategy was developed through a two-phased methodological approach. Phase 1, supported by the Climate Technology Centre and Network (CTCN) included a status quo analysis and stakeholder consultation, followed by a synthesis and write-up, which provided input to the strategy development Phase 2.

Phase 1

In the first phase, a comprehensive status quo analysis was conducted for circular economy and STI which represents the knowledge base for the strategy development. Using a mapping approach, relevant stakeholders, existing initiatives, instruments and tools were captured to provide an overview of the current South African STI circular economy ecosystem. This was followed by stakeholder consultations to gather inputs to inform the strategic context of the strategy. Stakeholder consultations included:

- An in-person workshop at the outset of the project to align the expectations of the DSTI, its entities and related government departments and implementing agencies.
- Interviews were undertaken with officials from relevant government departments to better understand their current initiatives related to a circular economy; in particular STI, and to identify their needs and expectations.
- A multi-stakeholder in-person workshop served to validate identified STI gaps and opportunities, ideate potential actions as a response and find focus on priority sectors and clusters.

The information gathered during Phase 1 was processed and synthesised into a technical report which fed into a DSTI-led Phase 2.

Specific outputs of Phase 1, included:

- Diagnosis Report (2023)
- STI Analysis Report – Ecosystem and Opportunities (2024)

Phase 2

The consolidated findings from Phase 1 were submitted by the CTCN to the DSTI, who in partnership with Circular Innovation South Africa (CISA), the DSTI's implementing agency for the circular economy, finalised the strategy.

Phase 2 included consultation with various technical experts within the DSTI to ensure alignment with the somewhat 'fluid' STI Decadal Plan landscape at the time of finalisation. A draft Circular Economy STI Strategy was presented to the DSTI Executive Committee in September 2024 and approved for finalisation. The strategy was sent out to external review for final validation in November 2024, before finalising the strategy.

The Circular Economy STI Strategy has taken into consideration a number of national STI roadmaps and strategies, including amongst others:

- Waste RDI Roadmap (2015-2025)
- Water RDI Roadmap (2015-2025)
- STI for Sustainable Human Settlements (2021-2031)
- Additive Manufacturing Strategy (2016)
- Hydrogen Society Roadmap (2021)
- Bio-economy Strategy (2013)

South Africa's strategic direction in terms of circular economy STI has been developed in conjunction with stakeholders working in the circular economy and related fields.

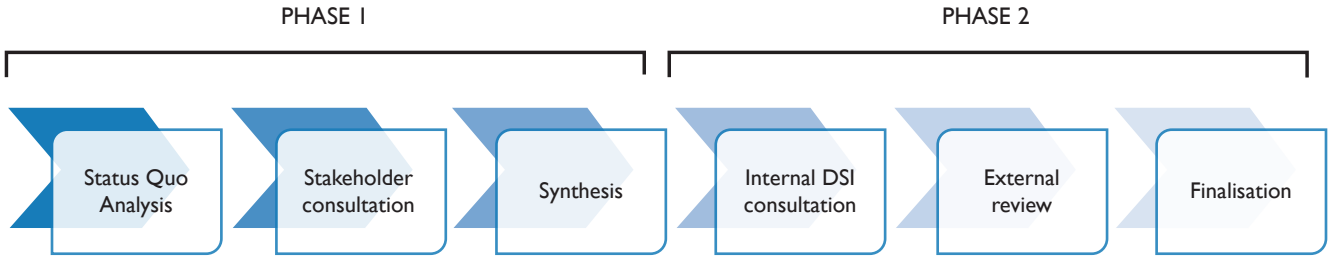

FIGURE 3. Overview of methodological approach.

3 STRATEGIC CONTEXT

3.1 INTERNATIONAL CONTEXT

The circular economy is gaining significant traction worldwide as an alternative to the traditional linear economy, which follows a "take-make-dispose" model. In Asia, countries like China and Japan have made notable strides in advancing circular economy principles. China has embraced circular economy strategies as part of its broader environmental reform agenda. In 2020, China introduced a national *"Circular Economy Development Strategy and Action Plan,"* aiming to reduce resource consumption per unit of GDP and increase the recycling rate of key materials. Japan has long been recognized for its waste management and resource efficiency practices, such as its *"Sound Material-Cycle Society"* policy (2014). This policy prioritizes waste reduction, recycling, and the efficient use of resources, alongside an emphasis on product longevity and repairability. Both countries demonstrate a growing recognition of the need for systemic change in production and consumption, alongside the growing role of digital technology in optimizing resource flows and supply chains.

The European Union (EU) has also been at the forefront of this movement, with its *Circular Economy Action Plan* (2020) aiming to promote sustainability across various sectors. This includes initiatives like the *EU's Waste Framework Directive* (2008) and the *Ecodesign for Sustainable Products Regulation* (ESPR) (2024), which encourage product design that facilitates reuse and recycling, as well as strategies for reducing waste and carbon emissions. The EU's comprehensive approach, combining policy, legislation, and market incentives, has provided a global model, influencing countries around the world to adopt similar frameworks.

In North America, while the circular economy is still in its developmental phase compared to Europe and Asia, the momentum is growing, particularly in Canada and the United States. Canada, through its federal government and provincial efforts, has pushed forward with initiatives aimed at reducing waste and improving resource efficiency, such as the Canada-wide Action Plan on Zero Plastic Waste. In the US, a mix of private sector innovation and state-level initiatives is driving circular economy practices. Several large companies have embraced circular principles, focusing on product longevity, remanufacturing, repair and recycling. While there are still challenges in scaling up circular practices across all sectors, North America is making significant inroads, especially in technology and consumer goods industries, setting the stage for broader systemic adoption in the coming years.

Countries around the world are increasingly investing in, and integrating science, technology, and innovation into their strategies to accelerate the transition to a circular economy. One key approach is the investment in research and development (R&D) of sustainable materials and circular product design; resource-efficient manufacturing; remanufacturing; urban mining; circular bioeconomy solutions; waste management, and the development and scaling of circular business models. In Europe, for example, the EU has committed substantial funding through programs like Horizon Europe, which supports innovation in circular economy practices.

Governments are also fostering innovation through policy frameworks that incentivize businesses to adopt circular practices. More and more countries are implementing Extended Producer Responsibility (EPR) laws requiring manufacturers to take responsibility for the full lifecycle of their products, which includes ensuring products are recyclable or reusable. These policies are often backed by technological advancements in product design, where digital tools such as 3D modelling and simulation are used to design products that are easier to disassemble, remanufacture, repair and recycle; and informed by tools such as life cycle assessment (LCA).

Emerging economies, including India, Brazil, Chile are increasingly adopting circular economy principles, using technology to tackle issues like resource efficiency, the circular bioeconomy, and waste management. These nations are also utilizing digital platforms and mobile technology to unlock circular economy opportunities at the local level, while also exploring new business models like product-as-a-service, where products are leased rather than sold, encouraging product return and reuse, thereby reducing waste.[56,57]

Finally, countries around the world are increasingly recognizing the strategic importance of securing critical raw materials (CRMs) to support their economic growth, technological advancements, and energy transition goals. To prepare for future demand, nations are developing comprehensive strategies that include diversifying supply chains, strengthening recycling capabilities, and investing in alternative materials and technologies.

