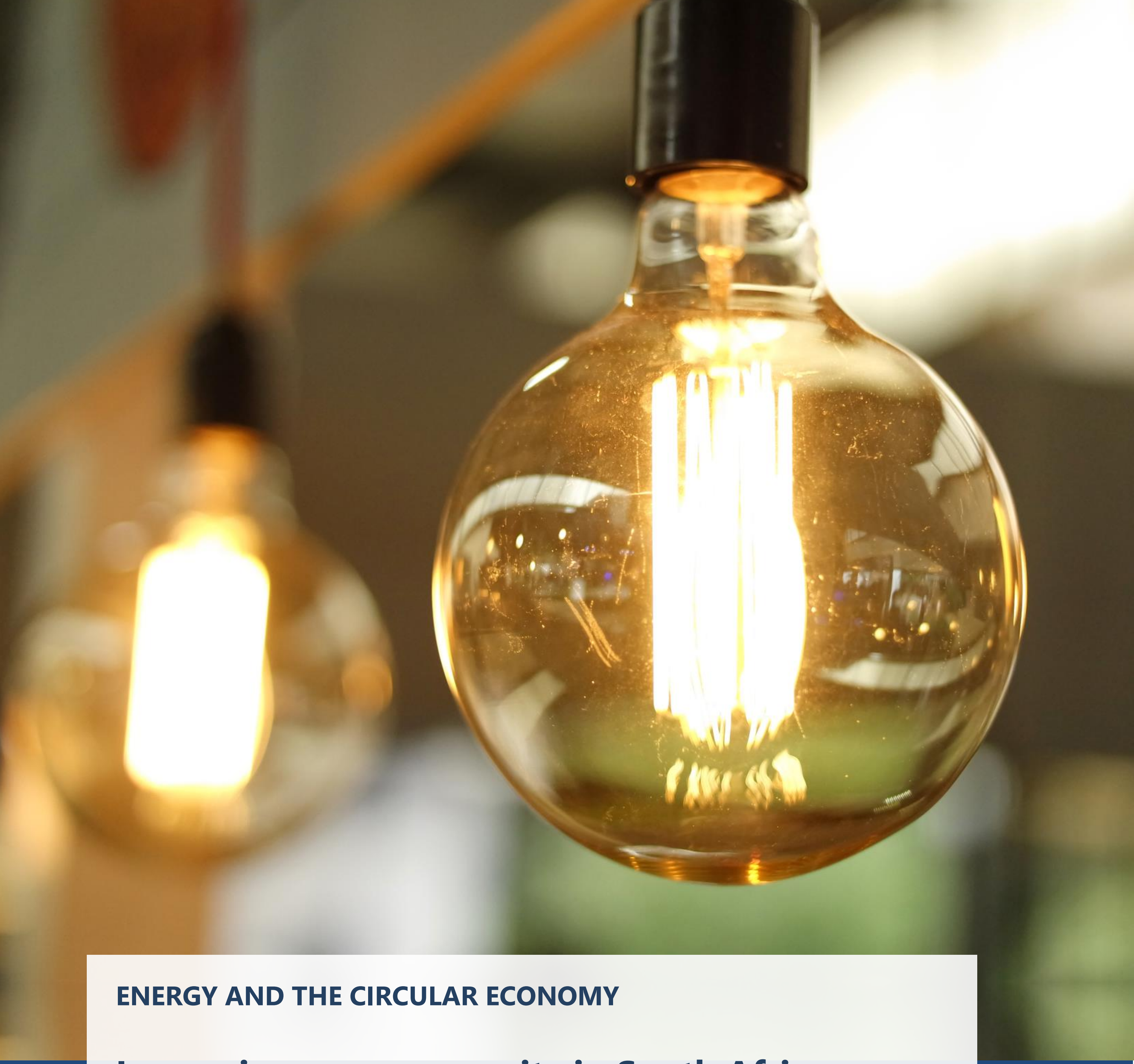

ENERGY AND THE CIRCULAR ECONOMY

Improving energy security in South Africa through a more circular energy sector

July 2023

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FOR A CIRCULAR ECONOMY SERIES

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EXECUTIVE SUMMARY

A review of the current development path of the South African energy sector, which can be broadly divided into the electricity and liquid fuels sub-sectors, confirmed that the sector is highly resource and carbon intensive. Approximately 80% of the nation's electricity is generated from coal and thermal generation, and about 14% from renewable sources (as at 2022). This results in approximately 46% of the country's greenhouse gas (GHG) emissions emanating from the electricity sector. However, South Africa has experienced growing energy insecurity since 2007, with rolling blackouts of increasing intensity. The development of a more circular energy sector represents a critical step towards a more resilient and sustainable energy future.

This study provides a review of the energy sector's current development path; explores the opportunities of a more circular development path for the energy sector; and identifies potential business opportunities that arise from the development of a circular energy path for South Africa. The methodology adopted included synthesising secondary data through a literature review, gathering primary data from an online questionnaire, a stakeholder workshop, and one-on-one interviews.

Unlike the other circular economy sector studies undertaken by the CSIR, the energy sector is somewhat unique in that it must consider circularity both in terms of the production, storage, distribution and consumption of energy (energy utility), as well as in the manufacturing and end-of-life management of energy technologies (energy materials). A total of 24 circular economy interventions were evaluated in this study, 19 in circular energy utility, and five (5) in circular energy materials.

The majority of stakeholders who participated in the study, agree that the proposed CEIs can benefit the South African energy sector, by improving sector competitiveness and resilience (75% of respondents); driving inclusive growth and decent jobs (88%); while also mitigating environmental pollution (75%). Stakeholders largely agree that the proposed CEIs are appropriate for the South African energy sector, with stronger agreement for more well-known, and adopted, interventions such as renewable energy technologies (solar PV and onshore wind), energy storage, energy efficiency, and waste-to-energy. The appropriateness of less familiar CEIs (many of which were considered not yet fully commercialised or mature) such as carbon capture, utilisation and storage (CCUS), emissions prevention (clean coal technologies), fly ash valorisation, freshwater substitution (dry cooling and desalinated), agrivoltaics, and concentrated solar power (CSP) were scored lower.

For circular energy materials, recycling of energy technologies; circular design of energy technologies; and materials efficiency in the manufacturing of energy technologies had the highest agreement rates in terms of appropriateness for South Africa. However, while South Africa has a growing share of renewable energy technologies that have been, and continue to be, introduced into the country's energy mix, the extent to which renewable energy technologies are designed, manufactured and recycled in South Africa is extremely limited, giving the country limited control (currently) over their design for longevity and circularity.

The results showed similar responses in terms of readiness to implement and current levels of implementation, with the sector most ready to implement solar PV, onshore wind, energy storage, hydroelectric, and WtE. There was strong support for energy efficiency as a circular economy intervention. The results showed low levels of readiness and implementation for CCUS and green hydrogen, offshore wind, and electric vehicles.

For circular energy materials, increasing energy technology lifespans and technology repair and recycling had the highest levels of readiness and implementation. South Africa has a few manufacturers of energy technologies, and since most of the materials used in manufacturing are imported, there may be opportunity to offset some (or all) of these imports with greater local recycling and resource recovery.

However, a number of constraints were raised by stakeholders as potential obstacles to fast-tracking the implementation of CEIs in the South African energy sector, including, amongst others, a lack of awareness of what the circular economy means for the sector. As with previous studies, this report has shown that circular economy interventions are not new to the South African energy sector, with a number of initiatives already in place. This has been driven largely by South Africa's energy insecurity over the past decade. However, these interventions have not yet achieved the scale necessary for meaningful impact. The extent to which respondents considered most energy CEI's to be only 'partly implemented' in the South African energy sector, suggests that there is significant room for implementing and scaling CEIs both under circular energy utility and circular energy materials.

The study confirmed that the adoption of circular economy initiatives in the energy sector can support greater energy security, decarbonisation of South Africa's economy, improved resource efficiency, increased competitiveness, and enhanced social and environmental sustainability. This may unlock opportunities to finance aspects of South Africa's transition to a more circular economy by tapping into international climate finance mechanisms. There is however a need for supportive policy frameworks, adequate financing mechanisms, and effective stakeholder engagement to ensure the successful implementation of CEIs in the energy sector.

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ACRONYMS

3Rs	Reducing, Reusing, and Recycling
AD	Anaerobic Digestion
AFD	Agence Française de Développement
AV	Agrivoltaics
BOS	Balance of System
CBMs	Circular Business Models
CCE	Circular Carbon Economy
CCUS	Carbon Capture Utilisation and Storage
CE	Circular Economy
CEI	Circular Economy Intervention
CH_4	Methane
CO_2	Carbon Dioxide
CSIR	Council for Scientific and Industrial Research
CSP	Concentrated Solar Power
CTL	Coal-to-Liquid
DACCS	Direct-air Carbon Capture and Storage
DSI	Department of Science and Innovation
EE	Energy Efficiency
EPC	Energy Performance Certificate
ERA	Electricity Regulation Act
EV	Electric Vehicle
GH_2	Green Hydrogen
GHG	Greenhouse Gas
GW	Gigawatts
GWh	Gigawatt hour
HELE	High-Efficiency, Low-Emission
HSRM	Hydrogen Society Roadmap
IEA	International Energy Agency
IRP	Integrated Resource Plan
kg	Kilogram
km	Kilometer
LFG	Landfill Gas
MSW	Municipal Solid Waste
Mt	Metric Tons
MW	Mega-Watt
MW_{ac}	Mega-Watt, Alternating Current
MWh	Mega-Watt Hour
NDC	Nationally Determined Contribution
NREL	National Renewable Energy Laboratory
PGMs	Platinum-Group Metals
PPA	Power purchase agreement
PV	Photovoltaics
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
RFID	Radio-Frequency Identification
RMIPPPP	Risk Mitigation Independent Power Producer Procurement Programme
RNG	Renewable Natural Gas
SA	South Africa
SEZ	Special Economic Zones
STI	Science, technology and innovation
TNA	Technology Needs Assessments
WtE	Waste-to-Energy

1 Introduction

1.1 Background

The energy sector is the backbone of the South African economy; however, it is one based on an antiquated "extract-make-use-dispose" linear economy model. South Africa's indigenous energy resource base is dominated by coal. This dependence on coal has multiple negative externalities, such as high resource intensity, inefficiency, carbon intensity with resultant greenhouse gases (GHG), and hazardous waste generation. These externalities exhibit the unsustainable nature of the sector and, more importantly, emphasise the need for transformation to reduce resource and carbon intensity and subsequently increase efficiency. Introducing the principles of the circular economy into the design, use, and selection of energy pathways and technologies can support this much needed transformation of the sector. The circular economy presents an opportunity to decarbonise the South African energy sector; reduce the sector's dependence on the extraction of non-renewable resources; reduce the generation of hazardous waste streams; grow energy generation and improve energy security for the country; and decouple economic development from resource intensity in the linked sectors.

The circular economy is a systemic approach to economic development, which is regenerative by design and aims to decouple growth from the consumption of finite resources. It is underpinned by principles of reduced resource consumption; efficient and productive use of resources; keeping materials in flow, at their highest value, for as long as possible, within the economy; renewable and regenerative inputs; and designing out waste.

As depicted in Figure 1, the circular economy has relevance to the South African energy sector in terms of:

i. **Circular energy utility**, i.e., the process of generating energy. Circularity in energy utility refers to the promotion and adoption of renewable and regenerative energy technologies to replace carbon-intensive. fossil-fuel-based energy generation.
ii. **Circular energy materials**, i.e., the process of designing and manufacturing energy technologies such as photovoltaic (PV) panels or wind turbines. It is based on the premise of improved product design for circularity; increased longevity and utilisation rates; production processes that are non-destructive (e.g., additive manufacturing); and recovery of energy technologies at end-of-life supported by greater reuse, repair, refurbishment and recycling, keeping products and materials circulating within the economy.

Applying the three circular economy principles (Ellen MacArthur Foundation, 2019) to the South African energy sector, points to opportunities in:

1. **Designing out waste and pollution:** designing or redesigning energy technologies and associated manufacturing processes to increase resource and material efficiency and longevity, thus reducing material input and minimising waste generation and pollution.
2. **Keeping products and materials in use:** promoting repair, reuse, remanufacturing, and recycling of products and materials in the sector, thus increasing utilisation rates and closing product and material flow loops.
3. **Regenerating natural systems:** increasing the use of renewable and regenerative systems and resources, for example, replacing fossil fuels with renewable energy sources such as wind or solar energy.

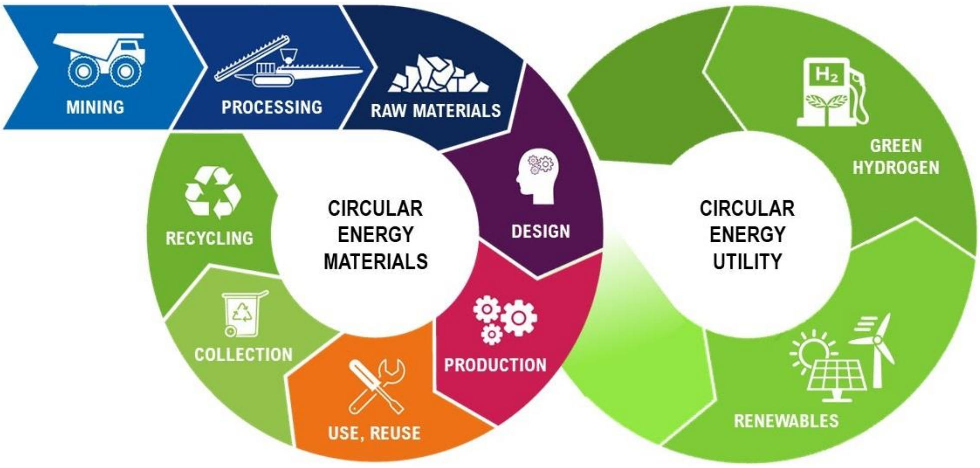


Figure 1: Circular economy paradigm for the energy sector (Msimanga *et al.*, 2021)

These three principles can be applied throughout the energy sector's value chain from raw materials sourcing, energy technology manufacturing, construction, energy generation and utilisation, to the end-of-life management of technologies. The application of these principles can provide a framework for South Africa to address its challenge of energy insecurity and promote decarbonisation. It is through understanding of these principles that it becomes apparent how the circular economy can be used as a tool to decouple economic development from resource and energy demand.

In this study, the prospects for greater circularity are explored in the South African energy sector. Section 1 outlines the objectives and methodology. Section 2 reviews the current development path for the South African energy sector. Section 3 presents an outline of the circular economy from an energy perspective, and the final section, Section 4, explores a circular economy development path for the South African energy sector, including climate change mitigation potential of energy sector circular interventions.

1.2 Objective

This study, which explores the opportunities for greater circularity in the South African energy sector, is a component of a larger CSIR project titled '*Identifying opportunities for a more circular South African economy – A resource perspective*'. The first phase of this project produced a series of short briefing notes, including one for the energy sector, titled "*Decoupling South Africa's development from energy demand through a more circular economy*" (Msimanga *et al*., 2021). The second phase of the project undertakes a more comprehensive assessment of the circular economy in various sectors of the South African economy, including the energy sector.

This report provides a deep-dive into Circular Economy Interventions (CEIs) in the South African energy sector. It seeks to provide further detail on the following:

a. The **current development path** of the South African energy sector, including a high-level overview of the sector, an overview of the current availability and demand for resources, expected trends (assuming little to no major disruption), an analysis of potential resource constraints for future growth of the sector, and the identification of key economic and socio-economic gains and losses associated with the current path,
b. A potential **circular development path** for the South African energy sector, including identifying circular economy interventions based on local and international examples; assessment of the appropriateness of these interventions for South Africa through engagement with key stakeholders; critical assessment of the readiness (including potential obstacles and unintended consequences) to implement these CE interventions in the South African context; assessment of business opportunities within the implementation of these CE solutions, including possible high-impact circular economy projects in the sector; and analysis of how these circular economy interventions could address resource constraints, while unlocking environmental, social, and economic opportunities.

1.3 Methodology

The methodology used in this study to explore the circular economy development path in the South African energy sector, included synthesising secondary data through a literature review, gathering primary data through an online survey, and testing the findings with key sector stakeholders through a workshop and one-on-one interviews. Primary data was sourced from energy sector experts involved in key decision-making, or in carrying out energy-related research, or direct implementation of energy solutions.

The literature review focussed on CEIs from the energy sector that are proposed and/or implemented internationally and locally. The potential for application in the local context was considered before identifying the options; furthermore, the ability of the intervention to help the country follow through with its Nationally Determined Contribution (NDC) targets to reach its net zero ambition for GHG emissions was also taken into consideration.

