Green Technologies Stocktake Study

Final Report

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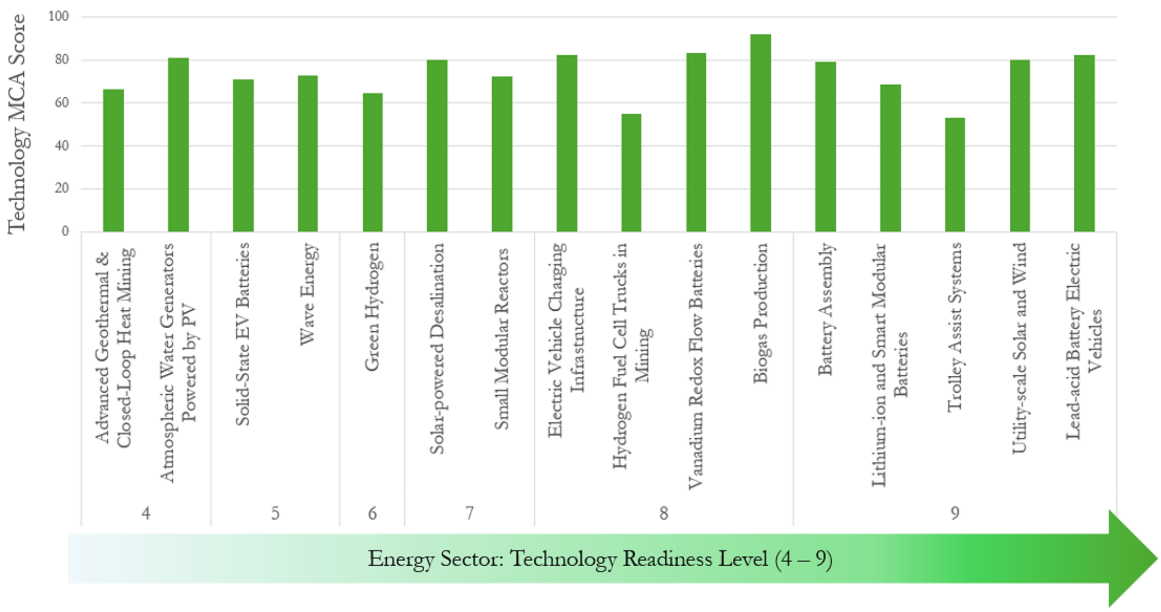
Executive Summary

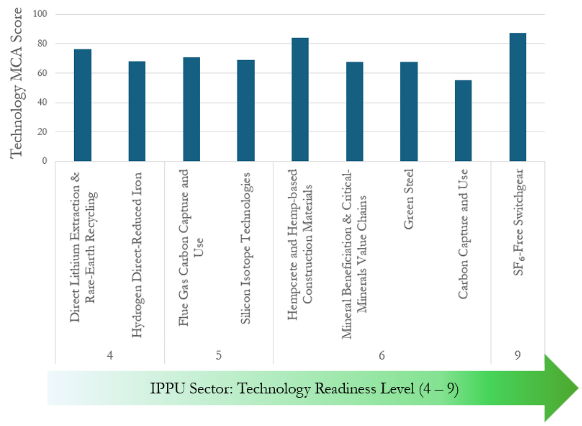
South Africa's transition to a low-carbon, climate-resilient economy demands not only accelerated deployment of commercially ready solutions but also strategic investment in emerging technologies that can bridge the gap between current trajectories and national climate commitments. The **Green Technologies Stocktake Study**, commissioned by the Technology Innovation Agency (TIA) in collaboration with the Presidential Climate Commission (PCC), provides a comprehensive mapping and prioritisation of low-carbon and climate-resilient technologies across the energy, industry, transport, agriculture, water, and waste sectors.

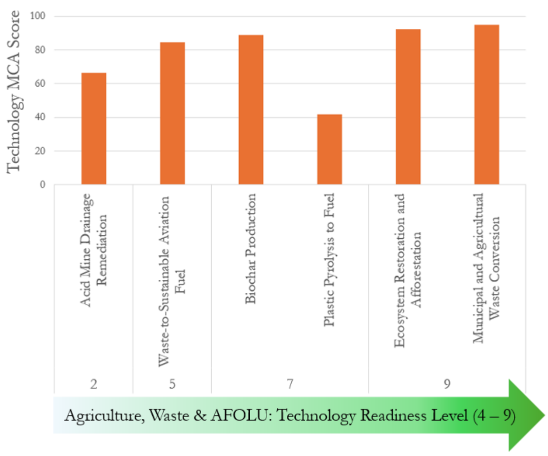
The study builds on the PCC's sectoral pathways for achieving South Africa's 2030–2035 Nationally Determined Contribution (NDC) targets and supports the country's broader Just Transition goals, ensuring that climate action delivers environmental sustainability, social equity, and economic resilience. It aligns with the Department of Science and Innovation's Decadal Plan, which identifies **energy innovation**, **climate change and environmental sustainability**, and **the circular economy** as national priorities.

The technology prioritisation process was underpinned by a Multi-Criteria Analysis (MCA), scoring each technology against climate impact (mitigation and adaptation), environmental benefits, Just Transition alignment, technology readiness, policy alignment, commercial viability, infrastructure requirements, and adoption risks. These criteria were weighted to reflect mitigation and adaptation priorities, with scores normalised for cross-sector comparability. Inputs included an extensive stakeholder survey, semi-structured interviews, and a detailed desktop review.

The MCA identified priority technologies at Technology Readiness Levels (TRL) 4–9 as shown in the figures below, ranging from advanced R&D through to operational commercial systems. These span mature solutions ready for rapid scaling, and promising innovations requiring targeted support to reach market readiness.







Other key findings from the study showed the following:

Strong existing capacity in certain niches: South Africa has global-competitive R&D and early commercial capabilities. The strongest near-term solutions are in the Energy sector, where EV charging infrastructure stand out for both readiness and performance, and battery assembly and long-duration storage via vanadium redox-flow batteries also indicate strong deployment and localisation potential. In the IPPU sector, SF_6-free switchgear could offer meaningful contributions, while in the Agriculture, Waste and AFOLU sectors, ecosystem technologies and waste-to-energy conversion indicate scalable mitigation and Just Transition benefits.

Slow scaling of commercially viable solutions: Mature low-carbon technologies such as utility-scale renewables, electric vehicles, and industrial energy efficiency remain under-deployed due to policy delays, infrastructure constraints, and limited local manufacturing.

Localisation opportunities: Critical minerals beneficiation, EV assembly, green hydrogen equipment, and battery manufacturing represent significant industrialisation and job creation opportunities if aligned with clear policy and demand signals.

Persistent innovation system gaps: R&D investment in green technologies remains below global peers; the "valley of death" between prototype and commercialisation remains a major barrier; and regulatory incentives for adoption are inconsistent.

Just Transition imperative: Technologies that deliver both decarbonisation and socio-economic benefits, such as distributed renewable energy, sustainable transport, and ecosystem restoration, should be prioritised to ensure equitable climate action.

To address systemic gaps, the study recommends that TIA lead the development of a **Climate Change Technology Innovation Programme** or **Roadmap**. This programme should:

- Define a **10 to 15 year mission-driven portfolio** of priority technologies to support South Africa's Nationally Determined Contribution and Just Transition.
- Integrate **R&D, demonstration, commercialisation, and localisation** support into a single, coordinated framework.

- Pool funding from national departments, development finance institutions, and international climate funds, targeting both mature deployment-ready technologies and high-impact **emerging innovations**.
- Embed **Just Transition principles**, ensuring community benefits, skills development, and economic diversification.

The Green Technologies Stocktake confirms that South Africa has notable strengths in certain green technology domains, while other areas remain underdeveloped and require targeted support. The current technology base offers significant potential to accelerate decarbonisation, strengthen climate resilience, and build a competitive green industrial economy.

The adoption of a dedicated Climate Technology Innovation Programme, supported by targeted investment, policy alignment, and coordinated implementation, remain important for realising this potential and meeting the dual imperatives of climate action and socio-economic transformation.

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1 Introduction

1.1 Project Background

The Technology Innovation Agency (TIA) is instrumental in driving technological innovation to spur economic growth and improve the quality of life in South Africa, particularly through the development and commercialization of innovations and public-funded intellectual property. TIA's efforts in fostering grassroots innovation and supporting small and medium enterprises and cooperatives, especially those owned by marginalized groups, align with the Sustainable Development Goals.