> *Countries around the world are increasingly investing in, and integrating science, technology, and innovation into their strategies to accelerate the transition to a circular economy.*

3.2 SOUTH AFRICAN CONTEXT

The South African government has recognised the declining contribution of the productive economic sectors to South Africa's GDP, with a shift towards services,[58] as experienced globally. However, it remains necessary over the short- to medium-term for South Africa to modernise and strengthen productive sectors such as mining, agriculture and manufacturing to absorb larger numbers of low-skilled workers. This is even more relevant following the global pandemic, which had a significant negative impact on the South African economy and on employment, including job security. Innovation has the potential to modernise these sectors, and to unlock new business opportunities that can absorb significant labour, contribute to exports, and support economic development. There is also the potential to increase the productivity of the South African economy through skills development, innovation, investment in infrastructure, regulatory reform, and information and communications technology. Greening the economy will be an important adjunct to such efforts. The circular and digital economies have been identified by the South African government as new sources of economic growth for the country.

Since many circular economy initiatives are not new to South Africa, there is a strong foundation from which to launch STI for a circular economy. For example, in response to high levels of unemployment, poverty and inequality, end-of-life products are often repaired and reused in South Africa.[59] As a result of water scarcity, grey water has been recycled and reused for decades, with returns making up more than 10% of South Africa's available water.[60] Additionally, amidst worsening energy insecurity since 2007, the installation of renewable energy technologies has grown significantly over the past decade.[61] Circular economy practices have been taken up within and across various sectors of the economy, and at varying scales of implementation. Common goals across such initiatives have included greater financial security and improved quality of life; resource security; increased resource efficiency and productivity; and retaining resources within the South African economy at their maximum value.

The DSTI has identified three economic sectors – mining, agriculture and manufacturing – as growth economic sectors that can serve as useful platforms for implementing circular economy initiatives. This strategy elaborates further on how circular economy STI can be effectively deployed in these sectors. To support government objectives, this strategy looks to drive greater circular economy related STI within these three priority economic sectors in the short- to medium-term (2024-2034).

The strategy also recognises the interface between the circular economy and digital economy. For example, on the journey towards deploying clean technologies in the mining sector, while considering socio-economic factors, embracing Industry 4.0 holds great potential to align with international trends, helping to optimise current processes[62] and shaping the further development of the sector. The integration of digital tools and data-driven approaches represent strategic enablers in several areas. Among others, these include the inclusivity and empowerment of small-scale and emerging mining companies, for instance related to accessibility to quality geoscience data, or facilitation of their participation in exploration activities.[63]

The DSTI has identified three economic sectors – mining, agriculture and manufacturing – as growth economic sectors that can serve as useful platforms for implementing circular economy initiatives.

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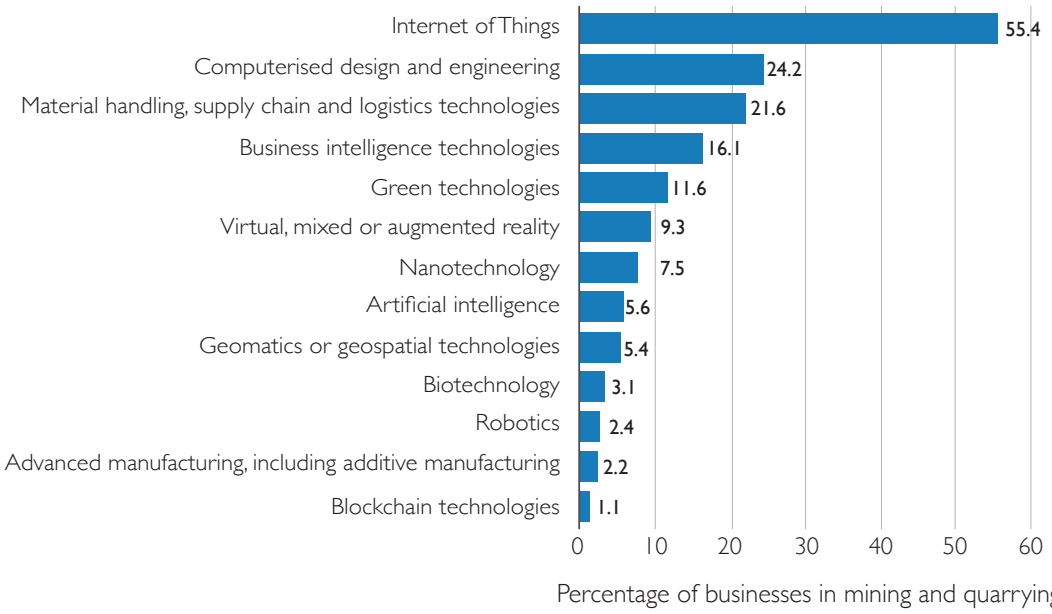

Figure 4. Percentage of businesses in mining and quarrying that used or developed advanced or emerging technologies.[66]

3.2.1 Mining

The South African mining sector plays a significant role in the country's economy, by providing valuable minerals and metals to domestic and global markets. Between 2022 and 2023, the mining industry's direct contribution to national GDP declined by 8.1% from R483.3 billion to R444.2 billion.[64] In 2023, mining contributed 6.3% to the economy (declining from 7.3% in 2022) and employed 479,228 people. Aside from the fact that mining is a traditionally extractive process, this sector accounts for up to 5% of national water demand, consumes approximately 14% of electricity supplied by Eskom, and is responsible for 6% of the country's GHG emissions. Mining's share of national energy demand increases to 30% when including smelters and refineries.[65] Importantly, Eskom will remain a primary source of electricity offtake for the mining sector because of its requirement for baseload supply, but this also opens opportunities for alternative, more sustainable energy sources.

Strategically, the mining sector is positioned to be a key contributor to the economy for many years to come. South Africa is also strategically placed to capitalise on the current global green energy and digital economy transitions, in terms of growing demand for certain critical raw materials (CRMs) at the heart of these transitions. South Africa holds the world's largest share of manganese (a key component in Li-ion batteries for EVs). However, the sector has an eventual sunset – given its focus on the extraction and processing of finite resources – as resources are depleted or become too expensive to extract.

The challenges facing the South African mining sector provide both the opportunity and the necessity for innovation. According to the HSRC's Business Innovaton Survey 2019-2021 for the Mining Sector,[66] *"New advanced technologies have become a distinct feature of mining industrial advantage, compelling industry to pursue a modernisation agenda."* However, the HSRC survey shows that mining and quarrying businesses have been slow to adopt advanced or emerging technologies, particularly green technologies (11.6% of businesses) (Figure 4). The most frequently adopted technologies included *Internet of Things* (IoT) (55.4%) followed by *Computerised design and engineering* (24.2%). Digital technologies serve many needs in mining, including advancing and enhancing safety and health, leadership and workforce capability, security and production.[67]

> *The challenges facing the South African mining sector provide both the opportunity and the necessity for innovation.*

PWC revealed a slightly improved analysis in 2023, in terms of the state of digital transformation in the South African mining industry.[67] Digital technology is being applied where it has the greatest measurable benefit, in tandem with the Environmental, Social and Governance (ESG) framework emerging as an intentional long-term shift in strategy.