Energy sector stakeholders (59) from relevant private sector institutions, government, and non-governmental organisations (NGOs) were invited to respond to the online questionnaire which went live on 27 January 2023 and remained active until 13 February 2023. The questionnaire was divided into 3 parts where part 1 captured the demographics of the respondents, part 2 captured their experience with the proposed energy sector CEIs, and part 3 assessed their opinions on the readiness to implement the proposed energy sector CEIs. In addition to the online questionnaire, the same stakeholders were invited to a virtual workshop that was held on 17 February 2023, attended by 12 stakeholders from organisations such as Eskom, the Innovation Hub, GreenCape, SAPVIA, Citypower and various private sector organisations. The workshop was aimed at presenting the proposed CEIs for the energy sector and assessing their relevance, the perceived sectoral readiness to implement these measures, and to gauge the degree to which stakeholders considered specific interventions already implemented or in progress of implementation. Stakeholders who indicated in the questionnaire they would be willing to be interviewed, were then invited for one-to-one interviews which were held between the 26 April – 3 May 2023. Further details on this are discussed in Section 4 of this report.

2 Current development path for South African energy sector

2.1 Overview of the energy sector

The South African economy is highly energy intensive. The energy sector can be broadly divided into the electricity and liquid fuels sub-sectors. The high resource intensity of the sector is the result of the use of coal as the primary energy source for most of the sector's activities; with approximately 80% of the nation's electricity generated from coal and thermal generation and about 14% generated from renewable sources (Pierce & Le Roux, 2023). Approximately 46% of the country's GHG emissions emanate from the electricity sector.

Approximately 51% of the energy demand is for industrial sector use, ~26% is for the transport sector, ~11% for commercial use, ~7% for residential use and ~2% for agricultural use (DMRE, 2021). Eskom, the South African electricity utility company, is the predominant market dominator in electricity generation and focusses on electricity generation and transmission. The vertically integrated state-owned power utility operates 14 coal-fired power stations, a nuclear power plant, hydroelectric power and pumped storage, a few renewable plants and peaking power plants. Eskom also owns and operates the country's transmission network, and distributes electricity to industrial, commercial, residential customers and municipalities – some of whom have their own local distribution networks.

The liquid fuels sub-sector focuses on the production of liquid fuels using crude oil refining, gas-to-liquids (GTL) and coal-to-liquids (CTL) technologies. The main players in this subsector are Sasol, which uses both GTL and CTL, the Petroleum Oil and Gas Corporation of South Africa (PetroSA), which uses GTL technologies, and other refiners such as BP and TotalEnergies. South Africa's liquid fuels sub-sector boasts one of the largest refining capacities on the continent, together with those of Egypt, Nigeria, Algeria, and Libya. South Africa has six oil refineries that could produce approximately 718,000 barrels/day (DMRE, 2021; EIA, 2022a).

The government recognizes the need to diversify the country's energy mix and reduce the country's dependence on coal, in order to reduce carbon emissions and meet its international climate commitments. In 2019, the mandated government entity i.e., Department of Mineral, Resources and Energy (DMRE) released its integrated resource plan (IRP) for the period 2019-2030. The IRP 2019 is an electricity capacity plan which uses the country's electricity demand as a basis for the optimal electricity generation mix based on technical and financial parameters. The document proposes a gradual shift from coal and an increase in renewable energy sources, including wind, solar, and hydro power (DMRE, 2019a).

South Africa has made significant progress in the deployment of renewable energy since 2012, through the government's Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), which has attracted substantial investment predominantly in wind and solar power. By 2021, renewable energy sources accounted for around 13.7% of the country's electricity production, with more than 6000 MW of installed capacity (Eskom, 2021b; IPP Office, 2021).

In 2020 the DMRE launched a Risk Mitigation Independent Power Producer Procurement Programme (RMIPPPP). The programme seeks to ease energy supply constraints by closing the short-term energy deficit and reducing Eskom's extensive use of diesel-powered peaking generators (IPP Risk Mitigation, 2022). Reforms on embedded generation are encouraging further private sector participation through the amendment of Schedule 2 of the Electricity Regulation Act (ERA) which has removed the licensing requirement for generation projects of any size to enable private investment at a much larger scale (Presidency, 2023).

Government has also introduced two tax incentive programmes for individuals for installation at their private residences and one for business owners. The tax incentives for behind the meter solar installations is for the 2024 financial year only and provides a tax rebate of 25% of the cost of new and unused solar PV modules. Through these programmes, households and business owners are encouraged to invest in additional decentralised, clean electricity generation capacity to supplement Eskom's supply. The incentives are meant to help individuals in their immediate decision-making, rather than postponing any solar installation until the legislative process can be finalised (National Treasury, 2023).

Government's focus on enablers such as tax incentives, amendments to the ERA and introduction of programmes such as the RMIPPPP, reflect a commitment to transitioning towards a more sustainable and reliable energy sector.

2.2 Current uses within the sector (availability and demand)

The South African energy sector has historically been, and is still, dependent on coal as its main energy source. This is illustrated by the total primary energy production and the total primary energy consumption during the period 1980-2018, as shown in Figure 2 and Figure 3, respectively (EIA, 2022b). The figures indicate that the country's energy consumption is mixed with notable contributions from petroleum and other liquid fuels, natural gas, nuclear, and renewables. The imbalance between what is produced locally and what is consumed, is a function of local demand and supply imbalances where South Africa, is for example a net importer of petroleum and other liquids.

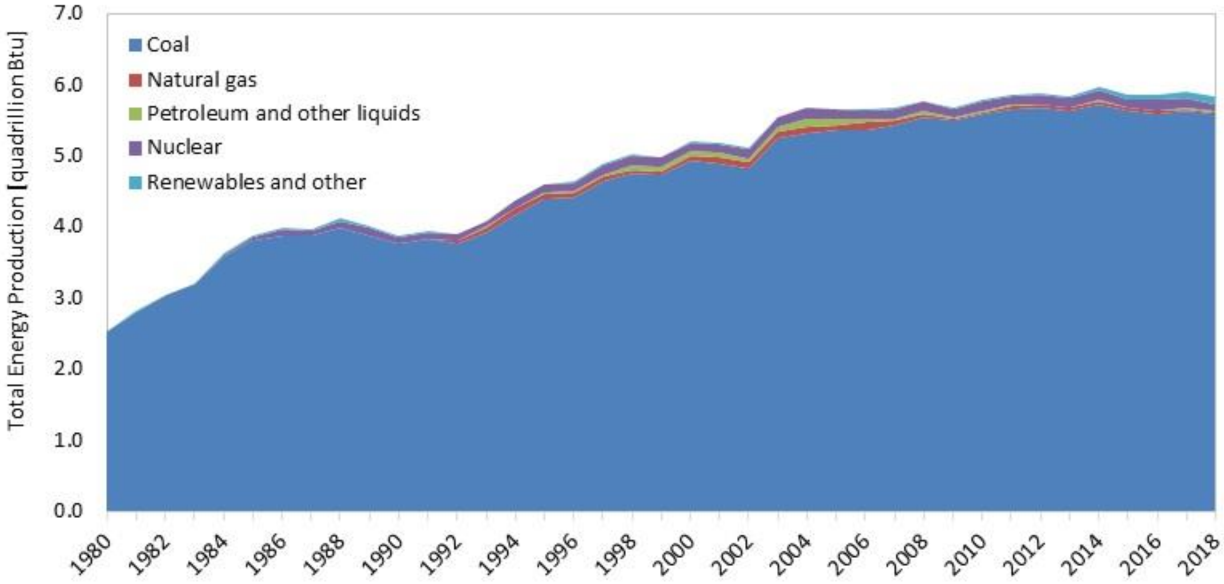


Figure 2: Total energy production in South Africa from 1980 to 2018 (EIA, 2022b)

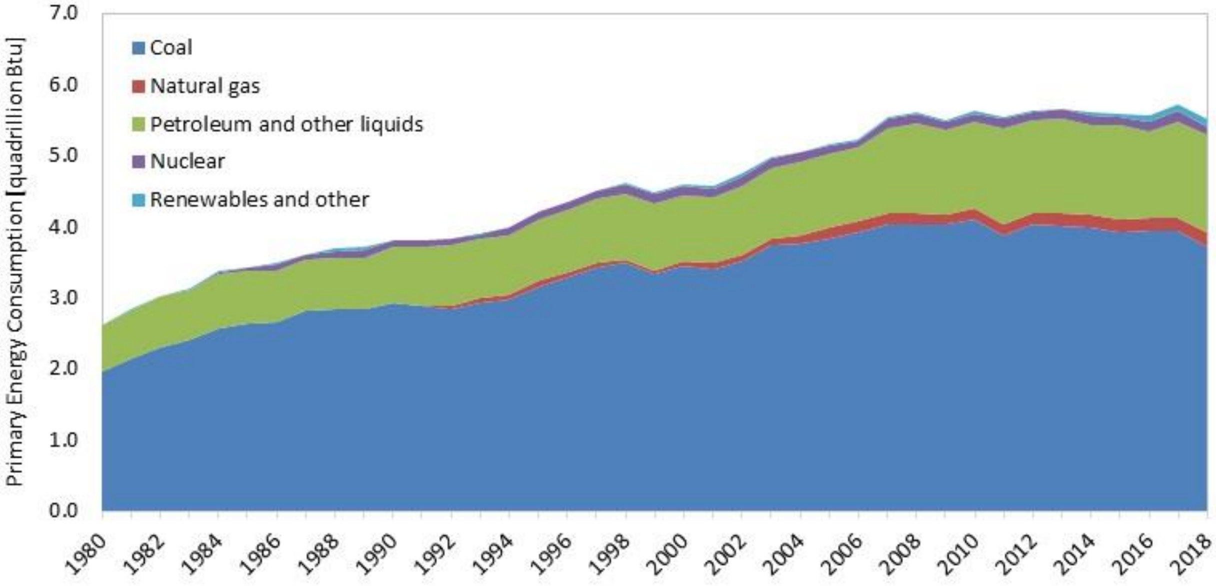


Figure 3: Total primary energy consumption in South Africa from 1980 to 2018 (EIA, 2022b)

Figure 4 shows the electricity production mix from 2010 to 2022 which illustrates how carbon-intensive the country's electric energy system is and how minimal its decarbonization has been thus far. This dependence on fossil fuels has made South Africa one of the most carbon-intensive economies in the world. In 2022, coal contributed 80.1% to the national electricity demand, followed by renewable energy, including hydro (13.7%), nuclear (4.6%) and the remaining (1.6%) came from diesel (Pierce & Le Roux, 2023).

2.3 **Expected trends in the sector** (with little to no major disruption)

After a sharp fall in 2020 due to the Covid-19 pandemic, energy consumption is expected to recover, with an average annual growth rate of 0.3% over the forecast period (2021-30) (ITA, 2021). The IRP 2019 projects that there will be average annual electricity demand growth of 1.24% by 2050 for a lower GDP forecast (DMRE, 2019a). Figure 5 shows the total electricity demand forecast as described in the IRP 2019. The modest pace of expansion will reflect improvements in energy efficiency and growth in the South African economy.

Despite environmental concerns, coal will continue to dominate the energy mix for the foreseeable future, while the share of renewables increases as outlined in the IRP 2019, where coal is expected to contribute to 40% of the country's electricity mix in 2030. The IRP 2019 introduces a set of ambitious generation targets for the penetration of the renewable energy market by 2030, with wind and solar PV expected to represent most of the future renewable electricity. Beyond 2030, the CSIR has modelled a least-cost path for the electricity generation mix (Figure 6) that sees a much more reduced role for coal and an increasing role for renewables compared to the IRP 2019. Energy storage deployment (especially battery energy storage) is also expected to increase in tandem with new additions of renewable energy capacity to the national electricity grid; this is shown by the estimate of 12.4 GW in 2050 by the CSIR compared to 1.5 GW of the IRP 2019 (Wright & Calitz, 2020).

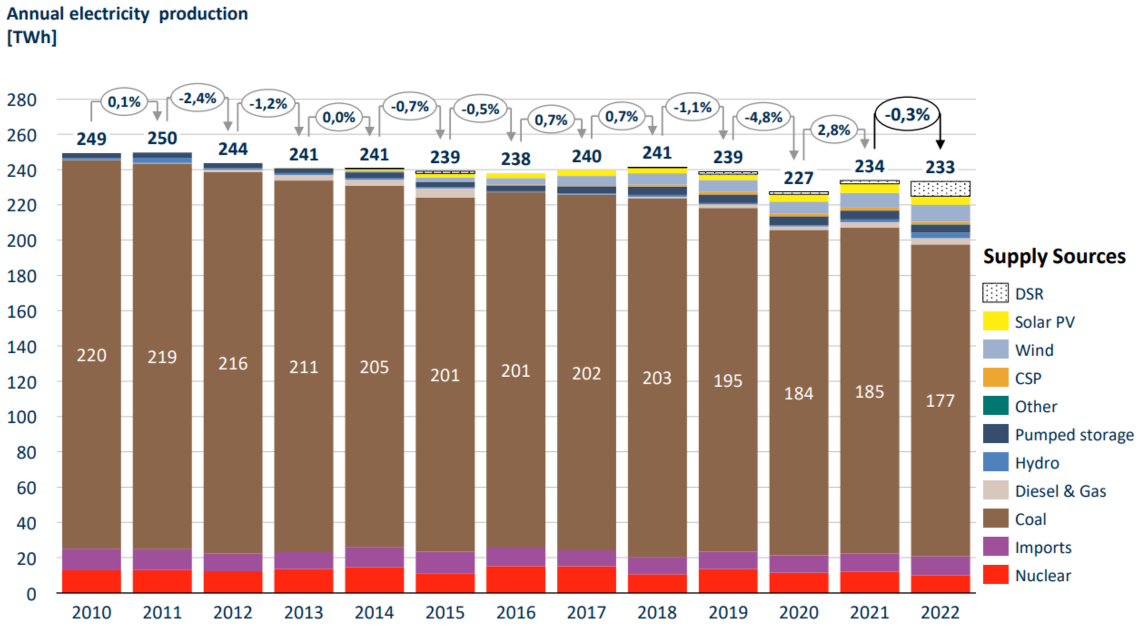


Figure 4: South Africa's electricity production mix from 2010 to 2022 (Pierce & Le Roux, 2023)

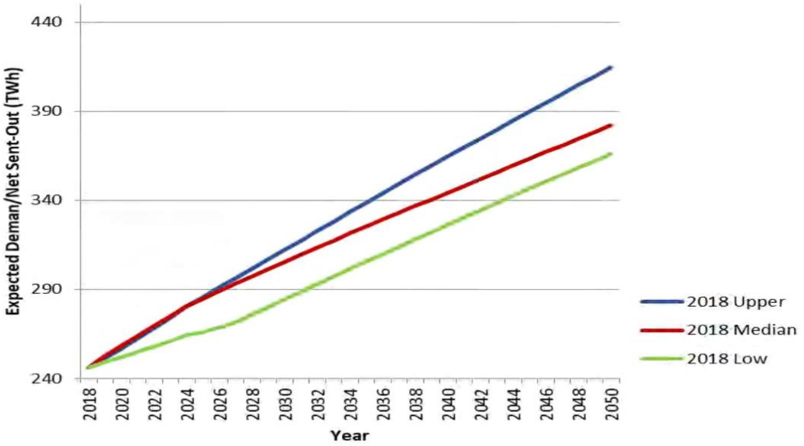


Figure 5: Projections of expected electricity demand to 2050 (DMRE, 2019a)