The Presidential Climate Commission (PCC) is South Africa's statutory multi-stakeholder advisory body on climate change, established by the Climate Change Act 22 of 2024. The Act provides that, once listed as a Schedule 3 public entity under the Public Finance Management Act, 1999 PFMA, the PCC is independent and has full juristic capacity; it is chaired by the President and may include not more than 25 commissioners representing government, organised labour, business, civil society, traditional leaders and South African Local Government Association. Its functions are to advise on the national climate change response strategies, including mitigation and adaptation, and on socio-economic matters related to the just transition. The PCC may establish committees to support this work, and must submit its reports to the National Assembly and affected Ministers. The PCC also adopted South Africa's Just Transition Framework in 2022, which sets principles and priority actions for a people-centred just transition.

TIA, in collaboration with the PCC, is addressing climate change and aiding the transition to a low-carbon, climate-resilient economy. Promethium Carbon has accordingly been appointed to assist in the development of a Green Technologies Stocktake Study for TIA and the PCC, with the aim of mapping South Africa's low-carbon technologies, identifying gaps, and guiding strategic investments towards achieving Just Transition goals. These goals go beyond the singular focus of the Just Energy Transition, promoting not only environmental sustainability but also social equity and economic resilience. This study highlights South Africa's commitment to leveraging technological innovation for sustainable development and positioning the country as a leader in global climate change efforts.

The purpose of this initiative is rooted in the global commitment of the 2015 Paris Agreement to limit the rise in global temperature to 1.5°C above pre-industrial levels. Despite some advancements, the global response to climate change remains insufficient, marked by a lack of urgency as we face escalating extreme weather events and biodiversity loss. The implications of surpassing the 1.5°C threshold are profound, with the Intergovernmental Panel on Climate Change (IPCC) highlighting the inevitability of increased climate hazards and risks to both ecosystems and human health. In response, the Department of Science and Innovation's (DSI's) Decadal Plan, aligning with the White Paper on Science, Technology, and Innovation, underscores the critical role of innovation in fostering inclusive and sustainable development within the evolving global context.

This plan positions science, technology, and innovation at the heart of South Africa's socio-economic growth, aiming to address poverty, inequality, and unemployment while safeguarding the environment. Recognizing the complexity of transitioning to a climate-resilient and low-carbon economy, this initiative advocates for a holistic approach that transcends a singular focus on energy. It calls for addressing interconnected challenges across all sectors of the economy to ensure a comprehensive and effective Just Transition.

The Decadal Plan identifies three key priorities essential for steering South Africa towards a sustainable future: **Energy Innovation**, which emphasizes the development of sustainable energy solutions to enhance energy efficiency and security; the **Societal Grand Challenge of Climate Change and Environmental Sustainability**, focusing on strategies and technologies to mitigate climate impacts and promote ecological balance; and the **Circular Economy** as a new source of growth, advocating for a regenerative economic model that minimizes waste and maximizes **resource efficiency**.

The PCC's recommendations for the updated 2030 – 2035 Nationally Determined Contributions (NDC) furthermore provide sectoral analysis of South Africa's mitigation potential and recommended pathways towards carbon neutrality, with quantified contribution ranges covering energy, industry, transport, agriculture, and waste. These pathways emphasise the accelerated deployment of commercially ready low-carbon technologies, complemented by targeted innovation in emerging solutions, to close the gap between current trajectories and the country's stated climate objectives. Aligning green technologies with these pathways can ensure that deployment-ready technologies are grounded in a credible, evidence-based vision for South Africa's transition.

These interconnected priorities collectively aim to drive inclusive growth, environmental conservation, and resilience against climate adversities, laying the foundation for a prosperous and sustainable future for South Africa.

In this context, a comprehensive Green Technologies Stocktake has been undertaken with the following objectives, where **Green Technologies** refer to products, services, and processes that use renewable materials or energy sources to reduce emissions and negative environmental impacts, improve resource efficiency, and support sustainable development. Green technologies are designed to mitigate climate change, enhance resilience, or enable low-carbon economic transitions across sectors.

1.1.1 Objective 1

Conduct an in-depth analysis of South Africa's current landscape in low-carbon and climate-resilient technologies. This objective aims to identify existing strengths and pinpoint areas where targeted research and investment could significantly enhance the nation's capacity for technological innovation. The goal is to support South Africa's transition towards a sustainable, low-carbon economy by providing a detailed mapping of the country's technological ecosystem, particularly in the context of a Just Transition.

1.1.2 Objective 2

Identify and assess South Africa's advanced-stage technologies in the realms of low carbon and climate resilience. The focus is on technologies that are nearing commercial viability and have the potential for localization and widespread implementation. This objective aims to spotlight innovations critical to transitioning South Africa towards an environmentally sustainable and economically sound future, while also exploring the integration of these technologies within the country's industrial landscape, with a strong emphasis on the principles of a Just Transition.

Data collection included an online survey distributed to stakeholders across the green economy value chain, semi-structured interviews with key stakeholders from government, industry, the private sector (including technology implementers and developers), and academia. These were complemented by extensive desktop research of active technology providers and sector-specific data sources.

1.2 Multi Criteria Analysis

The next phase of the project entailed a multi criteria analysis (MCA) of the technologies identified and discussed in this report. The MCA involves scoring of indicators associated with each criterion. The table below provide the criteria that each identified technology will be assessed against.

Criteria	Definition
Mitigation	The technology's capacity to **reduce or sequester** greenhouse gas (**GHG**) emissions.
Adaptation	The ability to adjust or respond to actual or expected climate change and its effects to **moderate harm** or take advantage of beneficial **opportunities**. **Resilience** against the impacts of climate change.
Environmental Impact	The positive or negative effects that a technology has on the natural environment throughout its life cycle, including how it uses **resources** and manages **waste**.
Just Transition Support	The extent to which a green technology contributes to a **fair, inclusive, and socially equitable** shift towards a low-carbon economy.
Technical Readiness Level (TRL)	The NASA's Technology Readiness Level (TRL) scale from **TRL 1 to TRL 9,** indicating how close technology is to full commercial deployment. • TRL 1 Basic principles observed • TRL 2 Concept formulated • TRL 3 Experimental proof of concept • TRL 4 Validated in laboratory environment • TRL 5 Validated in relevant environment • TRL 6 Prototype demonstrated in relevant environment • TRL 7 Prototype demonstration in operational environment • TRL 8 Actual system completed and qualified through testing • TRL 9 Actual system proven in operational environment

Policy and Regulatory Alignment	The extent to which a technology **aligns** with South Africa's **national climate, energy, and sustainability policies**, including any existing or anticipated **regulatory enablers** or **barriers** to its deployment.
Commercial Viability	The potential of a technology to **deliver financial returns** through favourable capital and operational cost dynamics, making it **attractive for investment**.
Infrastructure Requirements	The **compatibility** of a technology with **existing infrastructure** and the extent of new infrastructure needed to support its implementation, considering system **readiness for green industrialisation** across key sectors.
Adoption Risks	The potential barriers to technology uptake, including technical uncertainties, **stakeholder resistance**, **societal acceptance**, and global developments that may impact its feasibility in the South African context.

Some criteria are more prioritised than others. Accordingly, each criterion is weighted, with the weighting applied to the overall score from the scoring indicators, ensuring a standardised outcome for comparison between technologies where criteria have different levels of importance. The weighting of criteria will be confirmed in consultation with TIA and the PCC. Two scenarios of weighting will be analysed – a mitigation-focussed weighting, versus an adaptation-focussed weighting.

The final stage compiles the results of the assessment and translates them into actionable outputs: a list of priority technologies that serves as guidance for TIA to further explore, develop, or support, depending on their specific needs and strategic objectives.

1.3 Mapping Technology Priorities for South Africa's Climate Future

The final deliverable of this project culminates in this report. This report should be read in conjunction with three key complementary documents: the Mid-Term Report, Literature Review Report, and the full Multi-Criteria Analysis (MCA) output. The Mid-Term Report provides the foundational analysis of South Africa's low-carbon and climate-resilient technology landscape, including an assessment of enablers and barriers, sectoral trends, and initial findings that shaped the prioritisation process.

The full MCA output offers a detailed account of how technologies were assessed and ranked against five criteria: climate impact, commercial viability, technology readiness, Just Transition potential, and alignment with national policy objectives.

This report offers the output of the MCA and the various interviews and surveys conducted over the span of the project. The MCA and this report assess and rank low-carbon and climate-resilient technologies based on their climate impact, commercial viability, technology readiness, Just Transition potential, and alignment with South African policy objectives.

This MCA draws on the insights presented in the Mid-Term Report, including both mature and emerging technologies across multiple sectors. The analysis offers a transparent and evidence-based prioritisation framework to guide future support for green innovation in South Africa. This report integrates insights from stakeholder interviews and survey responses to strengthen the contextual relevance of prioritisation, ensuring selected technologies align with both national development objectives and the practical realities of implementation.