Costs and lack of access to finance were the main reasons provided by businesses for the barriers to innovation in the sector,[66] despite the acknowledgment that the adoption of technological innovation in mining may result in cost reduction.[68] However, what is concerning is that *Difficulty in finding co-operation partners for innovation*, was reported by 15.5% of businesses as being a barrier to innovation, despite considerable capability sitting within the South African NSI. Lack of technical and engineering skills were not considered to be a barrier to innovation, despite shortages of these types of skills in South Africa.[66]

Increased business resilience and adaptability to change, was considered to be the most important outcome for adopting innovation. This provides an encouraging motivation for the adoption of circular practices by mining companies, given the potential disruption of future minerals scarcity and resource security.

The South African Mining Extraction Research, Development & Innovation (SAMERDI) Strategy[69] outlines a vision for the South African mining sector *"To maximise the sustainable returns of South Africa's mineral wealth through collaborative research, development, innovation and implementation of mining technologies in a socially, environmentally and financially sustainable manner that is rooted in the local community and national economy."* The SAMERDI Strategy identifies a number of STI thematic areas that are aligned with the circular economy. These include:

- Input resources optimisation, i.e., optimal and efficient use of input resources such as electrical energy and water costs
- Mining engineering, i.e., next generation mining methods such as keyhole or precision mining
- Environmental impact management, i.e., minimising waste generation, waste beneficiation and lessening the impact on the environment

In response to the strategy, four SAMERDI Research Centres have been established at South African Universities. These include:

- Mechanised Mining Systems (MMS)
- Advanced Orebody Knowledge (AOK)
- Successful Application of Technology Centred Around People (SATCAP)
- Real Time Information Management Systems (RTIMS)

The Department of Mineral Resources' Beneficiation Strategy for the Minerals Industry[70] remains highly relevant, given the expected growth in global demand for minerals and metals. Government's beneficiation strategy aims to *"contribute to an incremental GDP growth in mineral value addition per capita"* in line with the vision of the National Industrial Policy Framework (NIPF), including the Advanced Manufacturing Technology Strategy (AMTS). The Beneficiation Strategy however recognises limited exposure to R&D and inadequate skills as constraints to local value-add; as does the Department of Mineral Resources and Energy's *Critical Minerals Strategy for South Africa*, currently under development.

Current activities in the mining sector present an opportunity to embrace STI and the circular economy, to further solidify this sector as a global player, and to create both comparative and competitive advantage for mining companies. To do this, South Africa needs to pursue avenues such as precision mining techniques; enhance its processing and refining capabilities; and embrace circular processes in extracting value from mine waste and through urban mining; while simultaneously driving greater resource efficiency; and renewable and regenerative practices. The Circular Economy STI Strategy will look to support current STI activities and add value to the broader mining value chain research agenda.

As noted in the STI Decadal Plan (2022-2032), *"In the mining sector, STI interventions can improve the sector's resource (energy and water) utilisation efficiency. The opportunities for embedding circular economy principles lie in optimising recycling efforts and fostering sustainable automated mining methods."*

3.2.2 Agriculture

Given South Africa's significance as a producer and exporter of agricultural products, the protection of agricultural resources is a key component of South Africa's agricultural policy.[71] Over the last 10 years, the country has continuously maintained its net-export status. This has corresponded with an increase in agricultural exports to a record high of USD12.4 billion and a rise in agricultural employment to 829,000 jobs in 2021.[72] The sector is dominated by both large-scale commercial farms, with sophisticated harvesting, storing and processing facilities, and small-scale family farms engaged in subsistence farming, providing a wide range of agricultural commodities.

Current activities in the mining sector present an opportunity to embrace STI and the circular economy, to further solidify this sector as a global player, and to create both comparative and competitive advantage for mining companies.

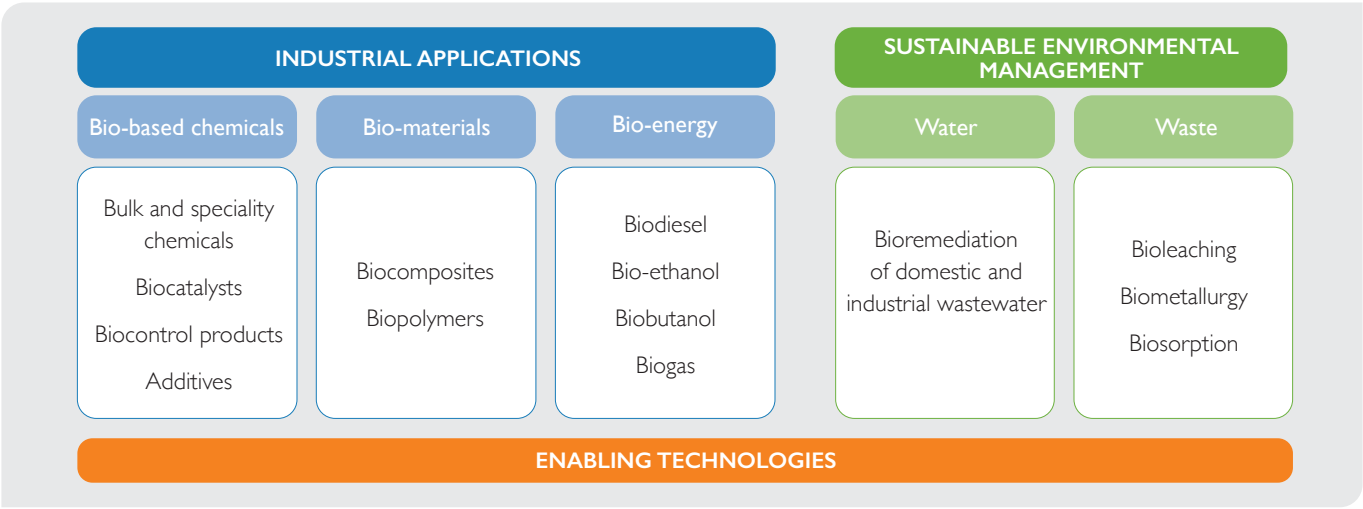

Figure 5. Relevant thematic areas of focus for the industrial bio-economy[79]

However, South Africa is a water scarce country, and agriculture accounts for 61% of water consumption,[73] with large irrigation schemes and storage dams contributing to further water losses through conveyance. While below the global average of roughly 70%,[74] agriculture is a water intensive practice. The sector also has high energy demands, accounting for 6% of South Africa's energy demand in 2019. Of this demand, 68% constitutes liquid fuels and 31% electricity.[75] Despite this considerable resource consumption, agriculture's share of GDP was 2.8% in 2022,[76] among the lowest in Africa. However, through varied supportive measures across land, labour and taxation, the performance of the agricultural sector has been progressively improving in recent years.[77]

The Agricultural Business Innovation Survey (2019-2021)[78] highlighted a high level of innovation adoption in the South African agricultural sector, with 67.1% of agri-businesses actively involved in innovation activities; particularly among medium-sized agri-businesses (72.9%) and large agri-businesses (70.8%). Much of this innovation was focussed on business process innovation (63.6%) aimed at improving yields and mitigating risks associated with climate change, and less on product innovation (38.5%). Environmental innovation outcomes were rated important by innovation-active agri-businesses. Improved soil fertility (26.2% of agriculture businesses) and increased water preservation (20.3%) were rated as highly important outcomes of their innovation. Over 50% of innovation-active agri-businesses involved in growing cereals and fruits had adopted precision agricultural technologies, and 54.9% of innovation-active businesses in the production of livestock had adopted precision livestock farming (PLF) technologies. The majority of innovation-active agri-businesses (55.4%) relied on in-house expertise for their product innovation, with limited awareness (32.5%) of government research facilities for innovation, and even lower application for use (17.7%).