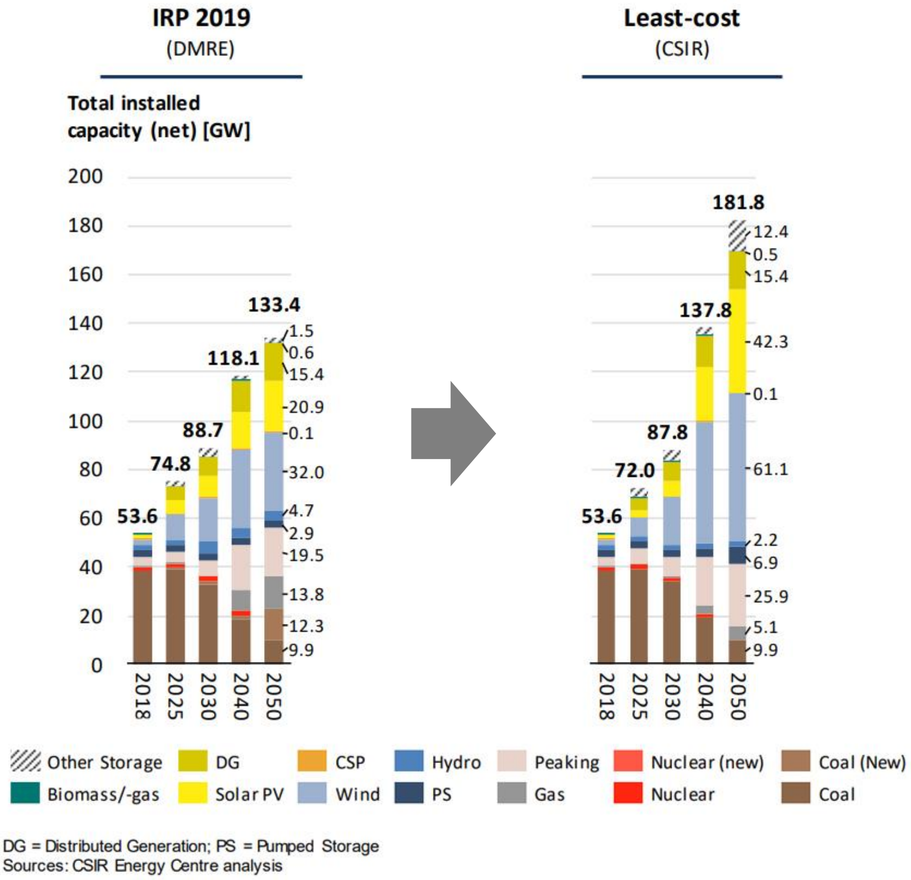


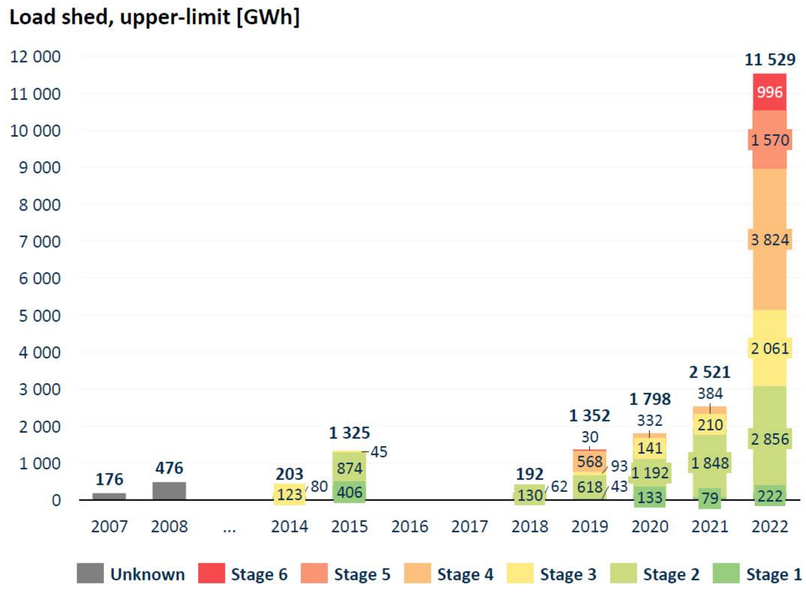
Figure 6: The DMRE's IRP2019 and CSIR's least cost pathway projections of South Africa's future electricity generation mix to 2050 (Wright & Calitz, 2020)

Furthermore, energy efficiency projects have also been extended to the building industry, with new solar panels, light-emitting diodes, motion-sensing automated lighting, and centralised heating and cooling installations in buildings. There is an opportunity for the development of new infrastructure to make use of low-carbon, high-thermal-efficient building materials to reduce the energy demand in the built environment.

2.4 **Analysis of potential resource constraints for the future growth of the sector** (based on the above findings)

The current linear model upon which the South African energy sector is based, is unsustainable and as aforementioned it is highly dependent on fossil fuels which are finite in nature. This is unlikely to change significantly over the next decade, due to the relative lack of suitable alternatives to coal as an energy source. South Africa's coal reserves are estimated at 53 billion tonnes and with our current production rate there should be almost 200 years of coal supply left. However, environmental concerns pose the main challenge for coal to continue being used as an energy source in South Africa (Eskom, 2021a). The government recognizes the need to reduce the country's dependence on coal in order to reduce carbon emissions and meet its climate commitments. By 2030 coal will only account for approximately 40% of the country's electricity mix, and this dependence on coal is expected to decrease through to 2050 in order for the country to achieve its net zero commitments (IPP Office, 2022). The country has abundant renewable energy potential, particularly onshore wind and solar, and although there are plans to increase the use of renewable energy sources, there are challenges associated with integrating renewable energy sources into the grid (SAWEA, 2023).

Another constraint facing South Africa's energy sector is the availability of water. Water is an essential resource for electricity generation, particularly in coal-fired power plants, which require large amounts of water for cooling. However, South Africa is a water-scarce country that receives an annual precipitation of 497mm/year, which is almost 50% less than the global average annual rainfall of 860mm/year (Joan Igamba, 2022), and therefore there are concerns about the impacts of water scarcity on the energy sector. This includes the potential for water shortages to limit the operation of power plants, as well as the impacts of pollution on water quality and availability (DWS, 2019). Furthermore, water scarcity presents a challenge to producing green hydrogen (GH2), which is a disruptive clean power fuel that South Africa hopes to become a major producer and exporter of; however, water scarcity may impede South Africa's production of GH2 and the country's potential to participate meaningfully in the global green hydrogen economy (Tokollo Matsabu, 2022).



Year	Duration of outages (hours)	Energy shed (GWh)	DSR (GWh)
2007	-	176	Not available
2008	-	476	Not available
....	....	....	....
2014	121	203	Not available
2015	852	1 325	Not available
....	....	....	....
2018	127	192	392
2019	530	1 352	1 362
2020	859	1 798	1 426
2021	1 169	2 521	1 936
2022	3 773	11 529	8 301

Figure 7: Loadshedding in South Africa over the past 15 years (Pierce & Le Roux, 2023)

Energy insecurity is a growing concern for South Africa. The country has experienced rolling blackouts for the past 15 years with increasing intensity. These pose a serious threat to the future growth of the sector and the economy at large. Figure 7 illustrates variable load shedding for the past 15 years (2007-2022) with 2022 being the most intense year to date (excluding 2023 data). In 2022 loadshedding occurred for 3,773 hours with an upper limit of 11,529 gigawatt hours (GWh) relative to the actual energy shed of 8,131 GWh, with load shedding dominated by stage four (Pierce & Le Roux, 2023). During 2022, loadshedding was driven by a declining energy availability factor (EAP) of the existing coal fleet, where overall the EAF was 58.1% for 2022 relative to 61.7% in 2021, 65% in 2020 and 66.9% in 2019 (Pierce & Le Roux, 2023).

2.5 Identification of key economic and socio-economic gains and losses associated with current path

As mentioned before, the country is highly dependent on coal-fired power stations to meet its energy needs and this path has both positive and negative impacts on the economy and society. One of the key economic benefits of the current energy path is that it provides a reliable baseload source of energy, given that coal is abundantly available in South Africa. This has historically helped ensure a reliable and stable supply of electricity, which is essential for economic growth and development. The sector further contributes to the country's GDP and generates significant revenue for the government. Lastly, the coal industry supports economic growth in the coal mining value chain and in 2022 created employment for 90,977 people (Minerals Council of South Africa, 2023). On the contrary, there are significant socio-economic losses associated with the current path. One of the most significant is the impact on the environment. Burning coal produces GHG emissions, which contribute to climate change which has a range of negative impacts including increased frequency of extreme weather events, including droughts; loss of biodiversity; damage to infrastructure; and rising sea levels. Furthermore, coal mining can have negative impacts on local communities, including displacement, loss of land and livelihoods, and pollution of water sources (Shongwe, 2018).

Section 2.1 has provided an overview of South Africa's energy sector, including the move to diversify the country's energy mix and reduce the country's dependence on coal. The introduction of renewable energy sources can have significant socio-economic benefits including job creation, reduction in GHG emissions, and economic benefits for local communities. As of March 2022, the REIPPP had created 64,590 employment opportunities for South Africans, with a contribution of R1.9 and R0.9 billion realised for socio-economic development and enterprise development respectively. 89.8 million kilolitres of water have been saved since the start of the REIPPP programme, and 75.9 Mton CO_2 has been offset by the electricity generated by these renewable energy projects (IPP Office, 2022). However, as the country continues to develop the renewable energy sector, it will be essential to consider the costs and benefits of expanding the presence of these energy sources and ensure that the implementation of projects is equitable and sustainable for all.

3 The Circular Economy – An energy perspective

Renewable energy technologies such as solar PV and onshore wind, are seen as forerunners to advance circularity in the energy sector, adopting the principle of regenerating natural systems. However, there are numerous other interventions being implemented locally and internationally. Possible energy sector CEIs that can be applied to the South African energy sector to promote circularity, as aligned with the circular economy principles outlined in Section 1, are briefly highlighted below. Since the circular economy applies to the energy sector both in terms of the manufacturing of energy technologies, as well as the actual generation, storage, distribution and consumption of energy, the CEIs are categorised here into circular energy utility and circular energy materials.

3.1 Circular energy utility interventions

Circular energy utility refers to the process of generating, storing, distributing and consuming energy, whether through regenerative and renewable energy systems, or in the case of currently installed fossil-fuel based systems, applying abatement technologies and closing process flow loops in order to mitigate associated impacts. The interventions considered for adoption in this segment of the circular economy can be clustered into –

- Clean energy technologies and related interventions, e.g.,
  - Renewable energy
  - Energy storage
  - Agrivoltaics
  - Electric vehicles
  - Green hydrogen
  - Freshwater substitution (desalination of sea and wastewater for green hydrogen)
  - Waste-to-energy
- Abatement of transitioning coal, gas and petroleum use, e.g.,
  - Carbon Capture Utilisation and Storage (CCUS)
  - Freshwater substitution (Dry cooling)
  - Emissions prevention (clean coal technologies)
  - Energy efficiency
  - Fly ash valorisation

3.1.1 Renewable energy

Globally, the predominant sources of energy consist of oil, coal, and natural gas with respective contributions of 30.9%, 26.8%, and 23.2%, respectively, to the global primary energy supply in 2019 (IEA, 2021b). However, the continued use of these energy sources is unsustainable due to the myriad of social and environmental challenges, the most significant being climate change induced by the GHG emissions emanating from electricity generation and liquid fuel production and use. Due to this, there is global consensus on the transition to low-carbon energy technologies, such as renewable energy. Renewable energy technologies that are considered within the circular economy include wind (onshore and offshore), hydropower, solar (PV and CSP), and bioenergy (Enel Green Power, n.d.).

Furthermore, the use of renewables in the energy sector can close the loop on resource use, encouraging repair, remanufacturing, recycling, and reuse of renewable energy technologies such as PV panels and wind turbine components.

3.1.2 Energy storage

Electricity generation from renewable energy technologies is intermittent and variable. For example, solar PV panels generate electricity during hours of the day when there is enough insolation, however this is usually outside of peak electricity demand periods. Energy storage technologies address this challenge by storing energy generated by renewables during off-peak periods and dispatching it when it is required, thus balancing supply and demand and providing flexibility to electricity systems. Besides pumped hydroelectric storage, the most prominent form of energy storage is battery energy storage systems (BESS) using lithium-ion cells. Lithium-ion batteries have versatility and broad range of applications in electric mobility, consumer electronics, and stationary storage (i.e., BESS). The dominant form of lithium-ion cells is based on the lithium-nickel-manganese-cobalt-oxide (NMC) chemistry. These cells have high raw material requirements, however, over 90% of their materials can be recycled and reused to make other cells allowing for circularity of materials. Furthermore, the cells can be repurposed for second-life battery applications. This highlights the circularity of lithium-ion battery energy storage systems which strongly aligns with the CE principle of keeping products and materials in use.

3.1.3 Agrivoltaics

According to the National Renewable Energy Laboratory (NREL), the average land-use for small-scale and large-scale PV plants is 1.25 hectares/MW_{ac} and 1.66 hectares/MW_{ac} respectively (Ong *et al.*, 2013). The increase in the deployment of solar PV worldwide has increased pressure on land resources for energy generation and other competing land uses (Walston *et al.*, 2022). Due to this pressure, there has been great emphasis on adopting land sharing strategies in tandem with solar developments. A prominent example of this land sharing is the development of 'agrivoltaics' (AV), which is the co-location of ground-mounted solar PV with agricultural activities. This intervention aligns with the circular economy principle of regenerating natural systems as it improves efficiency in land use, water use, and energy generation. There are three types of AV based on the agricultural activity that the solar development is coupled with, these are (Walston *et al.*, 2022):

- AV-cropping systems: co-location of solar PV and crop production,
- AV-animal systems: co-location of solar PV and animal husbandry and livestock, and
- AV-habitat systems: co-location of solar PV and habitat restoration.

3.1.4 Electric vehicles for decarbonization of small- to medium- vehicles

The transport sector is the second largest GHG emitter in South Africa producing 58.54 million tonnes CO_2-eq in 2019 as can be seen in Figure 8 below. Significant emission reduction in this sector can be achieved by using alternative fuels and electrification, thus applying the design out waste circular economy principle. When combined with public transport and renewable energy strategies, electric vehicles have the potential to play a significant role in decarbonizing small- to medium-vehicles, and a concerted effort by governments, businesses and consumers can help accelerate their adoption and deployment.

Production and use of electric vehicles (EVs), including hybrid models (combining electricity use and other fuel), is increasing globally and in South Africa. However, the adoption rate in South Africa is slow, with only 218 EVs sold in 2021 (NAAMSA, 2022). Electric vehicles, when powered through solar generated electricity, can have an emission reduction potential of up to 94% (Kobashi *et al.*, 2022).

3.1.5 Green Hydrogen

Green hydrogen is produced by using renewable electricity to split water molecules into hydrogen and oxygen. Green hydrogen holds significant promise to help meet global energy demand while contributing to climate action goals, by being able to decarbonise hard-to-abate sectors. It aligns with the circular economy principles of designing out pollution and regenerating natural systems given that renewable energy is used for its production. More than 95% of current hydrogen production is from gas and coal, that is, not 'green'. However, green hydrogen production technologies are seeing a renewed wave of interest. This is because of the possible uses for hydrogen in the energy sector and hard to abate sectors such as such as shipping, aviation, chemicals, steel production, cement production and trucking (Kane & Gil, 2022).

3.1.6 Freshwater substitution (desalination of sea and wastewater for green hydrogen)

Water desalination is not a new concept, as there are approximately 15,906 desalination plants that have been built globally (Jones *et al.*, 2019). It involves a process of removing salt and other minerals from seawater or brackish water and is becoming an increasingly important technology for addressing water scarcity and meeting the growing demand for freshwater (Iberdrola, 2023). While there are still challenges to be addressed, such as the energy requirements and environmental impacts of the technology, ongoing technological advancements and increased investment in the sector are helping to make desalination a more viable option for providing clean, freshwater around the world (Assem *et al.*, 2022). As mentioned previously, green hydrogen is a proposed method for decarbonisation for hard-to-abate sectors, and this process requires approximately 17 litres of water per kilogram of hydrogen produced (Newborough & Cooley, 2021), although other studies do reference higher values such as 60 to 95 litres of water (Coertzen *et al.*, 2020). Desalinated water could therefore potentially be used for green hydrogen production instead of freshwater, making GH2 production more sustainable and increasing water resource use efficiency.

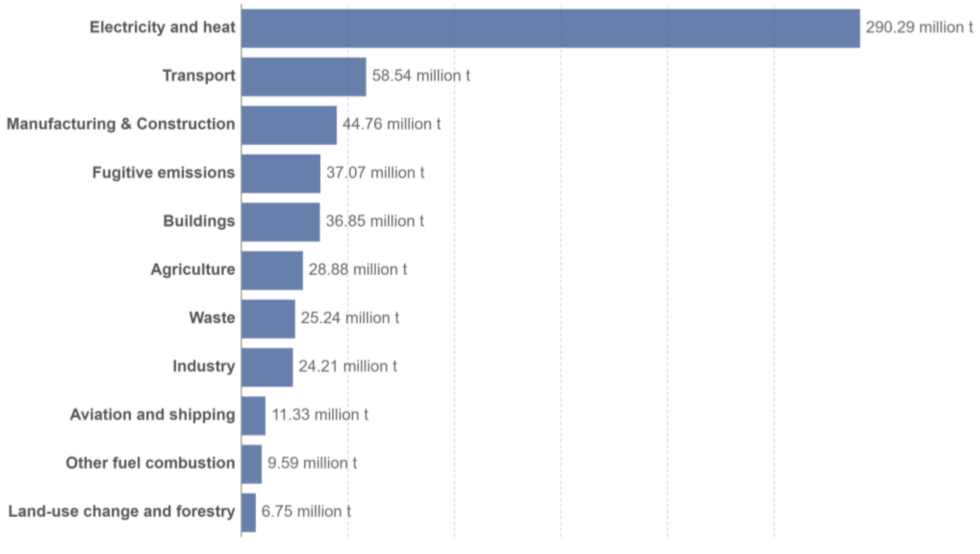


Figure 8: GHG emissions (CO_2-eq) from South Africa in 2019 (Our World in Data, 2019)

3.1.7 Waste-to-energy

Waste streams such as municipal solid waste (MSW), industrial solid and liquid waste, and agri- and agro-processing wastes present an opportunity for valorisation into energy using various 'waste-to-energy (WtE)' technologies. While the high-temperature thermal treatment of waste through e.g., incineration, gasification, or pyrolysis, typically sits outside of the circular economy – given the destruction of resources – low-temperature WtE technologies such as landfill gas recovery and anaerobic digestion (AD) do provide an opportunity to generate energy aligned with circular economy principles.