The MCA results aim to inform the strategic targeting of future support interventions, including areas for deepened research, demonstration, policy reform, or financing, while identifying opportunities to scale local innovations that have regional export or systems integration potential. The full MCA is available on request as a separate full deliverable, however, an overview table of the outcome can be found in Appendix A.

1.4 South Africa's Green Technology Context

South Africa faces the dual challenge of reducing GHG emissions (mitigation) and adapting to the impacts of climate change (adaptation) while pursuing economic development. As a coal-dependent economy and Africa's largest emitter, South Africa's transition to a low-carbon, climate-resilient path is critical. The country is a signatory to the Paris Agreement and has committed to ambitious targets in its Nationally Determined Contribution (NDC). Achieving these goals will require widespread deployment of low-carbon technologies (to cut emissions in sectors like energy, transport, industry, and buildings) and climate-resilient technologies (to adapt agriculture, water, infrastructure, and communities to a changing climate). This report provides a comprehensive mapping of South Africa's current technological landscape in this arena, identifies gaps in research, innovation and investment, and highlights opportunities and interventions to accelerate technological innovation, localization and deployment. Primary focus is given to South Africa, with contextual comparisons to international trends where relevant.

Policy context: South Africa's policy framework recognizes the central role of technology in climate action. The National Climate Change Response Policy (NCCRP) of 2011 and the National Development Plan 2030 emphasize transitioning to a low-carbon economy and enhancing resilience. More recently, the government's Just Energy Transition Investment Plan (JET IP) (2022)[1] outlines priority sectors for decarbonization (electricity, new energy vehicles (NEVs) and green hydrogen) and securing finance for a just transition. The JET IP stresses that South Africa can simultaneously tackle climate change and socio-economic challenges if it leverages the transition to create new industries and jobs. At COP26, an $8.5 billion Just Energy Transition partnership was announced to support South Africa – a significant step, though far below the estimated ~$98 billion needed to meet the lower-bound NDC target.[2] On adaptation, South Africa formulated a National Climate Change Adaptation Strategy (NCCAS) in 2020 and submitted its first Adaptation Communication (2021), which outline priority adaptation interventions (water,

[1] https://justenergytransition.co.za/wp-content/uploads/2024/10/South-Africas-Just-Energy-Transition-Investment-Plan-JET-IP-2023-2027-FINAL-1.pdf

[2] https://jthub.nbi.org.za/stay-informed/news/2021/south-africa-needs-to-commit-to-transitioning-to-net-zero-by-2050-report

agriculture, disaster risk reduction, health, etc.).[3,4] These policies provide an enabling framework, but implementation depends on available technologies and innovation.

Defining low-carbon and climate-resilient technologies: In this report, *low-carbon technologies* refer to technologies that substantially reduce or avoid GHG emissions compared to traditional alternatives. These include renewable energy (solar, wind, etc.), energy efficiency solutions, electric and fuel-cell vehicles, green hydrogen, carbon capture and storage, and many others across sectors. *Climate-resilient technologies* refer to those that help society adapt to climate impacts or build resilience – for example, drought-resistant crops, water recycling systems, early warning systems for extreme weather, and climate-smart infrastructure designs. Many technologies contribute to both mitigation and adaptation (for instance, green buildings reduce emissions and also improve thermal comfort under heat stress).

South Africa's technological response must address both mitigation and adaptation. The country has made progress in deploying certain green technologies (especially in renewable energy and some industrial efficiency measures) and has pockets of excellence in R&D (e.g. hydrogen fuel cells, climate-smart agriculture). However, major gaps remain. This report will map the current landscape of technologies in key sectors, summarize existing studies (by government, academia and industry) that have assessed this landscape, and identify gaps in innovation and investment. It will also identify specific technologies under development in South Africa that are nearing commercial readiness and could be scaled locally, highlighting opportunities for localization (domestic manufacturing and value chain development) in support of South Africa's just transition. Finally, the report recommends interventions to strengthen the national system of innovation and accelerate the adoption of low-carbon, climate-resilient technologies.

2 Previous Studies Mapping the Climate Technology Landscape

Over the past decade, several major studies have examined South Africa's climate technology landscape. These studies – undertaken by government departments, research agencies, and industry coalitions – provide foundational knowledge for identifying gaps and guiding interventions. Some of the most notable studies are discussed below.

2.1 Low-Carbon Technology Stocktake

Commissioned by the Department of Environmental Affairs (now DFFE) with support from GIZ, this study catalogued existing low-carbon technologies and mitigation options in South Africa and evaluated their potential. As a "policy informing study,[5]" it fed into strategy development (e.g. it is referenced in South Africa's LEDS and climate reports). The stocktake identified technologies across energy, transport, industry, agriculture, and waste management,

[3]https://www.dffe.gov.za/sites/default/files/docs/nationalclimatechange_adaptationstrategy_ue10november2019.pdf

[4]https://www.climate-transparency.org/wp-content/uploads/2022/10/CT2022-South-Africa-Web.pdf

[5]https://climateactiontransparency.org/wp-content/uploads/2021/09/D1_SA-Needs-Assessment-Report.pdf

assessing their maturity and barriers. Although the full report is not publicly published, references indicate it highlighted renewable energy, energy efficiency, electric vehicles (EVs) and other key mitigation levers, and likely pointed out where local capacity existed or not. The stocktake appears to have informed subsequent policy – it is listed as a key study in the climate policy monitoring framework.

Insights: South Africa had begun uptake of renewables and other low-carbon solutions by 2018 but needed accelerated deployment and support for emerging technology.

2.2 National Business Initiative (NBI) Climate Pathways and Just Transition project

The NBI, in partnership with Business Unity South Africa (BUSA) and Boston Consulting Group (BCG), led a comprehensive scenario analysis to chart pathways for South Africa to reach net-zero emissions by 2050[6]. Sectoral reports were developed for power, mining, industry, agriculture, and transport, along with an integrated Net Zero "2050" report launched at COP27. This work engaged over 450 stakeholders and was anchored in comprehensive modelling and consultation. Key findings included that it is technically feasible for South Africa to reach net-zero by 2050, but it requires massive investment (>R6 trillion by 2050) and coordinated action.

Critical actions identified included speeding up renewable energy deployment ten-fold (to around 6–7 GW new capacity per year), phasing out coal power by the mid-2040s, rapid electrification of transport (with ~700,000 EVs on the road by 2030), and banning new internal combustion vehicle sales by 2035. Even these actions only achieve the upper range of SA's NDC – to hit the lowest-emissions trajectory would require even more disruptive changes across sectors. The NBI/BCG study also emphasized just transition elements: managing socio-economic impacts, reskilling workers, and leveraging opportunities for new green industries (like manufacturing components for renewables and EVs).

Insights: South Africa's private sector recognizes both the necessity and opportunity of climate technology – but scaling up from current deployment rates is a major challenge.

2.3 Technology Needs Assessment (TNA)

An earlier effort led by the then Department of Science and Technology (DST) and submitted to the UNFCCC was South Africa's Climate Change TNA[7]. It identified priority sectors and technologies for both mitigation and adaptation. For mitigation, the 2007 TNA prioritized renewable energy (solar PV, wind), "clean coal" technologies (including carbon capture and efficient coal plants), industrial energy efficiency (e.g. boiler improvements), improved public transport and vehicle fuel efficiency, waste reduction and recycling, and sustainable land

[6]https://www.nbi.org.za/focus-areas/environmental-sustainability/climate-pathways-and-a-just-transition-for-south-africa/

[7] https://www.gov.za/sites/default/files/gcis_document/201409/dstsa-climate-change-technology-needs-assessment251020070.pdf

management (e.g. conservation agriculture, wildfire management). For adaptation, it highlighted technologies such as water supply and sanitation improvements, control of vector-borne diseases (health systems), development of drought-resistant crop varieties and improved pest management, water conservation technologies, and climate-resilient infrastructure design. Cross-cutting needs like data and early warning systems were also noted. While somewhat dated, the TNA underscored that many of the same areas remain relevant today (renewables, efficiency, climate-smart agriculture, etc.), though technological advancements since 2007 have been significant.

Insights: The TNA emphasized aligning climate technology with sustainable development; many of its suggested actions (e.g. boosting renewable energy, improving mass transit, water efficiency) are still in progress or yet to be fully realized.