There is therefore much to be done in growing and strengthening the role of the NSI in support of innovation in South Africa's agriculture sector. It is encouraging that 41.0% of innovation-active businesses in agriculture found *Government and public research institutes* to be highly important sources of information, with significantly less emphasis on *scientific journals and trade/technical publications* (14.1%) and *Conferences, trade fairs, exhibitions* (11.7%). More can therefore be done by universities and science councils to make their research outputs more accessible to agri-businesses.

Government's Bio-economy STI Strategy[79] recognises a number of strategic interventions aligned with the circular economy, particularly in the *Industrial and Environmental Sectors* (Figure 5). These include the manufacture of biobased products such as bio-based chemicals, biomaterials, biofuels, biocontrol products such as bio-pesticides, and bio-fertilisers; optimal management practices for irrigation and water recycling; wastewater treatment and organic waste beneficiation, including biomass to energy and integrated biorefineries; soil conservation; aquaculture; and reducing post-harvest losses and extending shelf life in the agro-processing sub-sector. The Bio-economy Strategy recognises the need to build high-value skills and capacities to enable agro-innovation.

There has been a growing call for innovations within the agriculture sector. These include, but are not limited to, technologies to improve resource efficiencies across the value chain (such as water use), climate smart practices, and precision agriculture.

As noted in the DSTI's STI Decadal Plan (2022-2032), *"For agriculture, STI contributions can drive the circularity of the sector by adopting reformative agricultural practices and improving resource utilisation through the implementation of precision and digital tools that are central to the regenerative model of the circular economy. STI interventions offer opportunities for waste elimination and chemical pollution reduction by embracing biorefining innovation opportunities for processing agricultural by-products."*

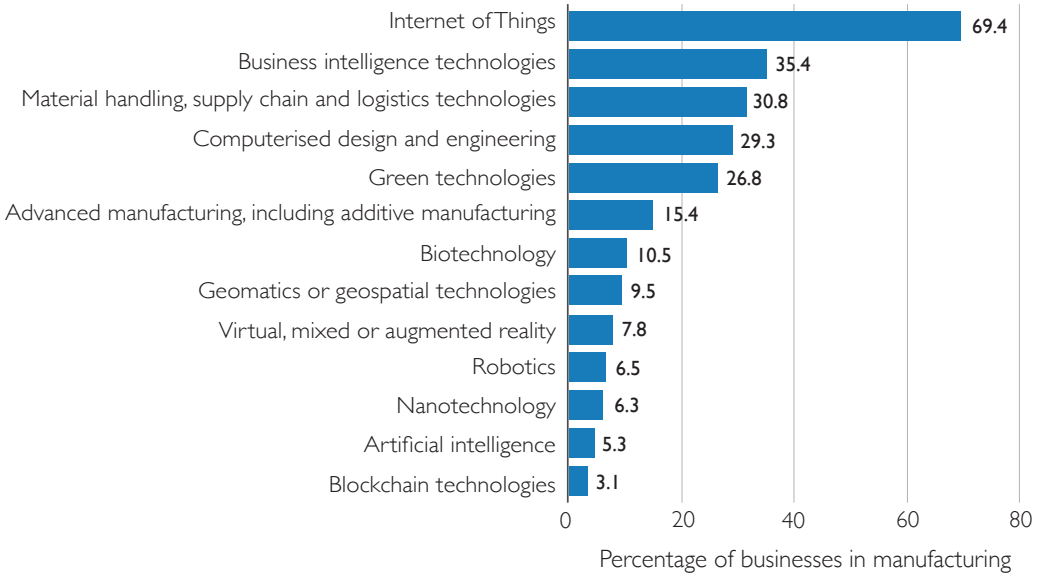

Figure 6. Percentage of businesses in manufacturing that used or developed advanced or emerging technologies.[83]

3.2.3 Manufacturing

The manufacturing sector is an important component of the South African economy. However, the sector's contribution to GDP has declined from 21% in 1995 to just 12% in 2019.[80] According to the South African Reserve Bank, manufacturing accounts for 12% of formal employment and 42% of the Rand value of exports.[81] Furthermore, the sector has strong linkages with a variety of supplier and supporting industries, particularly mining and agriculture, as well as service providers. Manufacturing still largely operates according to a linear economic model, leading to high resource demand, high wastage, heavy reliance on fossil fuels, and high GHG emissions. An economy-wide material flow analysis conducted in 2022 demonstrated the significant extent to which manufacturing contributes to the perpetuation of South Africa's linear, export-oriented and fossil fuel-based economy.[82]

However, South African manufacturing businesses are considered low-tech relative to their peers in competitor countries.[83] As with the mining sector, the challenges facing the South African manufacturing sector provide both the opportunity and the necessity for innovation. According to the HSRC's Business Innovaton Survey 2019-2021 for the Manufacturing Sector,[83] *"Manufacturing businesses did not engage with a wide variety of advanced or emerging technologies, despite these being important for modernisation."* As with mining, *Internet of Things* (IoT) (69.4%) ranked high in terms of the percentage of businesses in manufacturing that used or developed advanced or emerging technologies. Only 26.8% of South African manufacturing businesses reported using green technologies, despite them being important for modernisation (Figure 6).

Lack of funds (25.3% of businesses) and *high innovation costs* (24.8%) were considered major constraints to adopting innovation in the manufacturing sector. However, unlike the mining sector, manufacturing businesses did not consider *finding co-operation partners for innovation* a major constraint (6.3%).

Improved quality of goods or services (59.1%) was considered the most important reason for adopting innovation in manufacturing. This provides an encouraging motivation for the adoption of circular practices by manufacturing companies, in particular the growing international demand for improved product design for longevity, durability and circularity.

A recent report on *Revitalising South Africa's Manufacturing Sector*[84] confirmed the declining investment in skills development, and the lack of technological innovation due to limited investment in relevant R&D, which has resulted in some manufacturing sub-sectors losing their global competitiveness. Key manufacturing sub-sectors identified as being important to revitalising South Africa's manufacturing sector include:

- Agro-processing
- Automotive
- Furniture
- Meat
- Pharmaceuticals
- Steel, and
- Sugar

The above sub-sectors provide very real opportunities for the adoption of circular practices,[85] including amongst others, additive manufacturing,[86] remanufacturing, product design, and resource efficiency and cleaner production (RECP). As a result, building the capacity of the manufacturing sector to innovate is critical in enhancing the sector's competitiveness, productivity and sustainability.

As noted in the DSTI's STI Decadal Plan (2022-2032), *"In manufacturing, STI interventions are expected to reduce resource input dependence by integrating 4IR-based manufacturing technologies and innovations. Embedding circularity in manufacturing can be realised by embracing design thinking and reinforcing the principle of a remanufacturing regenerative approach across the sector's value chain."*

4 STRATEGIC INTENT

4.1 INTRODUCTION

Driving a resilient circular economy transition in South Africa requires a strong commitment to cross-sector and multi-level action. It requires putting in place an effective enabling environment, particularly with regards to building coordination among actors, generating and aggregating evidence of how circular economy interventions can drive broad developmental agendas, and building a skills base that is able to enact circular economy initiatives.