Landfill gas (LFG) is a by-product of the decomposition of organic matter under anaerobic conditions in landfills. It is composed of 50-60% methane (CH_4), 40-50% CO_2 and 2-5% nitrogen, and less than 1% ammonia, oxygen, and others (Adeleke *et al.*, 2021). Methane is a GHG that is estimated to be around 28-36 times more potent in trapping heat in the atmosphere than CO_2, therefore management of its emissions is very important to curb global warming and mitigate climate change. LFG capture and utilisation is one way this can be done and involves the extraction of methane from landfills, and its use as a renewable energy source for energy generation. Furthermore, LFG can potentially replace fossil fuels such as natural gas, coal and oil by increasing its methane content (conversely reducing CO_2, oxygen, and nitrogen content), resulting in renewable natural gas (RNG) or biogas (EPA, 2022). However, as the waste sector moves to restrict or ban the disposal of organic waste to landfill, as in the case of the Western Cape, the long-term potential for landfill gas recovery is limited.

Anaerobic digestion refers to the process of decomposing organic wastes in an oxygen-free environment to produce biogas. The anaerobic digestion energy value chain is shown in Figure 9. Instead of landfilling organic waste, it is used as feedstock into the anaerobic digester in which the AD process takes place.

LFG capture and utilization, and AD are organic waste valorisation pathways that can reduce our dependence on fossil fuels to produce energy and potentially contribute to decreasing GHG emissions. For instance, LFG capture and utilisation optimises energy consumption at solid waste disposal facilities, contributing towards reductions in GHG emissions, especially CH_4 and CO_2 (Ciuła *et al.*, 2018).

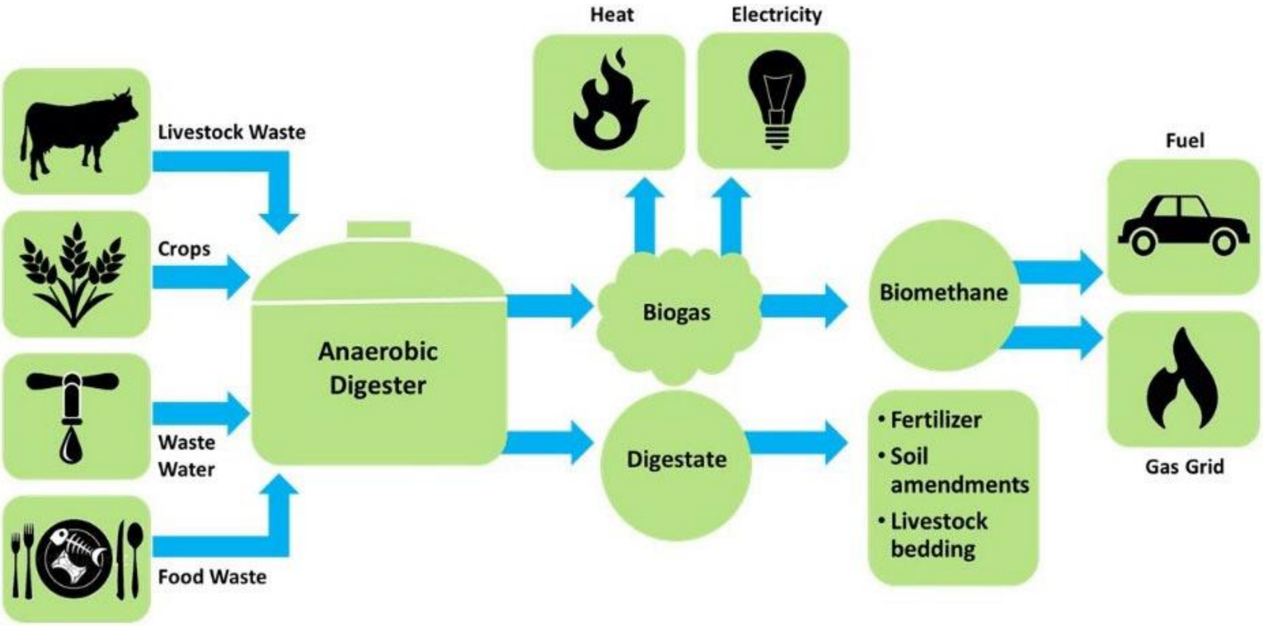


Figure 9: Anaerobic digestion energy value chain (Tanigawa, 2017)

3.1.8 Carbon Capture Utilisation and Storage (CCUS)

Given that the use of coal, gas and petroleum will continue to dominate the energy mix for the foreseeable future in South Africa, it is important that technologies are adopted to capture emissions. To this end, the Circular Carbon Economy (CCE) concept, an extension of the CE, which focuses on energy and carbon flows while retaining the material, water, and economic flows emphasised by the CE, is proposed as a circular framework to better manage CO_2 emissions from the energy sector (KAPSARC, 2020).

The CCE proposes the use of Carbon Capture and Storage (CCS) and Carbon Capture and Utilisation (CCU) technologies for the management of CO_2. CCS aligns with the reduce and remove strategies of the CCE, and there are generally two main categories of processes used for carbon capture and storage, that is, biological carbon sequestration (Climate Adaptation Science Centres, 2022) such as reforestation, and technological carbon sequestration solutions such as direct air carbon capture and storage (DACCS) (IEA, 2022) or bioenergy carbon capture and storage (BECCS) (Lyons *et al*., 2021). Technological CCS is a long-term approach through which the captured CO_2 is stored in geological formations. CCU, on the other hand, refers to the use of captured CO_2 in secondary processes (Lyons *et al*., 2021). CCU aligns with reuse and ensures that CO_2 as a material is recirculated within the economy for other purposes, thus closing the loop on carbon flows. There are multiple pathways for CO_2 as shown in Figure 10.

In addition, while resource use should be reduced, products reused and materials recycled as much as possible, if the energy driving these reuse and recycling processes is a source of CO_2, then a circular economy of materials and products will have limited effect in meeting climate change goals and net zero targets.

3.1.9 Freshwater substitution (Dry cooling)

Dry cooling is a technology used in coal fired electricity generation that uses air instead of water to cool equipment and processes, using approximately 95% less water than a wet cooling system (Hamon, 2023). It contributes to the circular economy by reducing water consumption, minimising waste, and improving resource efficiency. Dry cooling in electricity generation is growing globally, particularly in water scarce regions (IEA, 2018). While there are some challenges associated with dry cooling, such as high capital costs, increased maintenance requirements, and reduced efficiency compared to wet cooling systems, ongoing research and development are focused on improving technology to make it more efficient, cost-effective, and sustainable.

3.1.10 Emissions prevention (clean coal technologies)

High-efficiency, low-emission (HELE) coal technologies refer to technologies that consume less coal, therefore emitting less GHGs and consuming less water. The IEA estimates that HELE technologies could increase the thermal efficiency of power plants to 45% from the average of 33% and reduce GHG emissions by 25–33% compared to existing plants (World Coal Association, 2021). Implementation of technologies will require high capital costs, but the benefits come through consumption of less coal, water, and GHG emissions.

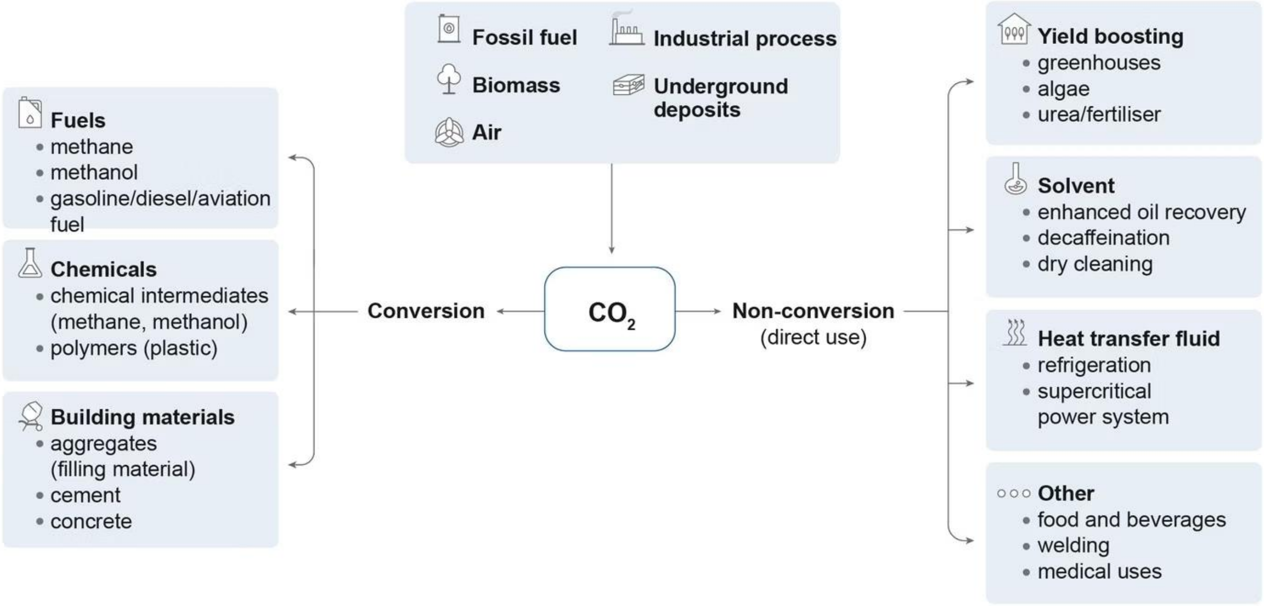


Figure 10: Possible utilisation pathways of CO_2 capture Source (IEA, 2021a)

3.1.11 Energy efficiency

Energy consumption is a major contributor to GHG emissions when a large percentage of energy consumed is generated from coal, gas and petroleum products (Our World in Data, 2019). Energy efficiency (EE) has been identified globally as a less costly, low hanging fruit for reducing energy demand with the potential to reduce 60% of global CO_2 emissions by 2050 (Nadel & Ungar, 2019). EE plays a critical role in promoting a circular economy by reducing energy consumption and its associated impacts, increasing resource efficiency, informing circular products and business model design, and supporting circular infrastructure. Energy efficiency strategies that can be adopted include:

- Procurement and use of energy-efficient equipment such as lights, motors, air and water heating and cooling equipment, variable speed drives,
- Centralisation of heating and cooling,
- Equipment and process control and automation,
- Zero-energy or passive buildings that use designs and materials that minimize energy consumption, and
- Passive buildings which consider renewable energy systems, insulation, surface colours, ventilation, efficient fenestration systems and designs, orientation, energy efficient equipment, etc. (GBCSA, 2020).

3.1.12 Fly ash valorisation

Fly ash is a by-product of coal combustion, which is often considered a waste material and is disposed of to land. This material can be reused and recycled to create value-added products. Examples of valorisation pathways of fly ash include (Li *et al.*, 2017):

- Cement & concrete industry: Fly ash can be used as a raw material in the production of blended cement, reducing the costs for clinker needed in cement production. The use of fly ash in the production of cement and concrete also reduces the demand for natural resources, such as limestone and clay, and reduces the amount of fly ash sent to landfill.
- Agriculture: Fly ash can also be used for soil amelioration to improve soil fertility and reduce soil acidity. It can be used as a source of micronutrients such as zinc and iron. The use of fly ash in agriculture reduces the demand for synthetic fertilizers, which can have negative environmental impacts.
- Other uses of fly ash include backfilling of mines, removal of gaseous pollutants, and recovery of valuable materials such as gallium.

3.2 Circular energy materials interventions

The transition to a low-carbon economy, and the adoption of clean energy technologies, will require more (and different) minerals and metals, with ever larger material footprints. While this resource demand has the potential to unlock new growth areas for the South African mining sector, it also has the potential to erode national resource security, with widespread environmental impacts. It is therefore important that the principles of a circular economy are applied to the sustainable use of resources – including critical raw materials – in the development and deployment of clean energy technologies.

Circular Energy Material interventions therefore have a strong focus on improved design of energy technologies to ensure greater repair, refurbishment, or recycling at end-of-life; designing energy technology manufacturing processes with reduced material and energy use; and increasing energy technology lifetimes, i.e., greater resource productivity. The interventions to be considered for adoption in this segment of the circular economy include:

- Circular design of energy technologies,
- Increased efficiency in energy technologies,
- Increased longevity of energy technologies,
- Repair of energy technologies,
- Recycling of energy technologies.

3.2.1 Circular design of energy technologies

Design of energy technologies to promote the circular economy includes having final components that can easily be repaired, disassembled, recycled or that are less toxic. This intervention reduces the disposal of components, in accordance with the CE principle of designing out pollution and waste, and ensures that valuable, and typically finite, materials are kept within the economy. Examples of such include:

- The manufacture of 100% recyclable wind turbine blades (Siemens Gamesa, 2022),
- The manufacture of lead-free and bismuth-based solar cells (Singh *et al.*, 2021), fluorine-free back backsheet (Fraunhofer UMSICHT, 2017)
- New Industrial Cell (N.I.C.E) makes recycling PV cells easier, and Radio-Frequency Identification (RFID) technology can provide recyclers with easy access to information on the manufacturing of components (Radavičius *et al.*, 2021),
- The use of lithium-based battery energy storage in combination with renewable resources. Lithium-ion batteries have fewer toxic materials than lead-acid batteries and have a >95% material recovery rate (Pražanová *et al.*, 2022). Designing new

technologies, such as fast battery charging, further reduces the quantities of components required[1].

Renewable energy components manufactured / assembled in South Africa include solar module and plant assembly, onshore wind towers, transformers, anchor cages, lead acid battery manufacturing, lithium-ion battery pack and module assembly, and balance of system components (electrical and structural) (GreenCape, 2023; SAPVIA, 2022; TIPS & WWF, 2022). However, the majority of the raw materials used are imported. Therefore, the procurement of materials that are designed for a circular economy can enable South Africa to promote the practice. It also stresses the importance of retaining these imported resources within the local economy at end of product life.

3.2.2 Increase efficiency in energy technologies

Efficiency in energy technologies refers to the ability to generate more energy from components without increasing their resource requirements. Examples include increases in efficiency in crystalline solar panels whose efficiencies have increased from about 13% to 27% (NREL, 2022). New technologies are also emerging with 32.5% efficiency (NREL, 2022). With this, such technologies can reduce the demand for several panels to achieve the required levels of energy generation. For batteries, efficiencies can be increased in manufacture (lithium-ion batteries (Rahimi, 2021)) and during use through good practises, such as cooling. For South African manufacturers, the import of highly efficient components and efficiency practices will help to improve the circularity of the country's energy sector.

3.2.3 Increase the longevity of energy technologies

Building longevity into the design of energy technologies, requires manufacturing energy technologies that use robust and durable materials, ensuring products have long useful life, high utilization rates, and are more efficient. This intervention can also include measures that improve resilience of energy technologies against climate change impacts such as extreme weather conditions and / or a broader range of operating temperatures. This can also include the refurbishment of renewable energy technologies to extend their life, e.g., designing EV batteries to allow for repurposing for second-life energy storage applications.

3.2.4 Repair of energy technologies

Driving greater repair of damaged or end-of-life energy technologies, such as solar PV components, reduces the need to purchase new components. Manufacturers and other maintenance companies have set up monitoring, diagnostics, and repair centres, and they also carry out maintenance on sites. Routine inspection and preventive maintenance techniques such as cleaning and monitoring are key activities in reducing failure rates, and these have been enhanced by technology advancements. Users must therefore be encouraged to use these services.