2.4 Green Economy Policy Review of South Africa's Industrial Policy Framework and The State of Green Technologies in South Africa

A consensus study by the Academy of Science of South Africa (ASSAf) for the Department of Science and Technology[8] provided a sector-by-sector review of green technologies and provided strategic recommendations. The report argued that South Africa should move from being merely an importer/implementer of green technology to becoming a developer and manufacturer of such technologies. It highlighted the importance of a strong National System of Innovation, increased R&D investment, and skills development to achieve localization. Policy coherence and coordination across government were stressed, to avoid fragmented efforts – this was echoed in the 2020 "Green Economy Policy Review of South Africa's Industrial Policy Framework" by the DFFE, Department of Trade, Industry and Competition (DTIC) and DSI[9]. The study also examined the role of the private sector, recommending deeper government-business collaboration on green technology initiatives. Interestingly, it called for systematically learning from failures – evaluating past unsuccessful green projects to improve future outcomes. Another key message was on technology adoption: having technology available is not enough; attention must be paid to user behaviour, incentives, and awareness to drive adoption. For instance, social marketing, demonstration by early adopters (even celebrities), and smart incentives were cited as ways to overcome public hesitancy to new technologies.

Insights: Many of the barriers identified in 2014, and 2020 (low R&D spend, siloed policies, slow uptake by users) persist. The recommendations to boost local innovation capacity and address non-technical adoption barriers remain highly relevant.

2.5 Green Economy Inventory for South Africa

This study by the Partnership for Action on Green Economy (UN-PAGE) and DEA catalogued projects and initiatives across green economy sectors[10]. It found that *all provinces and all economic sectors had some green initiatives*, with concentration in Gauteng, Western Cape, and KwaZulu-Natal.

[8] https://www.assaf.org.za/wp-content/uploads/2015/02/8-Jan-2015-WEB-526305-ASSAF-Green-Tech-mail.pdf
[9] https://www.dffe.gov.za/sites/default/files/reports/greeneconomy_policyreview.pdf
[10] https://www.dffe.gov.za/sites/default/files/reports/greeneconomyinventoryforSA_anoverview.pdf

Key sectors driving South Africa's green transition included renewable energy, energy efficiency, waste management, sustainable transport, water management, and sustainable agriculture. The inventory provided a snapshot of progress and highlighted gaps and opportunities for scaling up. For example, it noted that many initiatives remained pilot-scale and there was a need for better coordination and knowledge-sharing among stakeholders.

Insights: By 2017, South Africa had numerous projects indicating a broad interest in green technology, but many were isolated or small. This underscores the need for moving from pilot projects to large-scale implementation.

Aside from the big NBI Climate Pathways project, NBI and partners have produced related studies, such as sectoral decarbonisation pathways[11]. Business groups have released analyses on EVs, renewable energy procurement, etc., indicating private sector interest in viable transition technologies.

These studies provide strong alignment in their conclusions: South Africa has significant opportunities in adopting low-carbon and resilient technologies, but to realise them, it must overcome barriers in policy coherence, funding, human capacity, and local innovation. The existing studies call for scaling up renewable energy, electrified transport, energy efficiency, and climate-smart agriculture, while also investing in emerging areas like hydrogen and storage. Gaps identified include insufficient R&D and commercialisation support, slow rollout of known solutions (like public transit, building retrofits, etc.), and the need for enabling policies (e.g. EV incentives, aggressive efficiency standards, etc.).

2.6 State of Climate Tech 2024 (PwC)

International studies are also being taken into consideration. This global study by PricewaterhouseCoopers (PwC) mapped venture and growth investment across the global climate-technology ecosystem, profiling where capital is flowing, which themes are gaining share, and how corporate investors are shaping the market[12]. PwC expanded its dataset to more than 12 000 start-ups and over 52 000 deals worth upwards of US$600 billion to track momentum and gaps by sector and stage. The 2024 study found that climate-technology investing in the 12 months to September 2024 fell below 2019 levels, although the United States held steady, supported by policy. It highlighted three notable shifts: energy-related start-ups rose to nearly 35% of climate-technology funding; Artificial Intelligence (AI)-centred climate ventures raised about US$6 billion in the first three quarters of 2024, already surpassing 2023; and adaptation and resilience featured in about 28% of deals, see Figure 1.

[11] https://www.nbi.org.za/focus-areas/environmental-sustainability/climate-pathways-and-a-just-transition-for-south-africa/#explore

[12] https://www.pwc.com/gx/en/issues/esg/climate-tech-investment-adaptation-ai.html

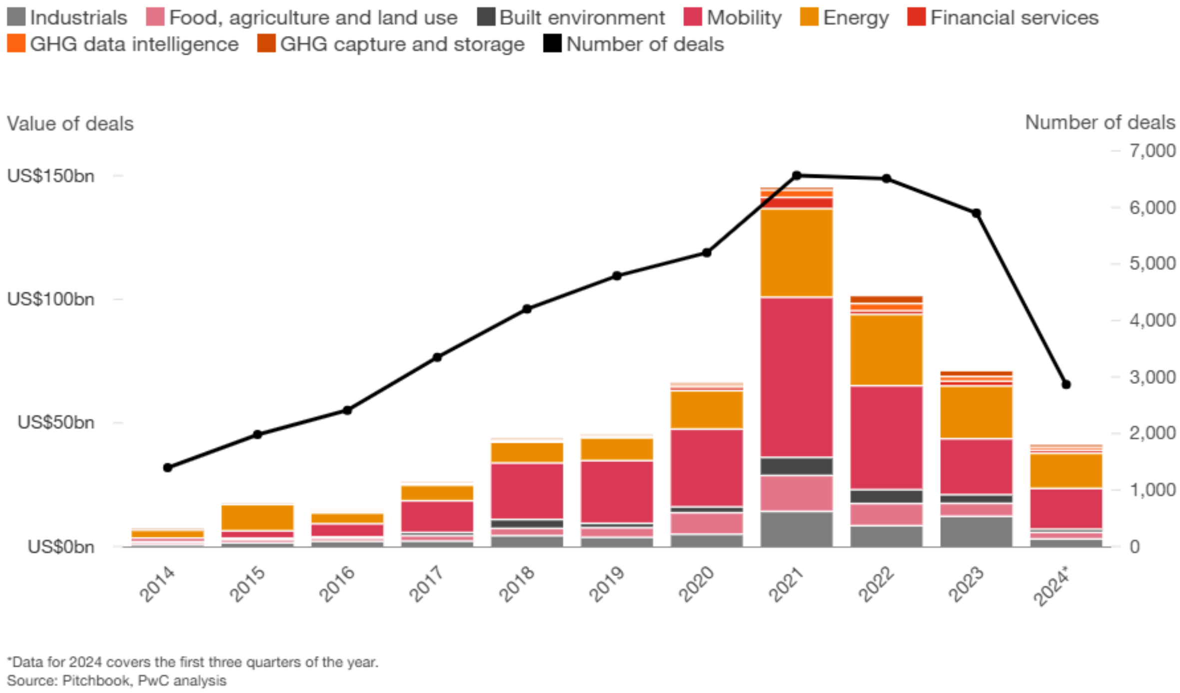

Figure 1: Global investment flows and deal volumes in climate technology

Insights: By 2024, global climate-technology investment had reduced and clustered around a few themes, notably energy and AI, while high-emitting sectors remained underfunded. This underscores the need for targeted policy and blended finance to shift capital toward hard-to-abate areas and earlier-stage innovation

2.7 IRENA World Energy Transitions Outlook 2024

The International Renewable Energy Agency (IRENA)'s Outlook set a 1.5°C-aligned pathway to mid-century and benchmarks real-world progress against what is required by 2030[13]. It concluded that the transition is off track despite the COP28 call to triple renewable power and double the rate of energy-efficiency improvement by 2030. The report identified three pillars to realign the pathway this decade: build enabling infrastructure at speed, strengthen policy and regulatory frameworks, and realign institutions and skills for a renewables-based system. It quantified the scale-up needed, including lifting annual investment in renewables, grids, flexibility, energy efficiency and conservation to roughly US$4.5 trillion per year in 2024–2030, and redirecting around US$0.7 trillion each year from fossil investments. IRENA's tracking indicated that current national plans would deliver only about half of the required growth in renewable power by 2030, implying a substantial shortfall without sharper policy and finance support.

[13] https://horizoneuropencpportal.eu/sites/default/files/2025-01/irena-world-energy-transitions-outlook-2024.pdf?utm

Insights: By 2024, the world was off track for 2030 goals on renewables, grids infrastructure, and energy efficiency. This underscores the need to accelerate enabling infrastructure and redirect finance at scale this decade, rather than announcing new targets.

These studies collectively also highlighted that capacity building is essential to ensure that all stakeholders, whether from an industrial development or green economy background, engage from a shared foundation of knowledge and understanding. Policy integration must occur in both directions, embedding sustainability principles within industrial policy while incorporating industrial development considerations into sustainability-related policies. There is also a need to generate and maintain credible, up-to-date evidence to guide decision-making throughout the transition. In parallel, transition planning must be significantly strengthened and better coordinated to manage a just transition for workers, women, small businesses, and low-income communities, enable the inclusive deployment of green technologies, and support the progressive transformation of South Africa's carbon-intensive economy.