Sections 1-3 have outlined the necessity of improving application of STI to drive effective uptake of a circular economy across specific sectors of the South African economy. These introductory sections set the foundation for Sections 4 and 5, which frame the vision and mission of the strategy; outline the priority economic sectors and associated STI priority areas; set out STI Clusters as the organising principle for the delivery of the strategy, and define an associated STI Outcome as the desirable end-state that can be achieved through the successful execution of the portfolio of planned investment and activity.

Vision: *Produce and use science, technology and innovation to support a sustainable, just, and climate resilient circular economy transition in South Africa.*

Mission: *Develop, de-risk and scale circular economy interventions through the application of STI by a capable and relevant national system of innovation, facilitated by the DSTI.*

Means: *The underpinning contribution of STI to strengthening South Africa's transition to a more circular economy is focused on three key enablers:*

1. *Strengthened STI capability and capacity*
2. *More effective decision-making*
3. *Faster insertion of context-appropriate technology*

4.2 PRIORITY SECTORS

The Circular Economy STI Strategy has prioritised three economic sectors – mining, agriculture and manufacturing – for implementation, in line with the priorities of Government's STI White Paper and STI Decadal Plan (2022-2032). This section outlines the priority STI opportunity areas that will help to move each of these sectors forward in terms of the uptake of circular economy practices and technologies. These priorities have been determined through engagement with sector experts from business, government and the NSI, and further refined through engagement with the DSTI.

4.2.1 Circular Economy and Mining

Until recently, the mining sector was not considered part of the circular economy, primarily because of its extractive nature. However, understanding the mining sector beyond purely extractive operations opens many circular economy opportunities, specifically in decoupling extraction from resource consumption (water, energy, materials), and driving greater circularity of minerals and metals at end of product life.

Three priority areas have been identified for mining, i.e., short- to medium-term opportunities where STI can play a role in driving greater circularity in the mining sector:

- **Resource Security:** Understanding South Africa's minerals and metals resource base for improved resource monitoring and management; supporting national resource security, with a specific focus on critical raw materials (CRMs), linked to resource cadastres.
- **Resource Efficiency:** Driving greater circularity within mining operations, including reducing the demand for resources in mining operations (energy, water, materials); precision-mining, with the aim of reducing the generation of mining waste during extraction.[87] This includes designing and optimising process steps with the aim of decreasing resource use and waste.
- **Diversifying Sources:** Strengthening alternative, local sources of minerals and metals through, for example, developing downstream industries that recover value from tailings, residue stockpiles and other mining waste; and growing local recovery and recycling of minerals and metals from municipal and industrial waste streams, such as waste electrical and electronic equipment (WEEE), lighting, end-of-life vehicles and associated components, and other mining equipment.

Supported by a just energy transition, including the adoption of clean energy technologies, renewable energy technologies, and green hydrogen, aimed at decarbonising the mining sector.[88] Additional opportunities exist in the fields of improving the environmental sustainability of mining operations, including water management and land rehabilitation.[89,90]

4.2.2 Circular Economy and Agriculture

The agricultural sector has an important position in the South African economy as it is connected to many other sectors, including export activities, and is crucial to ensuring national food security and improved quality of life. In the context of a rising population and ambitions to increase industrial value-added activities, there is a need to explore transformative technologies and lifestyle changes,[91] including creating biotechnology-based industries; regenerative and sustainable urban farming systems, especially for small-scale farmers; localised agro-processing to improve food security; and high-value product recovery from organic waste streams.

Four priority areas have been identified for agriculture, i.e., short- to medium-term opportunities where STI can play a role in driving greater circularity in the agriculture sector:

- **Resource Efficiency:** Decoupling food and feed production from resource consumption (water, energy, materials), including the adoption of innovative technologies such as precision agriculture,[92] smart irrigation schemes, and water reuse. With reduced waste generation across the agri- and agro-processing sectors, with a particular focus on reducing food losses and waste.
- **Regenerative Agriculture:** Mainstreaming regenerative agricultural practices, including zero till; permaculture; and the use of organic or bio-based fertilizers and pest-control products that are less harmful to the environment.
- **Agro-processing:** Ensuring sustainable practices in agro-processing, including sustainable packaging (link to manufacturing), and reduced wastage across the agriculture value chain.
- **Biorefinery:** Unlocking high-value product recovery from residual organic waste streams, through integrated biorefinery approaches.[93,94]

4.2.3 Circular Economy and Manufacturing

The NSI has an important role to play in facilitating and de-risking the adoption and scaling of circular practices in the South African manufacturing sector to improve global competitiveness and reduce GHG emissions.[95] Several opportunities are being pursued in the sector, including more efficient use and recycling of materials, and changes in energy usage. However, circular opportunities for product end-of-life management, such as maintenance, remanufacturing, refurbishment and repair for reuse in sub-sectors such as automotive, electronics and textiles, remain untapped.

Four priority areas have been identified for manufacturing, i.e., short- to medium-term opportunities where STI can play a role in driving greater circularity in the manufacturing sector:

- **Resource Efficiency and Cleaner Production:** The optimisation of resource use along different value chains holds major opportunities to increase circularity. These may include the reduction of raw material inputs, energy consumption, water consumption, and waste and wastewater production, while maximising output.[96]
- **Circular Product Design:** Building circular economy principles into both the product and its value chain, across its full lifecycle. This includes improved materials science and manufacturing processes; and design thinking to fully embed circularity from the beginning of a product's life.
- **Advanced Manufacturing:** While developing industrial capacities, the integration of advanced technologies and digital trends represents a key determining factor. Skills needed for the transition to high-tech innovation, as well as required resources for machinery and equipment play an enabling role in developing the sector. These considerations include: the integration of advanced technologies, such as additive manufacturing or 3D printing;[97] robotics and artificial intelligence; digitalisation; and green manufacturing technologies, including technologies that support the decarbonisation of high-production sectors such as steel and cement.
- **Remanufacturing:** Critical product components are restored to new specifications, creating opportunities for product improvement and the adoption of new innovations. Compared to the original product, the remanufactured or refurbished product performs the same or better; with the same quality testing, and an equivalent or better warranty, thereby keeping the product at its maximum utility.

These opportunities have the power to revolutionise existing business models, including the shift to service- and sharing-economy models, for instance, by adopting **Product-as-a-Service**, **Manufacturing-as-a-Service** models, or developing sharing platforms for matching manufacturing facilities with businesses.

4.3 STI CLUSTERS

Five priority STI Clusters (focus areas) frame the strategic STI gaps and opportunities within each of the priority economic sectors. These Clusters will guide the strategy, including the distribution of funding:

- Strategic Planning
- Modelling & Analytics
- Technology Solutions
- Resources and the Environment
- Society

The Clusters are unpacked in more detail in the following section.

Five priority STI Clusters (focus areas) frame the strategic STI gaps and opportunities within each of the priority economic sectors.

5 STI CLUSTERS

This section outlines the five priority STI Clusters (focus areas) which frame the strategic STI gaps and opportunities that will guide the strategy:

- Strategic Planning
- Modelling & Analytics
- Technology Solutions
- Resources and the Environment
- Society

The circular economy is a broad concept that includes a wide range of principles and activities. Adoption of circular economy principles requires a systems approach that considers sound evidence in the development and implementation of policy and in public- and private-sector decision-making. It requires the adoption of appropriate social and technological innovations that decouple South Africa's development from resource consumption and environmental degradation. These priorities are captured within the five STI Clusters.