3.2.5 Recycling of energy technologies

While the intention is to design energy technologies for greater circularity, i.e., reuse, refurbishment, repair, some products at end-of-life will require recycling to recover valuable materials than can be returned into the economy. With increasing uptake of clean energy technologies comes an expected increase in the generation of waste. According to the IRP (2019), solar PV installations are projected to increase and globally, solar PV is expected to generate 78 million metric tons of waste by 2050 (Chowdhury *et al.*, 2020). While recycling is a possible solution, recovery rates are still low for energy technologies. Another challenge is that with increasing demand for renewable energy systems, the demand for raw materials such as PGMs available in South Africa, which are finite and some toxic, is projected to increase[2]. Therefore, recycling reduces the need for extractive mining of materials. Recycled components can be put back into the energy value chain e.g., using recycled aluminium and silicon in the manufacture of solar PV components, and lead in the manufacture of batteries (Yanamandra *et al.*, 2022). Other sectors can also benefit, such as using recycled glass fibre composites in the manufacture of cement. It is important that recycling solutions that are put in place for the recycling of energy technologies in South Africa, look to whole product recycling and not just the targeted recovery of high-value metals.

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[1] Fast charging facts: *130197613453828886.pdf (mhi.org)*

[2] *jrc120228_-_raw_material_demand_two-pager_pubsy_final.pdf (europa.eu)*.


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4 Circular economy development path for the energy sector

The development of a circular economy in the energy sector requires significant changes in the way energy is produced, consumed, and managed. This includes adopting new business models, technologies, and regulatory frameworks that promote circular economy principles in the energy sector. In Section 3, several CEIs were identified as relevant to the energy sector, and these are summarised in Table 1 below. The development of a circular economy in the energy sector represents a critical step towards a more sustainable and resilient energy future.

This section therefore explores the development of a circular economy path for the South African energy sector and is informed by emerging energy sector trends, local and international experience, and local energy sector expert input, which was used to assess:

- the appropriateness of the envisaged CEIs,
- the sector's readiness to adopt the envisaged CEIs
- the level of implementation and identification of challenges which affect implementation of CEIs, and
- potential business opportunities arising from the implementation of the CEIs.

4.1 Appropriateness of Circular Economy Interventions for South Africa

This section of the study highlights the results of the stakeholder engagements that sought to assess the appropriateness of the proposed CEIs for the South African energy sector. Inputs gathered from the online questionnaire, stakeholder workshop, and one-on-one engagements with stakeholders on the appropriateness of CEIs are included below.

4.1.1 Stakeholder Engagement

The majority of stakeholders agree that the proposed CEIs can benefit the South African energy sector, by improving sector competitiveness and resilience (75% of respondents); driving inclusive growth and decent jobs (88% of respondents); while also mitigating environmental pollution (75% of respondents).

The stakeholders largely agree that the proposed CEIs are appropriate for the South African energy sector, with stronger agreement on more well-known interventions such as renewable energy technologies (solar PV and onshore wind), energy storage, energy efficiency, and waste-to-energy (Figure 11). There was some level of uncertainty regarding the appropriateness of less familiar CEIs (many of which were considered not yet fully commercialised/mature) such as CCUS, emissions prevention (clean coal technologies), fly ash valorisation, freshwater substitution (dry cooling and desalinated), agrivoltaics, and CSP. The level to which stakeholders agreed that specific interventions are appropriate, corresponded closely to their level of familiarity with the interventions. This was most evident for freshwater substitution (dry cooling), and agrivoltaics, where over 45% of respondents were neutral about whether agrivoltaics was appropriate for South Africa's energy sector. This suggests that agrivoltaics is a relatively new concept for the sector, as noted by a participant –

> "*We have seen an increase in the number of farmers installing rooftop solar to minimise the impact of loadshedding on their operations. However, these installations are not yet integrated with the crops or livestock on the farms as would be the case in agrivoltaics projects*".

South Africa has been actively developing renewable energy projects since 2012 with a focus on onshore wind and solar PV. Of the over 6000MW that have been procured to date, only 600MW are from CSP plants, and this is projected to grow, as per IRP 2019 (Craig *et al.*, 2017). Furthermore, while there are a few water desalination plants in South Africa, the costs can be high, and the energy required for the process can make it environmentally unsustainable.

For circular energy materials interventions, recycling of energy technologies, circular design of energy technologies, and materials efficiency in the manufacturing of energy technologies had the highest agreement rates. Although South Africa has a growing share of renewable energy technologies that have been, and continue to be, introduced into the country's energy mix, the extent to which renewable energy technologies are designed, manufactured and recycled in South Africa is extremely limited. This is despite procurement programmes stipulating local content requirements for projects to encourage local companies in the renewable energy supply chain. As noted by a respondent –

> "*We have not seen any policies or instruments that promote circularity for solar PV beyond the REIPPPP*" (SAPVIA, 2022).

While there is currently little to drive circularity in the upstream design of energy technologies, the Department of Forestry Fisheries and Environment (DFFE) introduced Extended Producer Responsibility Regulations (EPR) in 2021 in an effort to increase the downstream recycling of waste lighting and waste electrical and electronic equipment (WEEE). The EPR regulations set out mandatory collection, recovery and recycling targets for off grid solar lighting, lighting solar panels and solar lighting energy storage (Government Gazette No, 43881), and for batteries (Government Gazette No. 43880) over a five-year period.

Table 1: Proposed circular economy interventions for the energy sector.

CE interventions	**Description & Benefits**
Circular Energy Utility	
Agrivoltaics	Co-location of agricultural land use with solar PV energy generation, which optimises land use, water use, and energy generation.
Carbon Capture Utilisation and Storage (CCUS)	CO_2 management through technologies that reduce and remove CO_2. Captured CO_2 can either be stored in geological formations or used as a circular material in applications in the chemicals and building materials industries.
Electric Vehicles	Driver of the decarbonisation and electrification of road transportation by moving away from internal combustion engine vehicles.
Emission prevention (clean coal technology)	The term refers to several generations of technological advances that have led to more efficient combustion of coal with reduced emissions of sulphur dioxide and nitrogen oxide.
Energy efficiency	Demand side management to promote the use of less energy to perform the same task or produce the same result. Reduction of energy consumption contributes to reducing the use of coal used in energy generation and energy efficiency (EE) promotes this.
Energy storage	Store energy produced by intermittent renewable energy technologies and dispatches it when it is required, matching electricity supply and demand and providing grid flexibility. Most prominent form of energy storage is battery energy storage based on lithium-ion cells. These are highly modular, use highly recyclable materials, and their lifespans can be extended through repurposing for second-life applications.
Fly ash valorisation	Fly ash is a by-product of coal combustion, which can be reused and recycled to create value-added products. Applications range from use in the cement & concrete industry, soil improvement in agriculture, and others.
Freshwater Substitution (Desalination of sea water and wastewater for green hydrogen)	Process of removing salt and minerals from seawater, making it suitable for drinking, agricultural processes, and other uses, thereby reducing the demand for freshwater sources. It has great potential for use in hydrogen production.
Freshwater substitution (dry cooling)	Dry cooling removes heat from a plant by means of sensible heat rejection. The lack of water and any need for water treatment greatly reduces the demand for freshwater sources.
Green Hydrogen	A power fuel produced through either electrolysis. Green hydrogen, produced using renewable energy, and its derivatives has the potential to decarbonise heavy industries such as steel and cement production.
Renewable energy	Energy production from renewable sources (solar, wind, hydro & bioenergy).
Waste-to-energy	Provide a means of reducing the disposal of organic waste thereby reducing GHGs, generating clean energy, and recycling nutrients.
Circular energy materials	
Circular design of energy technologies	Designing energy technologies for greater circularity at end-of-life, e.g., design for repair, design for recycling.
Increase efficiency in energy technologies	Efficiency in energy technologies refers to the ability to generate more energy from components without increasing their resource requirements.
Increase the longevity of energy technologies	The design for longevity, aims at manufacturing energy technologies that use robust and durable materials, ensuring products have long useful life, high utilization rates, and are more efficient
Repair of energy technologies	Optimise material repairability to design out waste.
Recycling of energy technologies	Recycling of energy technologies to reduce waste and recover valuable materials (e.g., solar PV panels).

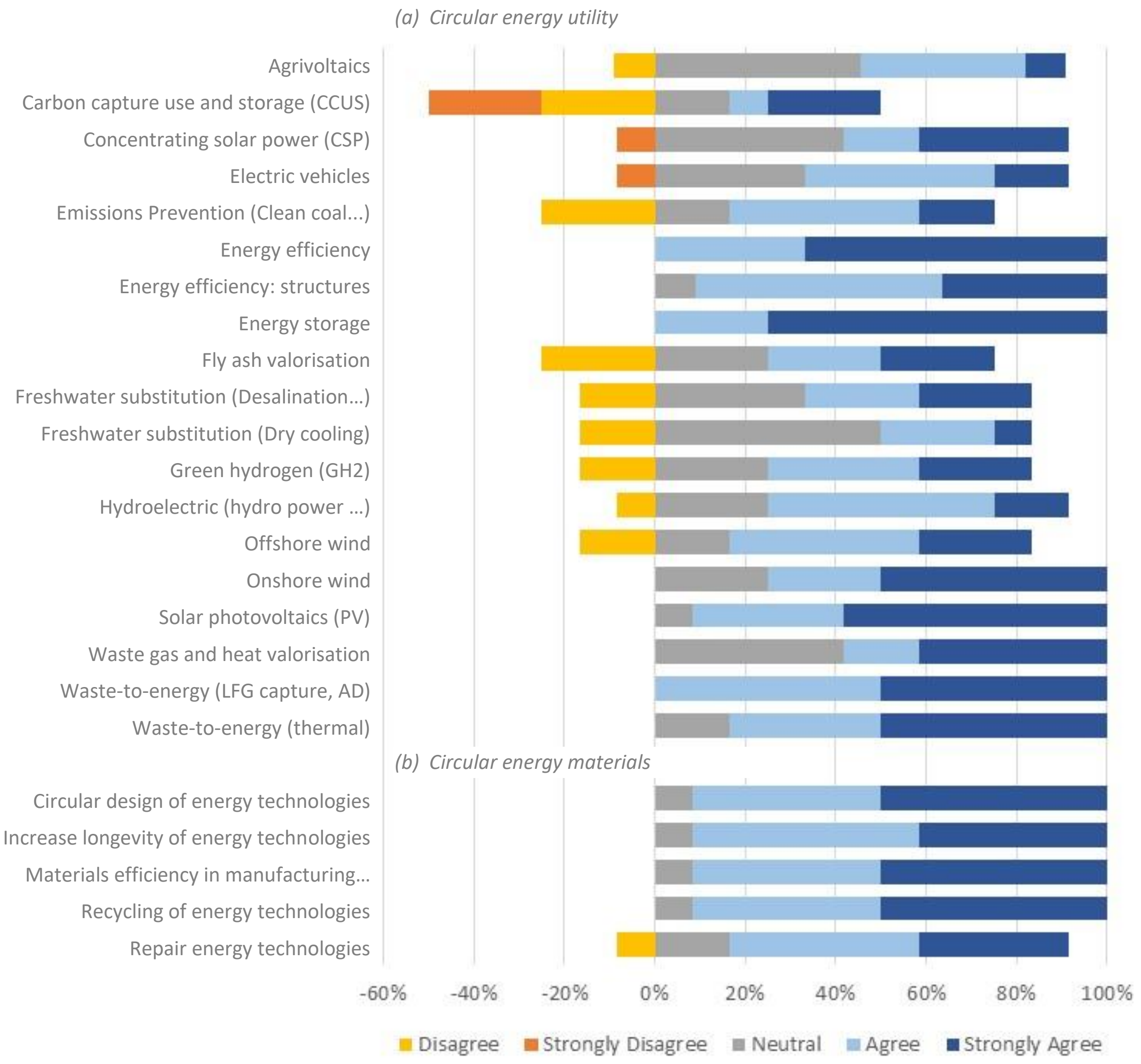


Figure 11: Responses received on extent of appropriateness of the proposed CEIs for the SA energy sector.

It should be noted that 75% of respondents were of the view that the South African energy sector does not have a good understanding of what the circular economy is, and its potential benefits for the sector. As a result, efforts must be taken to improve understanding of the circular economy and the contributions that various stakeholders in the energy sector's value chain can make to improve the sector's circularity.

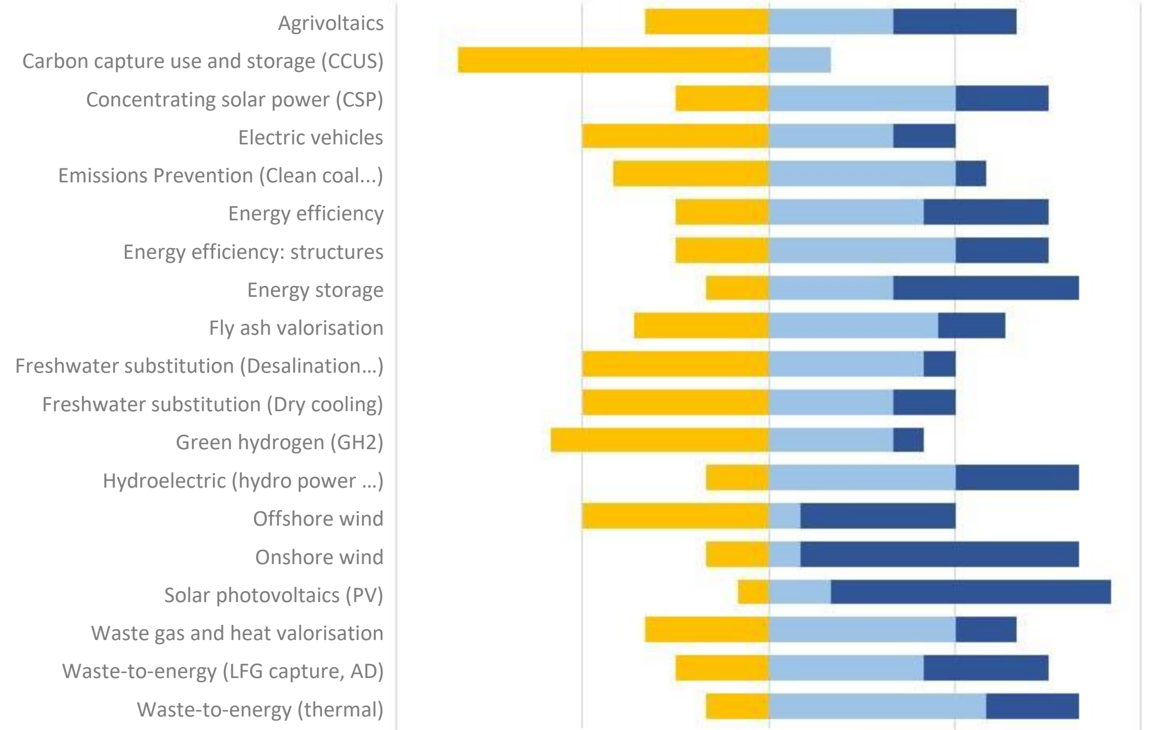
4.2 Readiness to implement interventions

Energy CEIs are being implemented internationally and locally to varying degrees. The stakeholders were asked to rate the sectoral readiness to implement these interventions (Figure 12) and the current level of implementation of the proposed CEIs (Figure 13).

4.2.1 Stakeholder Engagement

When asked to what extent stakeholders rate the sector’s readiness to implement CEIs and the level of implementation in the sector, the results showed similar responses in terms of readiness and implementation. The results show that the sector is most ready to implement solar PV, followed by onshore wind renewable energy technologies, energy storage, hydroelectric, and WtE. As mentioned in Section 4.1, South Africa has been actively developing renewable energy projects since 2012, most of the projects being solar PV and onshore wind, and this is projected to grow, according to IRP 2019. By 2030, the mix of electricity generation is set to comprise of 17,742 MW (22.7%) wind onshore wind and 8,288 MW (10.6%) solar photovoltaic PV (IPP Office, 2021a). Furthermore, policy enablers such as the lifting of licensing required for generation of electricity with any capacity of plant within the Schedule 2 of the Electricity Regulation Act provides more opportunity for increasing embedded generation where in South Africa, the main technology used as a SSEG is solar PV (SSEG, 2023).

(a) Circular energy utility



(b) Circular energy materials

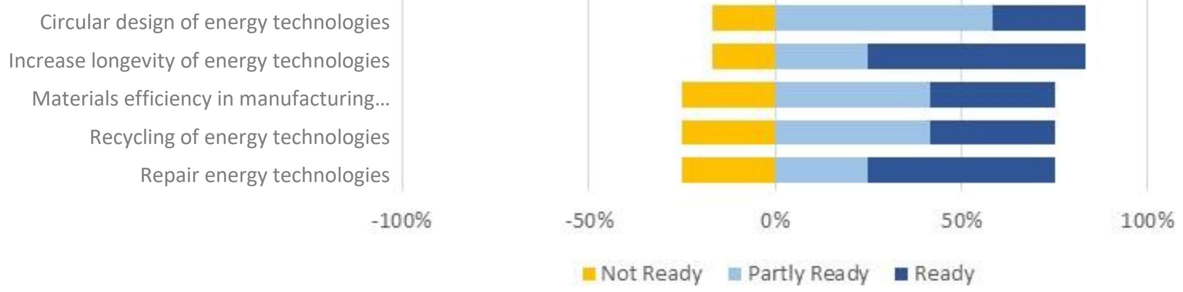


Figure 12: Responses received for state of readiness to implement circular economy interventions in the SA energy sector.