3 Current Landscape of Low-Carbon Technologies in South Africa

The current landscape of low-carbon technologies in South Africa cover technologies in key sectors including energy (electricity generation), transport, industry and mining, buildings (built environment), agriculture and land use, and waste/circular economy. For each sector, technologies that are already being deployed as well as those under development are considered. The extent of local innovation and technology maturity is discussed below and provided the basis for identifying gaps and opportunities.

3.1 Energy Sector – Power Generation and Storage

Electricity generation is the single largest source of South Africa's emissions, dominated by coal-fired power plants. Decarbonising the power sector therefore stands at the heart of low-carbon development. The technology landscape in energy is undergoing a shift from coal to renewables, albeit slowly. As of December 2024, about 88% of South Africa's electricity was still generated from fossil fuels (mostly coal)[14]. This indicates that despite more than a decade of renewable energy projects, their share remains relatively small.

The renewables sector is however growing. South Africa launched the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) in 2011[15], which successfully attracted private investments in wind and solar projects. By 2023, over 6,000 MW of utility-scale renewable capacity (solar PV, onshore wind, CSP) had been procured through multiple bid rounds, with around 4,000 MW connected to the grid. These projects demonstrated that renewables can be built relatively quickly and affordably in South Africa. For instance, the price of solar PV in the REIPPPP dropped by over 75% between early bid rounds and recent rounds, thanks to global

[14] https://www.csir.co.za/sites/default/files/Documents/Utility%20Statistics%20Report_Jan%202025_Final.pdf
[15] https://www.dmre.gov.za/energy-resources/reippp-programme

cost declines and growing local installer experience. Wind and solar plants are now among the most cost-effective new-build options for electricity in South Africa[16].

Yet, policy and procurement delays meant a slowdown between 2015 and 2018, leaving a gap in new project implementation. Only recently, amid an electricity crisis and loadshedding, has the government accelerated procurement again (including opening bids for battery storage and allowing municipalities to procure renewables). This slowdown also led to failed investment in South Africa's production of various input components, as the stalling of new projects undermined investor confidence. Predictable and consistent demand for inputs is critical to sustaining investment in the localisation of technology and manufacturing. The Integrated Resource Plan (IRP 2019) set a target of adding 20 GW of renewable capacity by 2030, but implementation is lagging. The Draft IRP 2023 introduces a planning horizon to 2050 but does not specify a renewable energy target for that endpoint. Conversely, it downgrades near-term wind and solar ambitions compared to previous IRPs, while leaning on coal and gas - leaving the power sector misaligned with a 1.5 °C Paris-compatible decarbonisation pathway.

Independent assessments conclude no scenario in the draft achieves net-zero power by 2050, underscoring the need for a much faster renewables rollout[17]. The NBI's pathways study calls for 6–7 GW of renewables to be added every year (an order of magnitude above current rates) to meet net-zero goals.[18]

In terms of technology types, onshore wind and solar PV are the main deployed options, taking advantage of South Africa's excellent wind regime (especially in coastal areas) and high solar irradiance. Concentrated Solar Power (CSP) also featured in the REIPPPP (several CSP plants with storage were built in the Northern Cape), showcasing a low-carbon technology that can provide power after sunset. However, CSP costs remain higher than PV or wind, and future CSP uptake is uncertain without further cost declines or storage value recognition. Hydropower is limited by geography and water availability; apart from some existing dams and the Cahora Bassa imports, no large new hydro is planned.

Nuclear remains part of the energy debate (South Africa has two reactors at Koeberg supplying around 5% of power). Nuclear energy presents a viable path to contribute to South Africa's energy and decarbonisation needs, given the availability of local experience in the technology, and access to mineral resources required. Small Modular Reactors (SMRs) represent a class of nuclear fission reactors designed for modular construction, scalability, and enhanced safety features. Globally, SMRs are at advanced stages of demonstration and early commercial deployment, with a small number of units under construction or operational in countries such as Russia and China. As such, SMRs are generally assessed at TRL 7–8 internationally. In the South African context, no SMR

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16 https://www.nersa.org.za/files/files/2025/04/Report-on-Monitoring-RE-Performance-of-Power-PLants-Issue-25____-Final.pdf

17 https://meridianeconomics.co.za/wp-content/uploads/2024/03/IRP2023-Modelling-Submission-20240318.0.pdf

18 https://www.nbi.org.za/focus-areas/environmental-sustainability/climate-pathways-and-a-just-transition-for-south-africa/#explore

designs have been licensed or built, and domestic readiness remains lower (TRL 3–4), reflecting early-stage feasibility and preparatory work.

While the IRP 2019 leaves the option open for nuclear new-build, including SMRs, their potential deployment in South Africa faces several challenges: lengthy regulatory processes, high upfront capital requirements, limited domestic supply chain readiness, and the need for long-term waste management solutions. Nonetheless, SMRs could provide dispatchable, low-carbon baseload power in a decarbonised electricity mix, particularly for industrial clusters or remote applications, if cost and policy barriers are addressed.

Energy storage technologies are increasingly important to support renewable integration and improve grid reliability (especially as loadshedding mitigation). South Africa is beginning to deploy utility-scale battery energy storage systems (BESS). In 2022, Eskom awarded contracts for around 360 MW (1440 MWh) of battery storage to be installed at several substations – among the largest BESS projects in Africa[19]. These lithium-ion battery installations (with some local assembly) aimed to come online by 2024 to provide peak shaving and support for renewables, although about only a fifth of the Phase 1 installation has been realised, with the remainder, as well as Phase 2, being deferred due to funding ad approval delays.

The local battery assembly industry, represented by companies such as Solar MD, Balancell, and First National Battery, has shown substantial commercial readiness. IDC forecasts suggest potential employment creation of between 44,000 and 70,000 jobs by 2030, adding R40 billion to R53 billion to GDP. A critical challenge remains the heavy reliance on imported battery cells, emphasizing the urgent need for domestic battery cell production or strategic international partnerships. Additionally, pumped hydro storage exists (the Drakensberg and Palmiet schemes), which have long helped balance the grid.

New storage technologies are also on the horizon:

- Vanadium Redox Flow Batteries (VRFBs): South Africa, being one of the world's top vanadium producers, has strategic interest in vanadium-based flow batteries for long-duration storage. Local company Bushveld Energy (a subsidiary of Bushveld Minerals) is actively promoting VRFB adoption. A notable development is the vanadium electrolyte manufacturing plant under construction in East London Industrial Development Zone, through a Bushveld Energy and IDC partnership[20]. This plant, expected to produce electrolyte for up to 200 MWh of VRFB storage per year, is designed to supply both domestic projects and export markets. Commissioning is slated around 2024, with capacity to scale. By localizing the high-value electrolyte production (vanadium electrolyte is the key component of VRFBs), South Africa seeks to position itself in this niche of the storage value chain. Interest is growing as VRFBs offer 4-10+ hour storage and long lifespan, aligning with needs for renewable firming. The government's support for this initiative

[19] https://www.eskom.co.za/eskom-appoints-service-providers-for-its-battery-energy-storage-project/

[20] https://www.tips.org.za/images/TIPS_Localising_vanadium_battery_production_for_South_Africas_energy_security_August_2023.pdf

illustrates linking mineral beneficiation with low-carbon technology manufacturing. Bushveld Minerals' construction of a vanadium electrolyte facility in East London is a landmark step, intended to position South Africa as a major VRFB producer. Eskom's pilot project at Rosherville further underscores the readiness and potential of VRFB technology in the local market. However, alignment with policy frameworks such as the IRP 2023 is crucial, given its lower proposed renewable energy allocation, potentially impacting the demand for energy storage technologies like VRFBs.

- Hydrogen for energy storage and power: Green hydrogen (produced from renewable electricity) is an emerging vector to store energy over long periods and decarbonize hard-to-electrify sectors. South Africa's excellent solar and wind resources make it a prime candidate for large-scale hydrogen production. The government released a National Hydrogen Society Roadmap (2021), envisioning SA as a "global hydrogen hub." While still at early stages, demonstration projects are underway (for example, in the Eastern Cape, a pilot hydrogen microgrid has been deployed at remote sites by Telkom and other partners, combining solar PV, electrolysers, and hydrogen fuel cell backup systems). Hydrogen as seasonal storage for electricity is a longer-term prospect, but it interlinks with transport and industry uses (discussed later).