The Clusters build upon those underpinning the Waste and Water RDI Roadmaps,[98] two strategies of the DSTI which have laid the foundation for this Circular Economy STI Strategy. The Outcomes described under each Cluster were refined through several consultations with diverse stakeholders and experts.

5.1 Strategic planning

Cluster Purpose

Build and strengthen the basis and application of strategic analysis and advice for the purposes of evidence-based decision-making to inform strategy formulation, planning and its execution and management.

STI Outcome for 2034

Evidence-based approaches are established and accepted practice in all strategic decision-making and planning for the transition to a circular economy.

5.2 Technology Solutions

Cluster Purpose

Design, develop, evaluate, demonstrate, localise and deploy technologies – both local and inbound – for customer-driven performance improvement.

STI Outcome for 2034

Technology development, localisation and exploitation driven by customer performance expectations is a key point of excellence in South African practices.

Deployment of socio-technical circular innovations is vital for demonstrating the effectiveness of the circular economy paradigm and building confidence for the adoption of new innovations.

5.3 Resources and Environment

Cluster Purpose

Strengthen the ability to identify, monitor, evaluate and report on environmental impacts of resource extraction and use, and the environmental benefits of adopting circular practices, in order to inform better targeted and more effective responses.

STI Outcome for 2034

Networked and inter-disciplinary RDI Programmes support the reduced impact of resource extraction and use on the environment, through circular practices.

The interplay between the circular economy, resource efficiency, climate change and social equity are poorly evidenced. Supporting the inclusion of circular economy in existing climate, environment, agriculture, water, energy, waste, trade, and human settlements strategies would be important for mainstreaming the concept across sectors.

5.4 Society

Cluster Purpose

Deepen understanding of resource-related opportunities and threats, to increase the ability to influence perceptions and practice positively.

STI Outcome for 2034

Integrated and coordinated RDI Programmes inform and influence perceptions and practices at the organisation, community and individual level.

Linkages between circular economy and social justice have only recently been articulated globally, providing a preliminary indication of potential opportunities for job creation and new employment.

It requires the adoption of appropriate social and technological innovations that decouple South Africa's development from resource consumption and environmental degradation.

Evidencing the potential for job creation in the South African context, and the development and acceptance of new types of business models, will be important in the acceptance and uptake of the concept. Ensuring that this evidence is distributed effectively to various stakeholders will be necessary for activating the widespread economic and social uptake of circular practices as a development opportunity. Helping to position circular economy as *pro-development* as opposed to a limit to growth, will support public and private sector buy-in. Building awareness of what a circular economy looks like in practice, as opposed to a broad conceptual frame, will be necessary for improving business and community uptake.

STRATEGIC PLANNING

SP1	**Policy and Legislation**	Improve the formulation and execution of national CE policy, in the context of global policy instruments and their implementation
SP2	**Governance**	Improve interactions between Government, Industry and Society in the adoption of CE practices
SP3	**Macro-Economics**	Improve understanding of the macro-economic impacts of a CE transition; and of the dynamics of, and interactions between, global and local economic systems
SP4	**Value Chain Strategy**	Improve understanding of the risks and opportunities across resource and product value chains

TECHNOLOGY SOLUTIONS

TS1	**Technology Development**	Design and development of technologies that support the decoupling of development from resource consumption
TS2	**Technology Evaluation and Demonstration**	Evaluation and demonstration of technologies, both locally developed and inbound
TS3	**Technology Localisation**	Adaptation and localisation of inbound technologies for South African conditions
TS4	**Technology and Process Optimisation**	Optimise operational performance, with a focus on efficiency and reducing processing costs and environmental impacts of technologies

RESOURCES AND ENVIRONMENT

RE1	**Regenerative, nature-based solutions**	Development, evaluation and demonstration of regenerative, nature-based solutions
RE2	**Water, energy, materials**	Improve understanding and modelling of South Africa's resource base
RE3	**Waste and pollution**	Improve understanding and adoption of technologies to reduce the generation and disposal of waste, and associated environmental pollution
RE4	**Climate Change**	Enable better management of climate change mitigation and adaptation associated with resource extraction and use

SOCIETY

S1	**Business Models**	Design and development of new approaches to creating and capturing value in relation to waste management and secondary resources
S2	**Job creation**	Improve understanding of the job creation potential of circular business models, including the sharing economy
S3	**Behaviour**	Understanding human behaviour with regards to circular practices, as a means to alter consumer behaviour
S4	**Awareness and Communication**	Awareness and communication in relation to behaviour change programmes

5.5 Modelling and Analytics

Ensuring that a circular economy transition in South Africa is based on sound evidence, the above four clusters are supported by a cross-cutting Modelling & Analytics cluster.

Cluster Purpose

Develop and use methods, tools, techniques, platforms, systems and frameworks for the analysis, monitoring and evaluation of technical, economic, social and environmental opportunities and impacts associated with resource extraction and use, and the transition to a circular economy.

STI Outcome for 2034

Driven by, and responding effectively and efficiently to, the needs of a well-managed portfolio of internal and external customers, and able to draw on massive data resources, a broad and deep distributed modelling and analytics services capability, performs and delivers a well-coordinated and robust set of analyses and evaluations to inform decision-making.

Building a circular economy evidence base is vital for ensuring that further resources flow towards its operationalization. Welcoming STI processes that effectively demonstrate socio-economic and environmental benefits of a circular economy transition is vital. There is limited data and analysis of the material weight of the economy, limiting the effectiveness of strategies, and the deployment of circular interventions.

MODELLING AND ANALYTICS		
MA1	**Data and indicators**	Production, storage and distribution of context appropriate data, and the tracking of appropriate CE indicators
MA2	**Systems Analysis and Modelling**	Methods, models, tools, and techniques to assess, project and evaluate costs, viability and sustainability of stocks, flows, processes and system interactions, including Value Chain Analysis; Material Flow Analysis; Systems thinking with related modelling
MA3	**Socio-Economic and Environmental Modelling**	Methods, tools and techniques to assess social, technical and economic viability and sustainability, including Resource Economics, Techno-economic feasibility assessment, Cost-Benefit Analysis, and Lifecycle Costing
MA4	**Product Assessment**	Methods, tools and techniques to facilitate improved product design, and to assess the social, environmental and economic impacts of products throughout their lifecycle; including Life Cycle Assessment and Life Cycle Sustainability Assessment