After solar PV and onshore wind, the results showed that 50% of the stakeholders felt that the sector was ready to implement energy storage technologies. This could be attributed to the fact that energy storage applications, more specifically battery storage in the current context of electricity, can provide ancillary services required to maintain grid stability as the penetration of renewable energy increases in the network. This commodity will become very valuable when Eskom does unbundle its services into three companies i.e., generation, transmission, and distribution. Energy storage can also provide energy arbitrage services where it makes it possible for users to store energy when there is little to no electricity demand and use the stored energy when there is electricity demand. Incentives such as net-metering or feed-in tariffs (already offered by certain municipalities) promote the injection of behind-the-meter energy generation into the grid. Energy generated at peak periods of the day is more valuable and therefore can provide incentives for energy storage.

Although the country does not generate much energy from WtE technologies such as landfill gas recovery (LFG) or anaerobic digestion, stakeholders are of the view that the sector is ready to implement the intervention in the country. This could be attributed to the fact that organic waste (agri- and agro-processing waste, garden and food waste) is the single largest general waste stream produced in South Africa (DEA, 2018), most of which is still disposed of to land (in-field, dumpsites, or landfills). The Western Cape Provincial Government has already implemented a landfill ban on organic waste, with targets for 50% diversion by 2022 and 100% diversion by 2027 (DEADP, 2018). This government signal creates opportunities for the private sector to invest in the appropriate technologies to unlock energy from organic waste. A study by Adeleke *et al.* (2021) revealed that South Africa has the highest potential for WtE generation on the African continent.

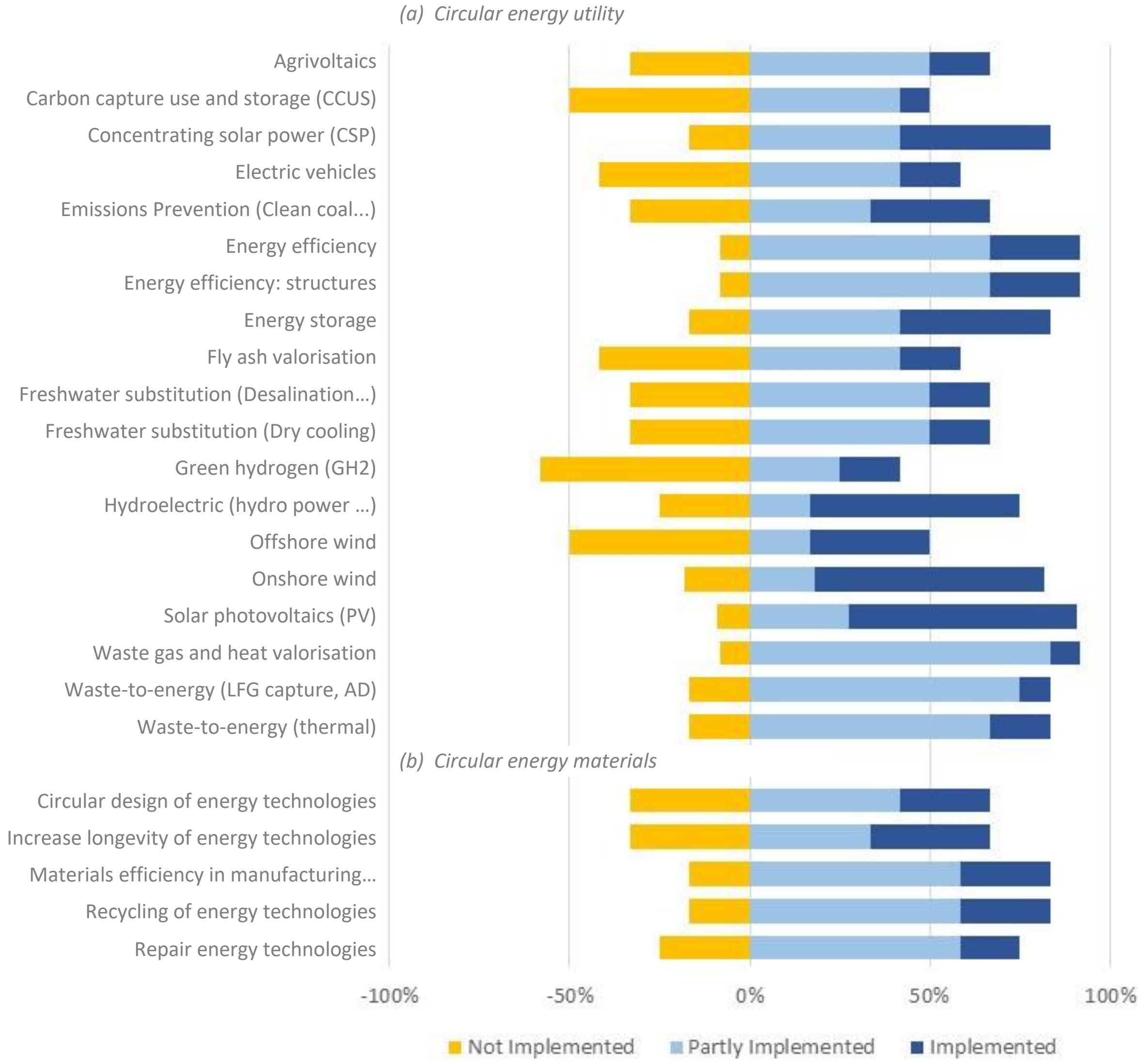


Figure 13: Responses received on level of implementation of circular economy interventions in SA energy sector.

However, the implementation levels of WtE in the sector are low, as noted by one stakeholder –

> "*WtE has the potential to have an impact on energy supply, waste reduction, and job creation but we need clear policy and regulatory frameworks that provide clear guidance to companies involved in different parts of the waste-to-energy value chain*".

High temperature WtE, remains contentious for South Africa, given the technologies high-cost relative to current landfill gate fees; perceived competition with mechanical recycling for high-calorific, highly recyclable plastic and paper waste; threat to informal waste picker livelihoods; typically wet municipal waste due to high organic waste content; high cost of maintaining air pollution abatement (scrubbers); and public pressure for NIMBY.

Government, through the DMRE, has implemented various policy and regulatory measures to promote energy efficiency, which creates opportunities for the private sector to invest in numerous energy efficiency programmes. This is reflected in the strong sentiment of the respondents about the appropriateness of energy efficiency as a circular economy intervention. Energy efficiency is regarded as the "first fuel" to reduce demand and CO_2 emissions. South Africa is one of the least energy efficient countries in the world, and the government has taken steps to promote energy efficiency interventions in recent years, starting with the introduction of the National Energy Efficiency Strategy in 2011. However, a respondent noted that –

> "*The extent to which energy efficiency programmes are implemented in municipalities is low due to 1) lack of awareness of available technologies and equipment, 2) capacity within the municipalities to identify energy efficiency interventions that can be funded from the fiscus, and 3) limited funding in the fiscus to drive implementation given governments' competing priorities*".

The notably high readiness ranking on hydroelectric power was unexpected. Hydroelectric power currently accounts for less than 5% of the electricity mix, and by 2030 it is estimated it will account for only 2.4% of the electricity mix (IPP Office, 2021a). According to the IRP 2019 no new hydro projects are planned in the country, with only 2500 MW being planned for import from the Democratic Republic of Congo (DMRE, 2019a).

The results showed low levels of readiness and implementation of CCUS, green hydrogen, offshore wind, and electric vehicles. Coal-fired electricity generation is expected to be in the energy mix for the foreseeable future, as detailed in the IRP2019. To this end, the government has started geological mapping at the country's first carbon capture and storage (CCS) site in Mpumalanga (Reuters, 2021). As noted by a stakeholder:

> *"In the short- to medium-term CCUS is not a viable solution. The technology has been punted as a solution for many years but there are not enough R&D funds being poured into the development of these technologies".*

With regard to green hydrogen, South Africa and the world are in the nascent stages of using green hydrogen as an energy carrier. It was in late 2021 that the government approved a Hydrogen Roadmap, which recognises South Africa as a strategic location for the production of green hydrogen for both domestic use and export. The Roadmap was developed through the DSI's long-term STI vision relating to hydrogen which commenced in 2007. This led to the HySA Infrastructure Centre of Competence co-hosted by the CSIR and North-West University. Sasol is advancing a number of green hydrogen studies, such as in Boegoebaai in the Northern Cape province. Freeport Saldanha is undertaking a prefeasibility study to investigate the potential for production, storage, and export of green ammonia and methanol (Sasol, 2021).

A study, '*Offshore Wind Resource Assessment Off the South African Coastline*' assessed the wind speed along the South African coastline and found four potential offshore sites with suitable resource availability for wind farms (L. Inambao & Cunden, 2019). To date, there are however no offshore wind projects that have been implemented in the country due to the high capital cost associated with the technology.

Amongst the circular energy materials interventions, increasing energy technology lifespans and technology repair and recycling had the highest levels of readiness and implementation. As noted by one respondent –

> *"We often get asked about the extent to which solar panels are recycled/recyclable and if the industry has end-of-life plans for PV panels. The answer we give is that where end-of-life is reached on utility scale PV, the panels can enter two streams – recycling, including the extraction of high value materials, or the second hand/used market. There is opportunity in both but there is currently no policy or regulatory framework providing guidance in both instances and no formalised processes for the treatment of end-of-life PV panels".*

There are currently two (confirmed) recycling companies operating in South Africa that are recycling solar PV, although in limited quantities.

While some recycling of fly ash is currently occurring, the level of readiness and of implementation were scored quite low. In 2017, South Africa produced 33.3Mt of fly ash which accounted for 63.9% of the hazardous waste produced in the country, 93% of this ash was disposed of in landfills and the rest was recycled (DEA, 2018). Only six of Eskom's 14 power stations sell their ash. This is because Eskom only sells to industries that are within 50km of the power station, which limits the potential to recycle the ash. In 2018, all the ash sold by Eskom was used in the construction industry for cement and concrete applications (DEA, 2018).

The highest levels of 'implemented' energy CEIs in South Africa, as noted by stakeholders (Figure 13), were solar PV, onshore wind, hydroelectric, and energy storage. The lowest levels of currently 'implemented' (i.e., not implemented) of energy CEIs in South Africa, were considered to be green hydrogen, CCUS, offshore wind, electric vehicles, and fly ash valorisation. The extent to which respondents considered most energy CEI's to be only 'partly implemented' in the South African energy sector (Figure 13), suggests that there is significant room for implementing and/or scaling these CEIs both under circular energy utility and circular energy materials.

A number of constraints were highlighted as obstacles to fast-tracking the implementation of CEIs in the South African energy sector. Some of these have been expanded upon in Sections 4.1 and 4.2. These included:

- Lack of awareness of the applicability of the interventions within the energy sector,
- Stakeholder willingness (or lack thereof) to transition away from fossil fuels,
- Lack of clear policies that require and/or encourage circularity in a sustainable and feasible manner,
- Lack of consistency in the roll out of renewables,
- Lack of adequate funding structures in the energy sector to implement these interventions; and
- Lack of appropriate skills and infrastructure
- Crime, corruption, and bureaucracy.

The responses received on the appropriateness and the readiness of the energy sector to implement the proposed CEIs shows a range of opinions and ideas from different stakeholders in the energy sector. These views also include the identification of challenges that hinder the implementation of CEIs in the energy sector. Despite this, the responses gathered in this study indicate that there are opportunities for businesses through increased roll-out of the CEIs.

4.3 Business opportunities to implement circular economy solutions

The circular economy presents an opportunity to disrupt markets and industries by offering alternative business models referred to as Circular Business Models (CBMs), such as offering products-as-services instead of selling them to customers, which ensures that the original equipment manufacturers retain ownership and can at the end-of-life of the products recover them for reuse, repair, refurbishment or recycling. Energy sector industry players can also adopt some of these CBMs or create new innovative models to capitalise on the opportunities presented by the circular economy. This section highlights some business opportunities linked to the CEIs proposed in this study.

4.3.1 Circular energy utility opportunities

Companies in the South African economy depend on electricity supply from Eskom for their daily operations, however due to the utility's current generation constraints and rolling blackouts, many companies are struggling to stay afloat. This requires them to look for alternative means of powering their operations; and currently, renewable energy technologies, especially solar PV coupled with battery energy storage, are the best option. Investing in solar PV will reduce their dependence on Eskom, reduce energy bill costs, and increase their sustainability, among others. Due to the current energy crisis, government is significantly enabling this solution with the recent announcement from National Treasury on a 125% tax deduction for businesses who invest in renewable energy systems of sizes above 1MW (SARS, 2023).

There is also an opportunity to enter the renewable energy market as independent power producers, either within REIPPPP or as embedded generation projects. This is also enabled by government with the removal of licensing requirements for embedded generation systems, thus developers can apply to install solar PV embedded generation systems of any size under the new guidelines as long as they have an offtake agreement (e.g., power purchase agreement [PPA]) (Botha, 2023). The country is reported to have a shortfall of over 10 GW from its IRP2019 targets and as 2030 approaches more renewable energy capacity is likely to be added to the grid, which represents a great opportunity for IPPs (West, 2022). Other value chain opportunities linked to the REIPPPP are in contracting, consultancy services such as conducting environmental impact assessments (EIAs), designing of systems, logistics and transportation. There are further opportunities in construction processes and operations and maintenance of such technologies.

Battery energy storage, particularly large-scale storage, also presents a great opportunity for companies to invest in. There are multiple business models and revenue streams associated with battery energy storage, such as the provision of ancillary services, transmission and distribution infrastructure services, and bulk energy services (IRENA, 2020). Furthermore, battery energy storage systems allow for 'revenue stacking', which is the ability to earn revenue simultaneously by providing multiple services with the same system (Sangha, 2022). These will be essential to support and enable SA's energy transition to renewable energy generation, providing much needed grid stability in the energy system.

Hydrogen, especially green hydrogen, is emerging for the decarbonisation of multiple hard-to-abate sectors and as an important energy carrier for sector coupling. This technology presents a variety of opportunities for local companies as the country seeks to become a major player in the global GH2 market as outlined in the South African Hydrogen Society Roadmap (DSI, 2021). Production of GH2 is still expensive due to electrolyser manufacturing costs; however, access to raw materials and competitive renewable energy resources will improve the business case for the localisation of the hydrogen value chain. South Africa is a major producer of platinum group metals (PGMs), critical materials in electrolyser manufacturing, such as platinum, iridium, and palladium[3]; which presents an opportunity for the localisation of electrolyser manufacturing.

The government supports energy efficiency initiatives, and these are recognised by businesses and individuals as a means of reducing electricity costs. Sector targets for energy efficiency, Energy Performance Certificate (EPC)[4] introduced by the government, and rising electricity costs provide the push and urgency to implement energy efficiency projects in all sectors of the economy. The government has introduced the allowance for Energy Efficiency (Income Tax Act 58 of 1962, Section 12L, 2019), which benefits implementers of energy efficiency projects. Multiple SMMEs have already found their footing in the EE market, paving the way for new entrants. Funding is also available for EE projects through the government and other entities such as the Sustainable Energy Fund for Africa[5], Agence Française de Développement (AFD) Green Energy Fund[6], among others. The carrying out of energy performance analyses is an opportunity on its own. Consultancy services that follow, such as recommending possible reduction techniques as well as design to improve thermal efficiency processes in the industrial sector, are other solutions that can be considered.

4.3.1.1 Circular energy materials opportunities

Recycling of end-of-life energy technologies is becoming critical, not only due to the increasing installation of new energy technologies, but also due to growing resource scarcity and access to critical raw materials that support manufacturing. In South Africa, recycling of electronic waste has been limited, with the State of Waste Report (DEA, 2018) reporting only a 9.7% WEEE recycling rate. In fact, this is usually only dismantling and pre-processing, with high value parts, e.g. printed circuit boards, extracted and exported for beneficiation overseas, resulting in the loss of these valuable resources to the South African economy (Lydall, 2017). Currently a few local companies, such as Reclite[7] and EWaste Africa[8], recycle solar panels (GreenCape, 2019). On a global scale, opportunities for recycling of solar panel components can recover raw materials - glass, aluminium, copper, silver and silicon - valued at US$450 million by 2030, rising to ~ US$15 billion by 2050 (PWC, 2020).