  The technology components – electrolysers, fuel cells, storage tanks – are largely imported currently, but South Africa has a strong R&D base in hydrogen (the HySA programme, see later in Transport/Industry sections) that could support local manufacturing of some components (especially those involving platinum group metals for catalysts). South Africa's commitment to green hydrogen is significantly strengthened by strategic frameworks including the Green Hydrogen Commercialisation Strategy and the Hydrogen Society Roadmap. Early commercialisation efforts such as Sasol's pilot electrolyser in Sasolburg and the 10 MW project in the East London Industrial Development Zone demonstrate tangible progress. These initiatives underline the significant infrastructure required, notably 80 GW of renewable energy by 2050. Due to logistical constraints, green ammonia exports currently present a viable short-term opportunity. This sector could substantially contribute 3.6% to South Africa's GDP and create around 370,000 jobs by 2050.

The power sector's low-carbon technology landscape is characterized by growing renewable energy deployment (wind and solar leading, CSP being niche), initial battery storage projects (mostly lithium-ion, with flow batteries on the horizon), and exploration of green hydrogen for future use. Key gaps include the overall pace of transition being too slow to meet climate targets (policies need strengthening to unlock faster renewable roll-out and decommission of coal-powered plants), and grid infrastructure is a bottleneck (technology to strengthen transmission, smart grids, etc., is needed to integrate more renewables). Additionally, local manufacturing of renewable energy components is limited, while some assembly plants exist, most hardware (turbines, PV modules, batteries) are imported. Localization opportunities will be discussed later, as they represent economic upside if South Africa can attract component factories (for solar panels, wind towers, battery assembly) in the coming expansions.

3.2 Transport Sector – Towards Electric and Low-Emission Mobility

Transport is South Africa's second-largest energy use sector and a growing source of CO_2 emissions (about 10.8% of national GHG emissions). The current transport technology landscape is still dominated by internal combustion engine (ICE) vehicles, largely petrol and diesel fuelled. South Africa has a significant domestic vehicle manufacturing industry (5 - 7% of GDP, producing around 0.6 million vehicles/year pre-COVID, mainly ICE motorcars). This industry is facing an "existential challenge" from the global shift to EVs. More than 60% of SA's vehicle production is exported, especially to Europe and the UK – markets that have announced bans on ICE sales from 2030. This means South African automakers must transition to New Energy Vehicles (NEVs) or risk losing export markets and jobs. It also means local consumers will gradually need to shift to EVs to align with global trends and mitigate emissions and local air pollution.[21]

EVs – including battery electric vehicles (BEVs) and plug-in hybrids – are the primary low-carbon technology for road transport. Adoption in South Africa has been very limited so far. As of 2021, cumulative EV sales were under 1,000 units (in a national fleet of around 12 million vehicles). High upfront costs, lack of consumer incentives, and limited charging infrastructure have constrained the market.

However, momentum is building: industry bodies like uYilo eMobility Programme and the Electric Vehicle Industry Association (EVIA) have been actively promoting EV readiness.[22] GreenCape, a Western Cape agency, also runs an EV hub tracking developments and assisting firms.[23] In 2022, a UK-sponsored Green Transport fund attracted US$179 million in low-carbon transport project applications, signalling growing interest.[1] On the supply side, some manufacturers have started laying groundwork - for example, Mercedes-Benz South Africa began assembling hybrid vehicles and has hinted at EV plans; BMW SA and Nissan SA offer a few EV models imported; and Toyota SA is investing in hybrid production (though full EV production is not yet confirmed).

Government policy is evolving to support EVs. A draft Auto Green Paper on EVs (2021) proposed incentives for local EV manufacturing and purchase, recognizing the risk to the auto sector if the sector does not pivot.[24] While detailed incentives are still pending, this policy direction is encouraging automakers to consider retooling for EVs. The JET-IP transport chapter reinforces this by focusing on supply chain localisation for NEVs and the need for an investment support programme to finance the pivot.

[21] https://assets.bbhub.io/company/sites/63/2022/11/south-africa_s-just-energy-transition-investment-plan-2023-2027.pdf

[22] https://justenergytransition.co.za/wp-content/uploads/2024/10/South-Africas-Just-Energy-Transition-Investment-Plan-JET-IP-2023-2027-FINAL-1.pdf

[23] https://greencape.co.za/market-intelligence/electric-vehicles/

[24] https://www.gov.za/documents/green-papers/auto-green-paper-advancement-new-energy-vehicles-south-africa-comments

Besides passenger cars, electrification is also being explored for public transport and freight:

- Busses: The City of Cape Town and City of Johannesburg have piloted electric busses for BRT (Battery electric MyCiTi busses were tested in Cape Town). Golden Arrow Bus Services in Cape Town has also begun trials with a few e-busses. These pilots need scaling, but they demonstrate viability. Local bus manufacturers (like Busmark) have showcased electric bus prototypes, indicating potential to assemble e-busses domestically if orders materialize.[25,26]

- Minibus taxis: The ubiquitous minibus taxi, responsible for most commuter trips, could be a game-changer if electrified. There are early explorations – for instance, conversion of a Toyota Quantum to electric was prototyped by the Stellenbosch University. However, cost and charging for taxis remain challenges to solve.[27]

- Freight and trucking: For heavy freight, battery EVs are less certain due to range needs, but hydrogen fuel cell trucks are emerging as an alternative. Anglo American unveiled the world's largest hydrogen fuel cell mining truck (a 290-ton haul truck) in 2022 at a Limpopo platinum mine. This "nuGen" truck[28] is a proof of concept replacing diesel with hydrogen fuel cells, leveraging platinum catalysis (a win for local mineral beneficiation). Anglo plans to convert more mine trucks if it performs well. Similarly, some logistics companies are starting to test dual-fuel hydrogen-diesel trucks or are eyeing future fuel-cell truck imports (e.g. Hyundai or Toyota FC trucks).

- Rail: Shifting freight from road to electric rail is inherently a low-carbon shift. South Africa's rail system has suffered neglect, but reviving and expanding electrified rail (for both freight and urban passenger corridors) is a stated goal.[29] Technologies here include modern efficient locomotives, possibly battery-electric shunting engines, etc. Transnet has some programmes to purchase new electric locomotives (though mired in past procurement issues).

- Alternative fuels: Alternative fuels remain relevant as an interim solution while electrification advances. South Africa approved a Biofuels Industrial Strategy several years ago, but its implementation has been limited. Current production of bio-ethanol (from sugar byproducts) and biodiesel (from used cooking oil, among others) remains small-scale, with no binding national mandates in place. A notable early initiative was Project Solaris, a partnership between South African Airways and Sunchem that cultivated a nicotine-free tobacco variant (Solaris[30]) in Limpopo to produce jet biofuel. In 2016, SAA operated

[25] https://greencape.co.za/wp-content/uploads/2023/08/CCT23_GABS-case-study_Electrification-of-public-transportation.pdf
[26] https://www.engineeringnews.co.za/article/cape-town-takes-second-stab-at-rolling-out-electric-buses-for-its-myciti-service-2024-04-10
[27] https://www.eng.sun.ac.za/su-partners-retrofit-first-minibus-taxi-in-sa-to-run-on-electricity/
[28] https://www.angloamerican.com/media/press-releases/2022/07-12-2022
[29] https://www.dffe.gov.za/sites/default/files/docs/publications/freightshift_roadtorail.pdf
[30] http://www.projectsolaris.co.za/

Africa's first flight using domestically produced bio-jet fuel. While these efforts demonstrated technical feasibility, they have yet to scale due to inconsistent policy support.

Momentum in the renewable fuels space has recently revived. In February 2025, Sasol, Anglo American, and De Beers signed a Joint Development Agreement to pilot the production of feedstock for renewable diesel. The partnership will assess the technical and commercial viability of producing vegetable oil from Solaris and Moringa plantations. Initial feedstock trials will be grown on De Beers-owned land in Blouberg and Marble Hall in Limpopo, as well as at the Voorspoed mine closure site in the Free State. Sasol's existing infrastructure allows for the use of a variety of feedstocks, enabling it to produce renewable diesel more rapidly and cost-effectively than greenfield projects. Renewable diesel offers a drop-in substitute for conventional diesel, meeting technical standards while significantly lowering GHG emissions. As customer demand for decarbonisation solutions grows, this partnership aims to establish a local value chain for sustainable fuel production in South Africa. Sasol is also well-positioned to produce sustainable aviation fuel (SAF) via the Fischer-Tropsch process if it pivots its inputs and technology, which could help sustain the competitiveness of South Africa's aviation industry and liquid fuels sector in a low-carbon future.[31]

- Vehicle efficiency: In conventional vehicles, improvements continue (e.g. more efficient engines, introduction of hybrid cars). South Africa has fuel economy and CO_2 standards under consideration (currently not as strict as Europe). The roll-out of cleaner fuels (low-sulfur petrol/diesel) has enabled newer efficient engines to be used. The country is moving to 10ppm sulfur fuels nationwide, which will facilitate Euro 6 vehicle technology, thus reducing emissions per km in new ICE vehicles pending the EV shift.[32]

A critical aspect remains the vehicle manufacturing industry's future. It needs to localise EV production. Government, through the South African Automotive Masterplan (SAAM 2021-2035), is working with automakers on this transition. Investments in battery assembly plants or even cell production could be game-changers. Already some local firms like Metair (an auto battery company) are exploring lithium-ion battery assembly to supply EVs or stationary storage. The JET IP notes that investments in a local lithium-ion battery value chain are being explored, which would serve both vehicles and grid storage needs. South Africa's mineral wealth (80% of global manganese reserves, significant nickel and platinum, etc.) gives it an edge to potentially produce battery cathode materials or fuel cell components. For example, manganese is used in many EV battery cathodes (NMC batteries) – local mining and refining of manganese sulphate for batteries is an opportunity if linked with battery manufacturers. These opportunities are discussed further under localization in chapter 4.