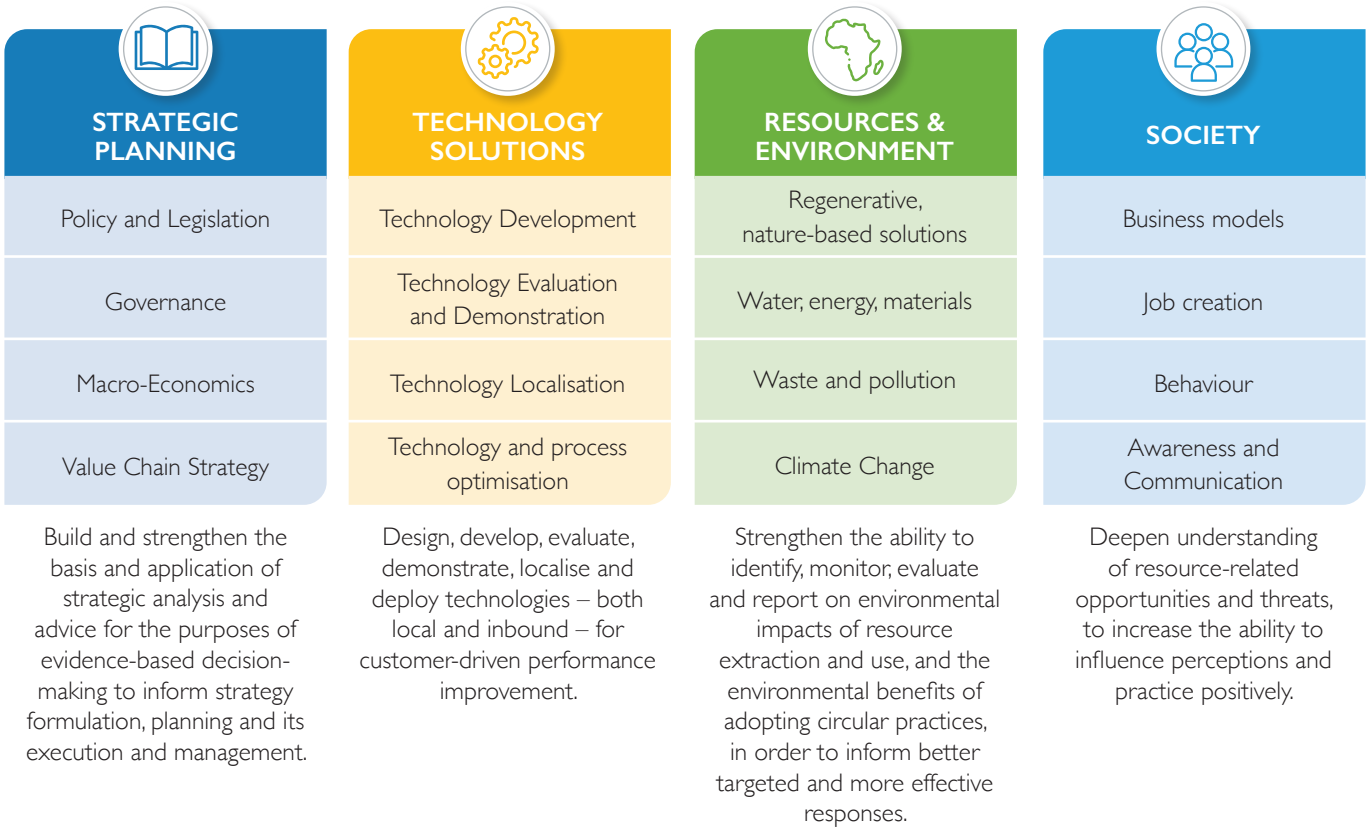

Figure 7. Identified clusters of circular economy science, technology and innovation activity

6 IMPLEMENTATION OF THE STRATEGY

6.1 ENABLING MEASURES

Based on the strategic priorities outlined in Sections 4 and 5, five enabling measures are proposed to give effect to the strategy (Figure 8, Table 1):

1. Enhancing inter-governmental, inter-sectoral and multi-stakeholder *collaboration*
2. [Re-] Directing *finance flows* toward circular economy STI activities
3. Integrating circular economy into *higher education and training*
4. Building and *using an evidence base* for a circular economy
5. Enabling implementation of a circular economy through *business support, capacity building and demonstration*

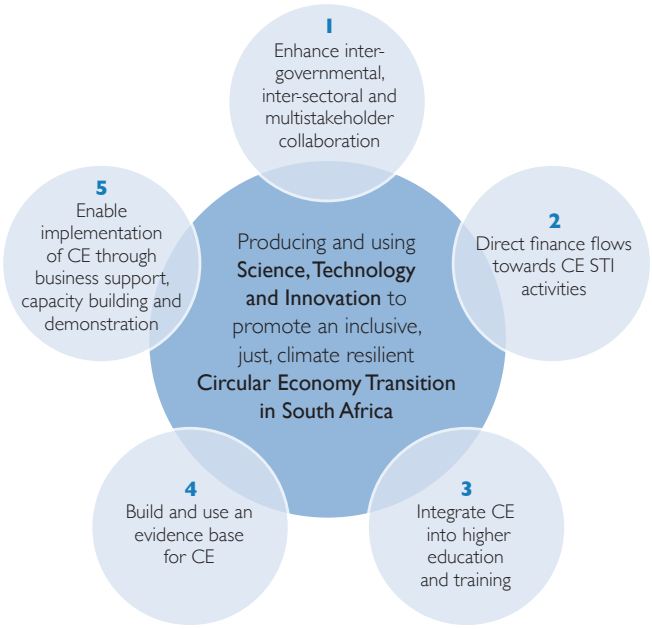

Figure 8. Overview of the vision and enabling measures for implementing the Circular Economy STI Strategy

The need for integration, coordination and clear, funded mandates for Circular Economy STI related initiatives is one of the most pressing challenges identified by this strategy. The following sections aim to provide guidance to the DSTI and its entities in supporting the successful implementation of this strategy, including integrated planning, financing, evaluation, and reporting on circular economy STI related initiatives.

6.2 FUNDING INSTRUMENTS

The following are by no means an exhaustive list of the types of funding instruments to be utilised to give effect to the strategy:

6.2.1 Circular Economy Initiatives

Implementation of various DSTI strategies and roadmaps has highlighted the impact of embedding strategic initiatives within the NSI, supported by catalytic government funding. This strategy will look to establish three strategic, sector-based circular economy initiatives, acting through a hub-and-spoke model to strengthen and focus circular economy related STI. These include the *South African Circular Minerals and Metals Initiative (SACMMI), the South African Circular Agriculture Initiative (SACAI), and the South African Circular Manufacturing Initiative (SACMI).*

As a first step, the sector-specific priority areas identified in Section 4 should be further developed to guide more detailed STI interventions (for example, through the development of sub-research strategies for each of the three sectors). The stakeholder consultation initiatives for each of the priority sectors will play an important role in developing concrete actions as well as promising demonstration projects. The prioritised economic sectors may be expanded as the strategy is implemented and matures.

6.2.2 STI Grants

Open and targeted grant projects, fully or partially funded by the DSTI, have been shown to be highly impactful in generating appropriate evidence, and strengthening capability within South African public research institutions. These grant projects have been shown in the implementation of other STI strategies and roadmaps to be catalytic in leveraging other public and private sector funding to support further R&D and/or implementation / demonstration. The grants are also a key instrument in building capacity through support for researchers and students. Funding mechanisms like the *Circular Economy Demonstration Fund,* as well as embedding circular economy into DSTI funded programmes, is required to ensure a transition to a more circular economy.

6.2.3 Research Chairs and Centres of Excellence

Research Chairs have proven to be an effective means of attracting and retaining excellence in STI at South African public universities. One of the main goals of Research Chairs is to strengthen and improve the STI capacity of public universities for producing high quality postgraduate students and STI outputs.

Centres of Excellence (CoE) are centres of research that concentrate existing research excellence, capacity and resources to enable researchers to collaborate across disciplines and institutions on long-term projects that are locally relevant and internationally competitive in order to enhance the pursuit of research excellence and capacity development.

6.2.4 Scholarships and bursaries

There is an urgent need to build national capacity in the circular economy, both within and across sectors. Embedding skills development within degrees and diplomas and supporting students (particularly post-graduate students) through scholarships and bursaries, will be key to giving effect to this.