Recycling of batteries can recover nickel, manganese, lead, cobalt and lithium (Mishra *et al*., 2022). Current Li-ion battery waste generation rates in the country are currently insufficient to support a commercially viable recycling plan (Gericke *et al*., 2021). Residues from burning of coal are recycled by using fly ash in the manufacture of cement. Companies such as Cemblocks have produced bricks using ash since 1981 (Cemblocks, 2023). Recycling can also provide much needed additional jobs through its value chain. Although South Africa has recycling skills, critical requirements for more viable recycling businesses include improvements in technology, costs, and access to waste streams, and a supportive regulatory environment that recognises 'waste' as a secondary resource.

The circular design of new energy technologies takes place upstream in the value chain. South Africa has a few manufacturers of energy technologies including solar panels, batteries, wind turbines, and the structural and electrical balance of system (BOS). Most of the materials used in manufacturing are imported (SAPVIA, 2022; SAWEA, 2022). There may therefore be an opportunity to offset some (or all) of these imports with greater local resource recovery and return of these resources back into the local manufacturing economy. This will also support South Africa's balance of trade, driving greater local beneficiation, resource recovery, and employment. South Africa can select materials that can be easily recycled, disassembled, and repaired and less toxic to the environment. Furthermore, as demand for renewable energy technologies increases, the government is promoting manufacturing through Special Economic Zones (SEZs)[9] and local content thresholds for energy

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[3] Critical materials for electrolyser production: *PowerPoint-Präsentation (wasserstoff-kompass.de)*

[4] *Energy Performance Certificates – SANEDI*

[5] *Sustainable Energy Fund for Africa | African Development Bank - Building today, a better Africa tomorrow (afdb.org)*

[6] *AFD Green Energy Finances Renewable Energy Projects | IDC*

[7] *Reclite.co.za | Recycling Through Innovation*

[8] *Services and Solutions – EWaste Africa*

[9] South Africa's Special Economic Zones: *SEZ-brochure_2021.pdf (thedtic.gov.za)*

projects[10]. The country is also well positioned for exportation, also as a distribution hub (SAPVIA, 2022). These increase business opportunities for the circular design of energy technologies.

The increasing demand for energy technologies, government support through policies, SEZs, and threshold requirements, provide opportunities to promote material efficiency in manufacturing energy technologies. Importation of components is already being done locally, with South Africa also exporting some of the manufactured and imported RE components for solar PV, batteries, and wind. High efficiency products are becoming attractive due to increased energy generation and reduced costs of Balance of System components (BOS) and installation which benefit clients.

4.4 Potential for climate mitigation

As mentioned previously, South Africa was the 12th largest emitter of CO_2 in 2020. Domestically, CO_2 accounted for 81.7% of the country's GHG emissions, with the energy sector contributing 95.2% of these CO_2 emissions (DFFE, 2020). The implementation of CEIs in the energy sector can therefore have a significant impact on decarbonising the energy sector and mitigating climate change. Some of these interventions include:

- Decarbonising electricity generation through –
    - the deployment of renewables, mainly solar PV and onshore wind
    - the adoption of green hydrogen in hard-to-abate sectors such as transport, chemicals, etc.
- Reducing energy demand through –
    - Greater energy efficiency across South Africa's economic sectors
- Decarbonising the transport sector (fuels) through –
    - The adoption of public transport, rail freight transport and electric vehicles for last-mile
- Sustainable use of resources – including critical raw materials – in the development and deployment of clean energy technologies.

Modelling for GHG emissions and non-GHG effects has been carried out to quantify the climate mitigation potential of CEIs in South Africa (Padayachi *et al.*, 2023). The mitigation potential assessment provides a basis to understand the linkages and quantify the potential benefits between increased circularity and GHG emissions. The findings of the GHG emissions modelling can be synthesised as recommendations for the Nationally Determined Contribution (NDC) and Technology Needs Assessment (TNA). This may create opportunities to access climate finance to finance circular economy initiatives in the South African energy sector.

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[10] National Treasury's local production and content requirements for solar PV system and components: *KM_754e-20150630151326 (thedtic.gov.za)*

5 Conclusion

The circular economy is becoming an increasingly important concept in South Africa’s energy sector as the country seeks to transition to a more sustainable and efficient energy system. Circular economy principles are being applied to various aspects of the energy sector, from energy generation, distribution, consumption, and waste management. This study provides an overview of South Africa’s current energy sector development path and identifies circular economy interventions that can be adopted in the current and future energy sector in South Africa.

A total of 24 interventions were proposed and these were segmented into circular energy utility options and circular energy material options. The options that would have the most impact on the reduction of GHG emissions were largely considered. These interventions were sourced from a detailed desktop study. To gauge the appropriateness of these interventions, their readiness level, and current level of implementation in South Africa, primary data was sourced from industry experts through an online questionnaire and one-on-one interviews.

It can be concluded that the CEIs outlined in this study can benefit the South African energy sector and are appropriate for transitioning the sector to a circular economy. The results showed that amongst the circular energy utility interventions, renewable energy technologies such as solar PV and onshore wind, energy storage, energy efficiency solutions, and waste-to-energy solutions, were considered the most appropriate. Carbon capture use and storage (CCUS), and emissions prevention (clean coal technologies) were amongst the least appropriate options. Among the circular energy materials interventions, recycling of energy technologies, circular design of energy technologies, and materials efficiency in manufacturing of energy technologies had the highest agreement rates for appropriateness.

In terms of the energy sectors readiness to implement the proposed CEIs, renewable energy technologies (solar PV and onshore wind), energy storage, hydroelectric, and WtE were rated with the highest readiness level, while recycling of energy technologies and materials efficiency in manufacturing were considered by the industry as having lower levels of readiness to implement. The implementation of CCUS, green hydrogen, offshore wind, and electric vehicles were not considered to be ready for implementation by stakeholders. Within the circular energy materials interventions, designing for increased longevity, and repairing energy technologies were the interventions that stakeholders felt the energy sector was mostly ready to implement.

The degree to which respondents considered specific CEIs already implemented suggests that there is significant room to strengthen and scale these CEIs both in circular energy utility and circular energy materials, given that the majority of the responses were ‘partly implemented’ as opposed to ‘implemented (e.g., energy efficiency).

Based on data collected from the literature review and stakeholder input, business opportunities for the circular economy were identified. The implementation of large and small renewable energy systems (coupled with energy storage) is considered to be the most important intervention, and these value chains offer various business opportunities for the country. These interventions should also be considered within future plans for reindustrialisation in the country. Other business opportunities which are encouraged are recycling and implementation of energy efficiency interventions.

The study confirmed that overall adoption of circular economy principles in the energy sector can bring numerous benefits, including greater energy security, decarbonisation of South Africa’s economy, improved resource efficiency, increased competitiveness, and enhanced social and environmental sustainability. There is however a need for supportive policy frameworks, adequate financing mechanisms, and effective stakeholder engagement to ensure the successful implementation of CEIs in the energy sector, and most importantly decoupling economic development from energy usage and demand.

6 References

Adeleke, O., Akinlabi, S. A., Jen, T. C., and Dunmade, I. (2021). Sustainable utilization of energy from waste: A review of potentials and challenges of Waste-to-energy in South Africa. Available online at https://Doi.Org/10.1080/15435075.2021.1914629, 18(14), 1550–1564. https://doi.org/10.1080/15435075.2021.1914629

Assem, J., Thompson, M., Murphy, Q., and Nath, S. (2022). Opportunities for impact in desalination. Available online at *https://assets.bii.co.uk/wp-content/uploads/2022/12/27172548/Opportunities-for-impact-in-desalination_BII.pdf*

Botha, G. (2023). Guide for Municipalities on Processing Embedded Generator Applications 1 MW and Larger. Available online at *https://www.sseg.org.za/wp-content/uploads/2023/01/Guide-EG-1MW-and-Larger-Working-version-January-2023-6.pdf*

Cemblocks. (2023). We use ash in our cement bricks. Available online at *https://www.cemblocks.co.za/ash-bricks*

Chowdhury, M. S., Rahman, K. S., Chowdhury, T., Nuthammachot, N., Techato, K., Akhtaruzzaman, M., Tiong, S. K., Sopian, K., and Amin, N. (2020). An overview of solar photovoltaic panels' end-of-life material recycling. Energy Strategy Reviews, 27, 100431. Available online at *https://doi.org/10.1016/J.ESR.2019.100431*

Ciuła, J., Gaska, K., Generowicz, A., and Hajduga, G. (2018). Energy from Landfill Gas as an Example of Circular Economy. E3S Web of Conferences, 30, 03002. Available online at *https://doi.org/10.1051/E3SCONF/20183003002*

Climate Adaptation Science Centers. (2022, March 3). Biological Carbon Sequestration. USGS. Available online at *https://www.usgs.gov/media/images/biological-carbon-sequestration#:~:text=Biological%20carbon%20sequestration%20is%20the,or%20in%20extensive%20root%20systems*.

Coertzen, R., Potts, K., Brannock, M., and Dagg, B. (2020). Water for Hydrogen. GHD. Available online at *https://www.ghd.com/en/perspectives/water-for-hydrogen.aspx*

Craig, O. O., Brent, A. C., and Dinter, F. (2017). The current and future economics of concentrating solar power (CSP) in South Africa. South African Journal of Industrial Engineering, 28(3). Available online at *https://doi.org/http://dx.doi.org/10.7166/28-3-1835*

DFFE. (2020). GHG Inventory for South Africa: 2000 - 2020. Available online at *https://www.dffe.gov.za/sites/default/files/gazetted_notices/8thnational-greenhouse-gasinventory-reportg47133gon2321.pdf*

DMRE. (2019a). Integrated Resource Plan (IRP2019). Available online at *https://www.energy.gov.za/irp/2019/IRP-2019.pdf*

DMRE. (2019b). Energy Balances - 2019. Energy Statistics. Available online at *https://www.energy.gov.za/files/media/Energy_Balances.html*

DMRE. (2021). The South African Energy Sector Report 2021. Available online at *https://www.energy.gov.za/files/media/explained/2021-South-African-Energy-Sector-Report.pdf*

DSI. (2021). Hydrogen Society Roadmap for South Africa.

DWS. (2019). National Water and Sanitation Master Plan. Available online at *https://www.gov.za/sites/default/files/gcis_document/201911/national-water-and-sanitation-master-plandf.pdf*

EIA. (2022a). Country Analysis Executive Summary: South Africa. Available online at *https://www.eia.gov/international/content/analysis/countries_long/South_Africa/pdf/south_africa.pdf*

EIA. (2022b). South Africa - Total Energy. U.S. Energy Information Administration. Available online at *https://www.eia.gov/international/data/country/ZAF*

Ellen MacArthur Foundation. (2019). Completing the picture: How the circular economy tackles climate change. Available online at *https://circulareconomy.europa.eu/platform/sites/default/files/emf_completing_the_picture.pdf*

Enel Green Power. (2023). The Circular Economy. Available online at *https://www.enelgreenpower.com/learning-hub/sustainable-development/circular-economy*

EPA. (2022). Basic Information about Landfill Gas . Landfill Methane Outreach Program. Available online at *https://www.epa.gov/lmop/basic-information-about-landfill-gas*

Eskom. (2021a). Coal in South Africa - Factsheet. Available online at *https://www.eskom.co.za/wp-content/uploads/2021/08/CO-0007-Coal-in-SA-Rev-16.pdf*

Eskom. (2021b). Desalination at Lethabo Power Station. Available online at *https://www.eskom.co.za/wp-content/uploads/2021/08/CO-0001-Desalination-at-Lethabo-Power-Station-Rev-11.pdf*

Fraunhofer UMSICHT. (2017). End-of-Life Pathways For Photovoltaic Backsheets. Available online at *https://www.umsicht.fraunhofer.de/en/projects/photovoltaic-waste.html*

GBCSA. (2020). GETTING TO ZERO: A Guide To Developing Net Zero Carbon Buildings In South Africa. Available online at *https://gbcsa.org.za/wp-content/uploads/2020/08/Getting-to-Zero_2020.pdf*

Gericke, M., Nyanjowa, W., & Robertson, S. (2021). Technology landscape report and business case for the recycling of Li-ion batteries in South Africa. Available online at *https://wasteroadmap.co.za/wp-content/uploads/2021/05/30-Mintek-Final_Technical-report_LIB-plan.pdf*

GreenCape. (2019). Solar Panel Waste Workshop at the Century City Conference Centre. Available online at *https://green-cape.co.za/assets/Solar-Panel-Waste-Workshop-Report-5Mar2020.pdf*

GreenCape. (2023). 2023 Energy Services Market Intelligence Report. Available online at *https://green-cape.co.za/wp-content/uploads/2023/04/ES_MIR_2023_DIGITAL_SINGLES.pdf*

Hamon. (2023). Dry Cooling System. Available online at *https://www.hamon.com/9-dry-cooling-system/index.html*

Iberdrola. (2023). Desalination. Available online at *https://www.iberdrola.com/innovation/desalination#:~:text=Desalination%20is%20the%20process%20by,human%20consumption%20or%20agricultural%20purposes.*

IEA. (2018). The Future of Cooling. Available online at *https://iea.blob.core.windows.net/assets/0bb45525-277f-4c9c-8d0c-9c0cb5e7d525/The_Future_of_Cooling.pdf*

IEA. (2021a). About CCUS. Available online at *https://www.iea.org/reports/about-ccus*

IEA. (2021b). World Energy Balances: Overview. Available online at *https://www.iea.org/reports/world-energy-balances-overview*

IEA. (2022). Direct Air Capture: A key technology for net zero. Available online at *https://iea.blob.core.windows.net/assets/78633715-15c0-44e1-81df-41123c556d57/DirectAirCapture_Akeytechnologyfornetzero.pdf*

IPP Office. (2022). Independent Power Producer Programme (IPPP) - An Overview. Available online at *https://www.ipp-projects.co.za/Publications/GetPublicationFile?fileid=53c81924-e2e8-ed11-95a7-00505685662d&fileName=20230417_IPP%20Office%20Q3%20Overview%202022-23_Final.pdf*

IPP Office. (2021). REIPPPP Focus on Free State, Limpopo, North West, KwaZulu Natal, Mpumalanga and Gauteng Provinces. Available online at *https://www.ipp-projects.co.za/Publications/GetPublicationFile?fileid=870fdddd-6dc4-ec11-956e-2c59e59ac9cd&fileName=20220324_REIPPPP%20Provincial%20Report%20Vol4_Other_Dec%202021_vFINAL.PDF*

IRENA. (2020). Electricity Storage Valuation Framework: Assessing system value and ensuring project viability. Available online at *https://www.irena.org/publications/2020/Mar/Electricity-Storage-Valuation-Framework-2020*

ITA (International Trade Administration). (2021). South Africa Country Commercial Guide. Available online at *https://www.trade.gov/country-commercial-guides/south-africa-energy*

Joan Igamba. (2022, July 5). Water Crisis in South Africa. Greenpeace. Available online at *https://www.greenpeace.org/africa/en/blogs/51757/water-crisis-in-south-africa/*

Jones, E., Qadir, M., van Vliet, M. T. H., Smakhtin, V., and Kang, S. mu. (2019). The state of desalination and brine production: A global outlook. Science of The Total Environment, 657, 1343–1356. Available online at *https://doi.org/10.1016/J.SCITOTENV.2018.12.076*

Kane, M. K., and Gil, S. (2022, June 23). Green Hydrogen: A key investment for the energy transition. World Bank Blogs. Available online at *https://blogs.worldbank.org/ppps/green-hydrogen-key-investment-energy-transition*

KAPSARC. (2020). CCE Guide Overview: A guide to the circular carbon economy (CCE) (C. Allen, Ed.). KAPSARC.

Kobashi, T., Choi, Y., Hirano, Y., Yamagata, Y., and Say, K. (2022). Rapid rise of decarbonization potentials of photovoltaics plus electric vehicles in residential houses over commercial districts. *Applied Energy*, 306, 118142. Available online at *https://doi.org/10.1016/J.APENERGY.2021.118142*

L. Inambao, F. and Cunden, K. (2019). Offshore Wind Resource Assessment off the South African Coastline. International Journal of Mechanical Engineering and Technology, 10(6), 95–119. Available online at *https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3451105*

Li, J., Zhuang, X., Querol, X., Font, O. and Moreno, N. (2017). A review on the applications of coal combustion products in China. *Int. Geol. Rev*. 60 (5-6). *https://doi.org/10.1080/00206814.2017.1309997*

Lyons, M., Durrant, P. and Kochhar, K. (2021). Reaching Zero with Renewables: Capturing carbon. Available online at *www.irena.org*

Minerals Council of South Africa. (2023). Mining in SA - Coal. Available online at *https://www.mineralscouncil.org.za/sa-mining/coal*

Mishra, G., Jha, R., Meshram, A. and K. Singh, K. (2022). A review on recycling lithium-ion batteries to recover critical metals. Journal of Environmental Chemical Engineering, 10(6). Available online at *https://doi.org/https://doi.org/10.1016/j.jece.2022.108534.*

Msimanga, X., Godfrey, L. and North, B. (2021). Decoupling South Africa's development from energy demand through a more circular economy (No. 7; 8). Available online at *https://www.circulareconomy.co.za/wp-content/uploads/2021/11/7.-Energy_CE-Briefing-Note.pdf*

NAAMSA. (2022). Quarterly review of business conditions: New motor vehicle manufacturing industry/automotive sector.