[31] https://www.sasol.com/media-centre/media-releases/sasol-anglo-american-de-beers-partner-generate-feedstock-renewable-diesel-production

[32] https://theicct.org/wp-content/uploads/2022/12/Soot-working-paper-26-A4-v4.pdf

3.3 Industry and Mining – Cleaner Production and New Processes

South Africa's industrial sector – including mining, manufacturing (iron and steel, cement, chemicals, etc.) – is both an emissions source and an enabler of other low-carbon technology (through materials supply). Key low-carbon technologies in industry aim at energy efficiency, fuel switching (to electricity or biomass/hydrogen), and process innovation to reduce emissions intensity.

For many years, South African companies have pursued energy cost savings which align with emissions reduction. Through programmes like the National Cleaner Production Centre (NCPC-SA) and its Industrial Energy Efficiency initiative (with UNIDO), many industrial plants have implemented measures such as efficient motors, boilers, compressed air optimization, waste heat recovery, etc. This has cumulatively saved substantial energy – for example, over 1,000 GWh and R5 billion in costs saved over 2010-2015 as reported by NCPC, while also building local expertise in energy management. Despite these successes, energy efficiency potential remains vast because of many aging, inefficient systems in use. Technologies like variable-speed drives, cogeneration units (e.g. using waste gases in smelters to generate power), heat pumps for low-temperature heating, and advanced process control (digital optimization) are increasingly adopted in larger firms. One barrier for smaller enterprises is capital and know-how; expanding financing for efficiency (e.g. through green loans or energy service companies (ESCO)[33] models) is a gap. From a technology perspective, most industrial efficiency technology is imported, but the services around it (audit, installation, etc.) have localized well.

Decarbonizing heavy industries (steel, cement, chemicals) is a tougher challenge requiring new processes:

- Iron and Steel: South Africa is a major steel producer (ArcelorMittal SA being the largest). Traditional blast furnace steelmaking uses coal/coke. Low-carbon pathways include using electric arc furnaces (EAFs) with scrap (already some smaller mills do this), or innovative routes like direct reduced iron (DRI) using green hydrogen instead of coal. This latter is being piloted globally (e.g. HYBRIT in Sweden). In SA, ArcelorMittal and Sasol announced in 2021 a partnership to investigate green hydrogen DRI to produce "green steel" at AMSA's plants in the 2030s, leveraging Sasol's potential hydrogen production. If realized, this would be a revolutionary technology locally. Carbon capture on steel plants is another theoretical option, but not yet near deployment in South Africa.

- Cement: The cement industry (PPC, AfriSam, etc.) emits CO_2 from limestone calcination and fuel combustion. Technology solutions include energy efficiency (new kilns, waste heat recovery), alternative fuels (using waste tyres, biomass instead of coal in kilns – some plants do co-fire waste materials), and clinker substitution (using fly ash or slag in cement blends to reduce clinker content). South African companies have made strides in clinker substitution (extenders like fly ash from Eskom's coal plants are used, though constrained

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[33] https://www.idc.co.za/esco-energy-solutions/

by fly ash quality and availability). A future prospect is geopolymer or carbon-neutral cements – there is research at CSIR and universities into novel cement chemistries that emit less CO_2. One company, Solidia Technologies, has a process to cure concrete with CO_2 (thus storing CO_2), which could be considered by local industry.

- Chemicals (Petrochemicals): Sasol, one of the largest point-source CO_2 emitters, produces fuels and chemicals from coal (and gas) via Fischer-Tropsch. Low-carbon technology focus for Sasol includes: increasing energy efficiency (they have cut relative CO_2 a bit by upgrading turbines, etc.), transitioning feedstock from coal to natural gas (which they did partially at Secunda, though gas supply is depleting), and in future, potentially shifting to green hydrogen and sustainable carbon sources to produce fuels (power-to-liquids, biomass-to-liquids). Sasol is actively studying green hydrogen to replace the grey hydrogen it currently makes from coal (used in its fuel synthesis). It has partnered on feasibility studies for a Boegoebaai green hydrogen project in Northern Cape – which envisages huge solar/wind farms to produce hydrogen and ammonia for export. Domestically, Sasol's expertise in Fischer-Tropsch could be turned to making sustainable aviation fuel (SAF) by combining green hydrogen with captured CO_2 or biomass – a technological pivot that is conceivable with right investments.

- Mining operations: Mines are reducing their carbon footprint by adopting renewables (e.g., Gold Fields' South Deep mine built a 50 MW solar plant, many mines now have solar or are planning wind farms for self-supply). Mines are also electrifying equipment – beyond the Anglo hydrogen truck, some mines use battery-electric underground mining equipment (for drills, loaders) which cut diesel use and improve air quality in shafts. Another technology in mining is methane capture: some coal mines trap methane (a potent GHG) from shafts and use it to generate electricity (e.g., the Beatrix gold mine has a methane-capture power plant because that gold mine incidentally hits methane pockets). This turns a hazard into energy and cuts emissions.

  Trolley-assist systems offer significant emissions and operational cost reduction potential for mine haul trucks in open-pit mining operations. Pilots by CAT and Hitachi in Limpopo and Mpumalanga mines demonstrated diesel savings of up to 60%, energy cost reductions up to 40%, and considerable GHG emissions reductions. Wider adoption would require infrastructure investments and supportive regulatory frameworks, making trolley-assist systems an important near-term technology for sustainable mining.

South Africa possesses significant reserves of critical minerals essential for global clean energy transitions, including platinum group metals (PGMs), manganese, vanadium, and rare earth elements. These minerals underpin key green technologies such as hydrogen fuel cells, battery storage systems, wind turbines, and electric vehicles. Strategic investment in domestic beneficiation and refining could capture more value locally, create skilled jobs, and strengthen South Africa's position in global low-carbon value chains.

The technology readiness of beneficiation processes varies by mineral. Established refining processes for PGMs and manganese are at high TRLs, supported by existing industrial capacity. However, beneficiation of rare earth elements and advanced battery materials remains at lower TRLs domestically, with limited large-scale processing infrastructure. Advancing these capabilities will require targeted R&D, pilot plants, and supportive industrial policies that align with Just Transition objectives. Integrating beneficiation into national decarbonisation strategies can also reduce the embodied emissions of green technology exports by shifting processing towards cleaner energy sources.

South Africa has a strong materials research base that is contributing to industrial process innovation and R&D of low-carbon technologies:

- Hydrogen and Fuel Cells: Through the Hydrogen South Africa (HySA) programme (initiated by DSI in 2008), research centres at University of the Western Cape, CSIR, and North-West University have worked on fuel cell catalysts, membranes, systems integration, etc. This has led to local companies like HyPlat (a spin-off producing fuel cell membrane-electrode assemblies with local platinum catalysts) and Isondo Precious Metals (IPM) (scaling up membrane and electrode manufacturing with local PGMs).[34] The presence of these firms indicates an emerging fuel cell industry cluster. While still R&D-stage, they aim for advanced manufacturing of components – HyPlat has exported some components for international fuel cell makers, proving South African capability. As the fuel cell market grows (for vehicles, backup power, etc.), SA could supply components, leveraging our platinum. Another start-up, Mitochondria Energy Systems, is working on fuel cell backup solutions for telecom and has deployed small units. These efforts are at advanced R&D or pilot commercialization stage and could scale with proper support (e.g. government procurement of fuel cell systems for hospitals or remote stations to create local demand).

- Battery value chain: Besides the vanadium battery activities mentioned, South African research institutions also contribute to battery materials innovation. The University of Limpopo and others have projects on manganese-based battery cathodes (given SA's mineral strength in Mn). The CSIR and NECSA (Nuclear Energy Corporation) have done work on battery electrodes and recycling techniques. A few local companies assemble Li-ion battery packs for stationary and mobility uses – e.g. BlueNova and Balancell produce battery systems (they import cells but do local battery management system (BMS) design and integration).[34] This shows growing expertise in the "downstream" part of batteries (system integration). There is potential for South Africa to move further upstream (cell manufacturing or at least producing processed battery materials like precursor chemicals for cathodes/anodes). The government's Battery Storage Initiative under the ESSP (Energy Storage Research, Development and Innovation Programme) seeks to support such opportunities.