6.3 GOVERNANCE AND INSTITUTIONAL ARRANGEMENTS

The effective governance of this strategy will require the establishment of appropriate institutional arrangements to ensure operational efficiency, accountability and advisory support. As such, in support of this strategy, the DSTI is encouraged to convene the following operational bodies ensuring that the priorities of this strategy are adequately integrated into DSTI and other governmental processes while ensuring that all practices are in place to enable good governance in accordance with government requirements:

1. **Operations Committee –** to provide strategic linkages and oversee the implementation of this strategy and provide guidance for its effective translation into action.
2. **Management Committee –** to direct and organise the implementation of the strategy's actions.
3. **Advisory Committee / Technical Advisory Group / Working groups** (by sector or stakeholder group) – to provide external guidance and linkages that can enhance the efficacy and reach of this strategy, and to support appropriate implementation across the identified industry sectors and stakeholder groups.

Through the following initiatives, DSTI is able to drive coordination, collaboration and integration amongst the various ministries and government departments with linkages to the circular economy and STI. They also act as a mechanism to systematically integrate the circular economy into other departments and to support their research efforts:

- **Circular Economy Inter-Governmental Committee:** This committee promotes a strong partnership between government departments and aims to guide the Circular Economy STI Strategy. The structure has been approved by DSTI EXCO and is chaired by the Deputy Director-General (DDG). Given the cross-cutting nature of the circular economy, this Committee should include representatives from key line departments, such as (but not limited to):
  - Department of Forestry, Fisheries and Environment
  - Department of Water and Sanitation
  - Department of Trade, Industry and Competition
  - Department of Mineral Resources and Energy
  - Department of Agriculture, Land Reform and Rural Development
  - Department of Human Settlements
  - Department of Transport
  - National Treasury

In addition to these entities, the Department of Planning, Monitoring and Evaluation is encouraged to join, to increase alignment and mutual support.

At an operational level, the following initiatives will support the day-to-day implementation of the strategy:

- **Circular Innovation South Africa (CISA):** CISA acts as the Portfolio Management Unit (PMU) tasked with giving effect to the circular economy STI aspirations of the DSTI. The launch of CISA in 2023, hosted by the CSIR, and the Circular Economy Demonstration Fund[99] by the DSTI, are positive indications of initiatives to strengthen and build circular economy STI in South Africa.
- **Circular Economy STI Forum:** This forum, including representatives from relevant Portfolio Management Units, e.g., CSIR, WRC, ARC, SANEDI, TIA, and IDC, will help to provide a broad understanding of current circular economy STI related investment and activities within and across various sectors. The forum should be formulated by the DSTI, in partnership with CISA, to provide a coordination function to circular economy related STI on behalf of government.

6.4 EXISTING INITIATIVES TO BUILD UPON

The South African Government has several instruments and tools already at its disposal to support the creation of an enabling environment for a circular economy transition. These include the carbon tax and EPR regulations, as well as tailored SMME innovation support and capacity development programmes. There is a role for STI and for the DSTI to support the implementation of these various tools and instruments in order to ensure impact and progress.

As shown in previous sections, there are a number of existing DSTI initiatives that support and/or align with the circular economy. It is not the intention to duplicate these activities, but to align and provide support, where appropriate.

6.5 FINANCING THE STRATEGY

The DSTI must ensure that the Circular Economy STI Strategy is appropriately resourced. As a start the DSTI should consider coordinating its own funding to address the circular economy in its Annual Performance Plan (APP). This should be followed by other government departments coordinating their circular economy STI efforts in partnership with the DSTI. Given increasing constraints on the national fiscus, it will be important to align existing funds for wider-reaching outcomes and to leverage new sources of external funding to give effect to the full scope of this strategy. This includes a coordinated approach to international funding in support of circular economy STI, that aligns with the priorities of government. Partnerships with industry through new STI coordination mechanisms should drive private funding to circular economy STI needs.

Enabling Measure 2 of the Implementation Plan specifies additional pathways for resourcing STI efforts, which can be used as considerations for increasing the available resources for broadening or scaling implementation of this strategy.

Enabling Measures 4 and 5 of the Implementation Plan specify ways to leverage evidence to drive private innovation and uptake of STI.

6.6 MONITORING, EVALUATION AND LEARNING

A robust data and monitoring system is essential to track progress and evaluate the impact of the strategy. The Monitoring, Evaluation and Learning (MEL) framework can evaluate implementation at two levels: the direct implementation of this strategy can be measured using the indicators associated with each action, while the broader desired outcomes of this strategy (contributions to the circular economy, socio-economic and environmental outcomes), will need appropriate indicators. The MEL framework should identify realistic indicators and targets for each expected/anticipated outcome. During the development of the MEL framework and indicator set, related strategies should be reviewed to identify existing indicators for use, to avoid duplication and to benefit from existing monitoring and data collecting processes.

As considerations for the development of an MEL Framework for the Circular Economy STI Strategy, it is important to note that MEL reporting and auditing on performance aspects related to DSTI functions are embedded in a range of reference documents, including:

- STI Indicators Report[100]
- DSTI Annual Report[101]
- CISA Annual Report

The **DSTI Annual Report** provides a record of expenditure and progress in the various programs, along with audited financials (including tracking of planned and actual budget expenditure).[101]

CISA Annual Performance Report, a deliverable of CISA hosted by the CSIR, provides an overview of the strategic investment made during a financial year and the performance against key indicators.

Given that this strategy is a living document, the DSTI will determine when it is appropriate to undertake a review of this strategy and determine the scope of such a review and revision.

Given increasing constraints on the national fiscus, it will be important to align existing funds for wider-reaching outcomes and to leverage new sources of external funding to give effect to the full scope of this strategy. This includes a coordinated approach to international funding in support of circular economy STI, that aligns with the priorities of government.

MEASURE 1 Enhance inter-governmental, inter-sectoral and multi-stakeholder collaboration	MEASURE 2 Direct finance toward CE STI activities	MEASURE 3 Integrate CE into higher education and training	MEASURE 4 Build and use an evidence base for CE	MEASURE 5 Enable implementation of CE through business support, capacity building and demonstration
1 Improve CE collaboration, shared learning, and communication between government departments	1 Mobilise and streamline funding for STI through alignment and collaboration between government departments	1 Embed CE in higher and basic educational programmes	1 Promote interdisciplinary and trans-disciplinary research, as well as multi-institution collaboration	1 Empower and enable businesses, particularly SMMEs, to produce or adopt new innovations, and attract funding
2 Improve communication, collaboration and shared learning between the public and private sectors (formal and informal) for greater uptake and application of STI across economic sectors	2 De-risk CE through the allocation of catalytic funding for demonstration projects and implementation programmes	2 Ensure that businesses of all sizes are aware of, and can access, upskilling opportunities related to CE STI	2 Identify and prioritise research needs related to the CE with public and private actors	2 De-risk small business practices through partnerships with business incubators and the deployment of knowledge for building more robust business models through STI
3 Facilitate international collaboration for CE STI production and uptake in South Africa	3 Leverage industry funding for STI – development and uptake		3 Develop processes for ensuring that research outcomes are fed into practice	3 Promote the uptake of CE STI by local governments and support innovation through practice
	4 Attract and secure international funding aligned with identified STI priorities		4 Evidence CE uptake in South African policy and practice through STI	4 Reduce barriers for entrepreneurs and businesses to utilise protected intellectual property (IP)

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