Nadel, S. and Ungar, L. (2019). Halfway There: Energy Efficiency Can Cut Energy Use and Greenhouse Gas Emissions in Half by 2050. Available online at *https://www.aceee.org/sites/default/files/publications/researchreports/u1907.pdf*

National Treasury. (2023). Frequently Asked Questions - Solar Panel Tax Incentives for Individuals. In 2023 Budget. National Treasury.

Newborough, M. and Cooley, G. (2021). Water savings from green hydrogen. Available online at *https://itm-power-assets.s3.eu-west-2.amazonaws.com/Green_Hydrogen_Water_Use_56b96f577d.pdf*

NREL. (2022). Interactive Best Research-Cell Efficiency Chart. Photovoltaic Research. Available online at *https://www.nrel.gov/pv/interactive-cell-efficiency.html*

Ong, S., Campbell, C., Denholm, P., Margolis, R. and Heath, G. (2013). Land-use requirements for solar power plants in the United States. Available online at *https://www.nrel.gov/docs/fy13osti/56290.pdf*

Our World in Data. (2019). Greenhouse gas emissions by sector, South Africa, 2019. Available online at *https://ourworldindata.org/grapher/ghg-emissions-by-sector?time=latest&country=~ZAF*

Pierce, W., & Le Roux, M. (2023). Statistics of utility-scale power generation in South Africa. Available online at *https://www.csir.co.za/sites/default/files/Documents/Statistics%20of%20power%20in%20SA%202022-CSIR-%5BFINAL%5D.pdf*

Pražanová, A., Knap, V. and Stroe, D. I. (2022). Literature Review, Recycling of Lithium-Ion Batteries from Electric Vehicles, Part II: Environmental and Economic Perspective. Energies 2022, 15(19), 7356. Available online at *https://doi.org/10.3390/EN15197356*

PWC. (2020). Taking on tomorrow: The rise of circularity in energy, utilities and resources. Available online at *www.pwc.com/circularity*

Radavičius, T., Van Der Heide, A., Palitzsch, W., Rommens, T., Denafas, J. and Tvaronavičienė, M. (2021). Circular solar industry chain through technological design changes. Insights into Regional Development, 3(3), 10–30. Available online at *https://doi.org/10.9770/IRD.2021.3.3(1)*

Rahimi, M. (2021). Lithium-ion batteries: Latest advances and prospects. Batteries, 7(1), 1–4. Available online at *https://doi.org/10.3390/BATTERIES7010008*

Reuters. (2021, August 23). South Africa aims to bring pilot carbon capture project online in 2023. Creamer's Engineering News. Available online at *https://www.engineeringnews.co.za/article/south-africa-aims-to-bring-pilot-carbon-capture-project-online-in-2023-2021-08-23/rep_id:4136*

Sangha, I. (2022, August 25). Understanding BESS revenue stacking. Modo. Available online at *https://blog.modo.energy/understanding-bess-revenue-stacking*

SAPVIA. (2022). The Localisation Potential of the South African Solar Photovoltaic (PV) Industry and Recommendations to Support Local Manufacturing in South Africa.

Income Tax Act 58 of 1962, Section 12L, (2019) (testimony of SARS). Available online at *https://www.sars.gov.za/wp-content/uploads/Legal/Notes/LAPD-IntR-IN-2017-01-IN95-Deduction-for-energy-efficiency-savings.pdf*

SARS. (2023). Budget 2023 Tax Guide. South African Revenue Services. Available online at *https://www.sars.gov.za/wp-content/uploads/Docs/Budget/2023/Budget-2023-Tax-Guide.pdf*

Sasol. (2021, October 6). Sasol announces lead role in feasibility study for the Boegoebaai Green Hydrogen project. Available online at *https://www.sasol.com/media-centre/media-releases/sasol-announces-lead-role-feasibility-study-boegoebaai-green-hydrogen-project*

SAWEA. (2022, September 22). IDC Explore Wind Sector Industrialisation. Available online at *https://sawea.org.za/idc-explore-wind-sector-industrialisation/*

SAWEA. (2023, January 23). Wind body wants independent assessment of grid constraints in Cape provinces after shovel-ready projects are frozen out. SAWEA News. Available online at *https://sawea.org.za/wind-body-wants-independent-assessment-of-grid-constraints-in-cape-provinces-after-shovel-ready-projects-are-frozen-out/*

Shongwe, B. N. (2018). The impact of coal mining on the environment and community quality of life: A case study investigation of the impacts and conflicts associated with coal mining in the Mpumalanga Province, South Africa [Masters Thesis/Dissertation, University of Cape Town]. Available online at *https://open.uct.ac.za/handle/11427/28127*

Siemens Gamesa. (2022). Commanding circularity: Siemens Gamesa announces Recyclable Blade for onshore wind power projects. Available online at *www.siemensgamesa.com*

Singh, A. K., Srivastava, S., Mahapatra, A., Baral, J. K. and Pradhan, B. (2021). Performance optimization of lead free-MASnI3 based solar cell with 27% efficiency by numerical simulation. Optical Materials, 117. Available online at *https://doi.org/10.1016/j.optmat.2021.111193*

SSEG Municipal Resource Portal. (2023). SSEG-FAQ. Small-Scale Embedded Generation (SSEG) Municipal Resource Portal. Available online at *https://www.sseg.org.za/faq/*

Tanigawa, S. (2017). Fact Sheet | Biogas: Converting Waste to Energy. Available online at *https://www.eesi.org/papers/view/fact-sheet-biogasconverting-waste-to-energy*

TIPS and WWF. (2022). Insights into the Wind Energy Value Chain in South Africa. Available online at *https://www.tips.org.za/research-archive/sustainable-growth/green-economy-2/item/4442-insights-into-the-wind-energy-value-chain-in-south-africa*

Tokollo Matsabu (2022, May 16). The "Fuel of the Future" and Water Insecurity in South Africa's Platinum Belt. New Security Beat. Available online at *https://www.newsecuritybeat.org/2022/05/fuel-future-water-insecurity-south-africas-platinum-belt/*

Walston, L. J., Barley, T., Bhandari, I., Campbell, B., McCall, J., Hartmann, H. M. and Dolezal, A. G. (2022). Opportunities for agrivoltaic systems to achieve synergistic food-energy-environmental needs and address sustainability goals. Frontiers in Sustainable Food Systems, 6, 374. Available online at *https://doi.org/10.3389/FSUFS.2022.932018/BIBTEX*

West, E. (2022, October 9). Renewable energy, already ‘booming’ in South Africa, will require much more investment. IOL. Available online at *https://www.iol.co.za/business-report/companies/renewable-energy-already-booming-in-south-africa-will-require-much-more-investment-5851e5bb-e7a1-4b82-8b17-8a373cd0193a*

World Coal Association. (2021). Clean Coal Technology in ASEAN. Available online at *https://mcusercontent.com/c35475364a541a1bdee7dc50b/files/41eab407-db3a-900c-6656-f47dd2cec035/WCA_ACE_Clean_Coal_Technology_in_ASEAN_Report.pdf*

Wright, J. and Calitz, J. (2020). Systems analysis to support increasingly ambitious CO_2 emissions scenarios in the South African electricity system.

Yanamandra, K., Pinisetty, D., Daoud, A. and Gupta, N. (2022). Recycling of Li-Ion and Lead Acid Batteries: A Review. Journal of the Indian Institute of Science, 102(1), 281–295. Available online at *https://doi.org/10.1007/S41745-021-00269-7/TABLES/5*

Appendix 1: Survey questionnaire

Circular Economy Interventions for the South African Energy Sector

Dear Participant

You have been selected as a suitable candidate for this survey based on your current (or previous) role within the energy industry. The aims of the survey are to assess the suitability of proposed circular economy interventions for the South African energy Sector, and the readiness of the sector in adopting these interventions. You are kindly requested to complete the questionnaire based on your knowledge and experience regarding circular economy practice within the energy sector and related industries. The information provided will remain completely confidential and the anonymity of respondents will be retained indefinitely. Based on your specific response, we may contact you directly for further discussions and possible participation in ongoing or future sustainability related projects within the CSIR.

The survey should take about 15-20 minutes to complete.

PART 1: DEMOGRAPHICS/PROFILE

In this section, we would like to request information about your company/organization

1.1. Please indicate which energy sub-sector you are currently active in

Energy Sub-Sector	Select One
Power generation	
Electricity distribution	
Large scale renewable energy	
Small scale renewable energy	
Energy storage	
Synthetic fuels	
Gas	
Bioenergy	
Green hydrogen	

Energy Sub-Sector	Select One
Energy Efficiency	
Policy development	
Regulation	
Waste to energy	
Waste to electricity	
Waste to building material	
Carbon Capture, Usage and Storage	
Repair and recycle of energy technologies	
Other	

If other, please specify: ___________________________

1.2. Please select the category to which your organization belongs.

Type of organisation	Private sector	Government	Labour	Research Institutions	Other

If other, please specify: ___________________________

1.2. How many years of experience do you have working in the South African energy sector?

Sectoral Experience	< 1 year	1 – 2 years	3 – 4 years	5 – 10 years	>10 years

1.3. Please indicate your main level of responsibility within your organization?

Leve of Responsibility	Select One
Executive	
Senior Management	
Project Management	
Engineer/Technical	

Leve of Responsibility	Select One
R&D	
Finance	
Other	

If other selected, please specify: ___________________________

PART 2: CIRCULAR ECONOMY EXPERIENCE

Circular economy interventions can broadly be categorised under three principles: (i) designing out waste and pollution; (ii) keeping materials and products in use, and (iii) regenerating natural systems. This survey seeks to appraise a number of proposed circular economy interventions for the South African energy sector.

2.1. Please rate your personal knowledge of the Circular Economy (CE)

CE Knowledge	None	Novice	Working	Good	Excellent

2.2. Are you currently (or have previously been) involved in Circular Economy related projects and/or interventions?

☐ Yes ☐ No

2.3. How many years of experience do you have with Circular Economy (CE) related projects?

CE Involvement	< 1 year	1 – 2 years	3 – 4 years	5 – 10 years	>10 years

2.4. Please elaborate on any Circular Economy related projects you are or have been involved in.

1. ______________
2. ______________

2.5. Is your company affiliated with any Circular Economy related organizations, e.g. African Circular Economy Network (ACEN), Ellen McArthur Foundation, WEF, SA Plastics Pact, etc?

☐ Yes ☐ No

Please provide details of any such affiliations below.

1. ______________
2. ______________

PART 3: PROPOSED CIRCULAR ECONOMY INTERVENTIONS

In this section, we would like to assess the following:

- whether you agree with the proposed Circular Economy interventions,
- your personal views regarding key interventions to be implemented or scaled, and
- some of the challenges/barriers to the implementation of Circular Economy activities within the South African energy sector

Based on your personal knowledge and experience with the Circular Economy, please provide responses to the following questions or statements.

3.1. Which of the following Circular Economy Interventions are you familiar with?

Circular economy interventions	Unfamiliar	Partly Familiar	Familiar	Very Familiar
Energy utility (generation and use)				
• Agri-voltaics				
• Carbon capture use and storage (CCUS)				
• Electric vehicles				
• Energy-based industrial symbiosis				
• Energy efficiency (demand management)				
• Fly ash valorisation				
• Green hydrogen				
• Renewable energy (RE)				
• Waste gas and emission prevention				
• Waste gas and heat valorisation				
• Waste-to-energy (bio-energy, AD)				
• Waste-to-energy (thermal)				
Energy materials (equipment, technology)				
• Circular design of energy technologies				
• Increasing energy technology lifespans (durability)				
• Materials efficiency in manufacturing energy technologies				
• Recycling of energy technologies (resource recovery)				
• Repair energy technologies (repurposing)				
• Other				

3.2. To what extent do you agree that the following Circular Economy interventions can benefit the South African energy sector?

Circular economy interventions	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Energy utility (generation and use)					
• Agri-voltaics					
• Carbon capture use and storage (CCUS)					
• Electric vehicles					
• Energy-based industrial symbiosis					
• Energy efficiency (demand management)					
• Fly ash valorisation					
• Green hydrogen					
• Renewable energy (RE)					
• Waste gas and emission prevention					
• Waste gas and heat valorisation					
• Waste-to-energy (bio-energy, AD)					
• Waste-to-energy (thermal)					
Energy materials (equipment, technology)					
• Circular design of energy technologies					
• Increasing energy technology lifespans (durability)					
• Materials efficiency in manufacturing energy technologies					
• Recycling of energy technologies (resource recovery)					
• Repair energy technologies (repurposing)					
• Other					

3.3. The South African energy sector needs Circular Economy interventions to improve resilience and competitiveness of the sector

Your Rating	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

3.4. The implementation of Circular Economy interventions within the South African energy sector would lead to inclusive growth and decent jobs

Your Rating	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

3.5. The implementation of circular economy interventions within the South African energy sector could mitigate environmental pollution

Your Rating	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

3.6. The South African energy sector is strongly dependent on access to resources (e.g., energy, water, materials)

Your Rating	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

3.7. The South African energy sector is adversely affected by the export of unbeneficiated raw materials

Your Rating	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

3.9. The SA energy sector has a good understanding of what the Circular Economy is and the potential benefits for the sector

Your Rating	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

3.10. How would you rate the South African energy sector in terms of readiness towards implementing the proposed Circular Economy interventions listed below

Circular economy interventions	Not Ready	Partly Ready	Ready
Energy utility (generation and use)			
• Agri-voltaics			
• Carbon capture use and storage (CCUS)			
• Electric vehicles			
• Energy-based industrial symbiosis			
• Energy efficiency (demand management)			
• Fly ash valorisation			
• Green hydrogen			
• Renewable energy (RE)			
• Waste gas and emission prevention			
• Waste gas and heat valorisation			
• Waste-to-energy (bio-energy, AD)			
Energy materials (equipment, technology)			
• Circular design of energy technologies			
• Increasing energy technology lifespans (durability)			
• Materials efficiency in manufacturing energy technologies			
• Recycling of energy technologies (resource recovery)			
• Repair energy technologies (repurposing)			
• Other			

Please elaborate on your response above, particularly where you consider the sector is **not ready** _____________

3.11. Which of the listed Circular Economy interventions would you say are already being implemented within the South African energy sector or broader economy?

Circular economy interventions	Not Implemented	Partly Implemented	Implemented
Energy utility (generation and use)			
• Agri-voltaics			
• Carbon capture use and storage (CCUS)			
• Electric vehicles			
• Energy-based industrial symbiosis			
• Energy efficiency (demand management)			
• Fly ash valorisation			
• Green hydrogen			
• Renewable energy (RE)			
• Waste gas and emission prevention			
• Waste gas and heat valorisation			
• Waste-to-energy (bio-energy, AD)			
Energy materials (equipment, technology)			
• Circular design of energy technologies			
• Increasing energy technology lifespans (durability)			
• Materials efficiency in manufacturing energy technologies			
• Recycling of energy technologies (resource recovery)			
• Repair energy technologies (repurposing)			
• Other			

Please elaborate on your responses above, particularly where you consider any of these interventions are **already implemented** ________________

3.12. Are there other interventions you consider important that may have been omitted? Please elaborate ___________________

3.13. What would you consider are the main obstacles towards the implementation of the proposed Circular Economy interventions for the South African energy sector?
Please list possible obstacles _____________________

3.14. Please provide any additional information you consider relevant to the implementation of the Circular Economy within the South African energy sector ________________________________

3.15. Would you be willing to be interviewed (if needed) to discuss the above issues in further detail?
☐ Yes ☐ No

Thank you for your participation in this questionnaire, your insights are highly valued!

Privacy Statement

- This privacy statement will inform you what the CSIR will do with the Personal Information it collects from you and which you voluntarily provide to the CSIR, it also indicates your rights as a data subject.
- The Personal Information required for this study is strictly the name of your organization, email address and telephone number.
- The CSIR will use such Personal Information only for purposes of further engagements with you, based on outcomes of the study, and to share any relevant innovation & technology developments in its portfolio.
- You may opt-out of sharing your Personal Information and still be able to continue with the study anonymously.
- Data collected is strictly for the CSIR's internal use and will not be shared nor transferred to any third parties.

Read more ***click here***

- ● Yes I want to participate
- ○ No thank you, I do not want to participate