The industrial sector is a mix of incremental improvements (efficiency, fuel switch to gas or electrification where possible) and transformational technology changes on the horizon (green

[34]https://www.tips.org.za/images/TIPS_Localising_vanadium_battery_production_for_South_Africas_energy_security_August_2023.pdf

steel, green hydrogen chemicals, fuel cells, etc.). South Africa's immediate gains can come from wider adoption of existing best-available technologies (e.g. high-efficiency motors, digital process control, waste heat to power - many of which have good payback due to high energy prices), and these also build capacity for future improvements. A gap, however, is *policy-driven demand* - unlike the power sector which now has REIPPPP, industry decarbonization lacks strong policy levers. The carbon tax (implemented 2019, albeit at a low effective price after allowances) is one lever to nudge industry to adopt cleaner technology. Strengthening the carbon price (which is expected with phase 2 of the carbon tax) and regulations (e.g. mandatory energy management plans, green public procurement favouring low-carbon materials) would incentivise faster uptake of industrial low-carbon technologies. The challenges however that go hand-in-hand with this type of regulation should also bear in mind South Africa's unique socio-economic make-up, and should be rolled out with careful consideration of a just transition for all, especially in hard-to-abate sectors, and sectors that face other economic challenges.

3.4 Built Environment – Green Buildings and Sustainable Cities

The built environment – buildings and construction, as well as urban infrastructure – offers meaningful opportunities for both mitigation (through energy efficiency and clean energy integration) and adaptation (through climate-resilient design). South Africa's construction sector has embraced some green building practices, but there is vast room for scaling up in mainstream buildings and retrofit of existing building stock.

Over the past decade, South Africa saw a surge in green building certifications. The Green Building Council of South Africa (GBCSA) introduced the Green Star SA rating system (for commercial buildings) and more recently supports the EDGE rating (for homes). As of 2023, GBCSA celebrated its 1000th building certification milestone, up from the first certification in 2009.[35] This includes offices, malls, universities, factories and homes that meet various levels of sustainability criteria. The demand for certified green buildings has been rising steadily, demonstrating market recognition of the value (in terms of energy savings, higher asset value, etc.). Leading corporations and property developers now routinely aim for 4-Star or 5-Star Green Star ratings in new builds. Notable examples are the Department of Environmental Affairs head office (6-Star rated), Vodafone Innovation Centre (6-Star, net-zero energy), and a growing list of Net Zero certified buildings (including some Net Zero Carbon and Net Zero Water industrial facilities).

Key technologies and features in green buildings include improved thermal insulation (walls, roofs, double-glazing), passive design for daylighting and natural ventilation, energy-efficient lighting (LEDs) and HVAC systems, solar water heaters or heat pumps for hot water, rooftop solar PV installations, smart meters and building automation, and increasingly, on-site battery storage for resilience. Solar water heating had a big government push earlier (with a target to install 1 million solar water heaters) – though the programme encountered implementation issues, thousands of units were installed, mainly in middle-class and low-income housing, cutting electricity use for water heating. Efficient appliances (fridges, air conditioners, etc.) are promoted through appliance

[35] https://www.gbcsa.org.za/wp-content/uploads/2024/07/GBCSA-2023-Integrated-Report.pdf

energy labelling and MEPS (minimum efficiency standards) set by the government – these policies align new appliance imports with global efficiency improvements.

South Africa's national building regulations were also amended (SANS 10400-XA) to require new buildings to meet certain thermal performance and energy efficiency standards (for example, requiring insulation or solar water heaters). Enforcement is still variable, but it sets a baseline for future construction to be more energy efficient.

Despite these advances, it must be noted that the majority of South African buildings (especially residential and small commercial) remain inefficient – with poor insulation, old appliances, and little renewable integration. Retrofitting existing buildings is a major challenge and opportunity. Technologies for retrofit like ceiling insulation installation (in low-cost houses), cool roof coatings (to reduce heat absorption), and upgrading to efficient lamps and appliances can yield large energy and comfort gains. Some municipalities (e.g. Cape Town) have run programmes to insulate roofs in low-income homes and install efficient lighting, which also have adaptation co-benefits (cooler homes in heat waves).

Resource efficiency in buildings and construction also extends to water and materials. Many green buildings incorporate greywater recycling, low-flow fittings, and rainwater harvesting – crucial in a water-scarce country. After the 2018 Cape Town drought, water-saving technologies became mainstream in Western Cape (e.g., widespread rainwater tanks, and some adoption of atmospheric water generators by businesses). On materials, recycled content is being used more frequently (for instance, fly ash in concrete, recycled steel in rebar).

A circular approach in construction is nascent but growing. Some companies are focusing on recycling construction and demolition waste into aggregates, and designers are exploring use of sustainable materials (bamboo, timber, hempcrete, etc.) although conventional materials still dominate.

Beyond individual buildings, city-level technologies are also advancing:

- Efficient public lighting: Many municipalities are retrofitting streetlights with LED and smart controls (e.g. Johannesburg's city-wide streetlight retrofit saved energy and reduced maintenance).
- Transit-oriented development and mobility: while the physical technology is vehicles (discussed in the transport section above), cities are using Information and Communication Technology (ICT)[36] for smarter traffic management and developing plans for electric bus rapid transit and integrated mobility applications – technology that can reduce congestion and emissions indirectly.

[36] Smart traffic management through ICT include a combination of tools such as AI, machine learning, vision systems and cameras.

- Urban cooling and nature-based solutions: Durban, for example, has implemented cool roof pilot projects (white or reflective paint on roofs in informal settlements to reduce indoor temperatures) as an affordable climate adaptation technology. Green infrastructure like expanded urban tree cover and permeable pavements are also part of making cities resilient (although not a "technology" per say, but an important innovation in practice).

- Building adaptation: Climate-resilient building design is becoming ever more important. Architects and engineers are now considering future climate in designs – e.g., ensuring structures can handle more intense storms/flooding, using materials that perform under higher temperatures or wildfire exposure. Simple but effective measures like raising floor levels of houses in flood-prone areas, or fire-resistant landscaping in the wildland-urban fringe, are being promoted. The concept of "climate-proofing" new infrastructure is recognized in national adaptation strategy documents, but implementation tools (like updated design standards factoring in climate projections) are still evolving.

The built environment in South Africa has pockets of world-class green building practice, but the average building still lags. The technological solutions are largely available; the gap is in scaling adoption to mainstream all new buildings to be green and aggressively retrofitting existing stock (homes, offices, public buildings) for efficiency and resilience. There is opportunity in training and jobs creation –an expanded programme to install solar water heaters or insulate RDP houses would employ many while reducing emissions and enhancing adaptation.

South Africa's green building movement, driven by GBCSA, is one of the more successful in the developing world (with certification numbers on par with some developed countries). However, energy performance of the average home or building is worse than in, say, Europe due to historically more affordable electricity rates and lack of heating needs (homes were often built without consideration of thermal performance, leading to high electric heating in winter and cooling in summer). Strengthening and enforcing building codes, incentivising retrofits (through subsidies or green financing), and possibly mandatory energy disclosure for buildings could drive wider technology uptake.

3.5 Agriculture, Land Use and Water – Climate-Smart and Resilient Technologies

Agriculture and land use are critical for both mitigation (through carbon sequestration and reducing emissions like methane) and adaptation (ensuring food security under changing climate). South African agriculture is vulnerable to droughts, heatwaves, and shifting rainfall – thus climate-resilient agricultural technologies are paramount. At the same time, agriculture accounts for emissions (about 5-10% of SA's GHG, mainly from livestock methane and fertilizer N_2O), so low-carbon farming methods are also needed.

Climate-Smart Agriculture (CSA): This concept encapsulates many of the needed technologies:

- Drought-resistant crop varieties: South Africa's Agricultural Research Council (ARC) and private seed companies have been developing crop cultivars that can tolerate heat and drought, especially maize, the staple. For instance, ARC's Dryland Stress programme produced maize varieties with better yield under water stress, and work is ongoing on more drought-tolerant sorghum, cowpea, and sunflower. The adoption of these varieties helps maintain yields as climate extremes intensify. Similarly, research on more heat-tolerant or disease-resistant livestock breeds (e.g. hardier cattle breeds for smallholders) is an important resilience tech in the broader sense.

- Efficient irrigation technology: With agriculture being a major water consumer, technologies like drip irrigation and micro-sprinklers have seen increasing uptake, particularly in horticulture. These can halve water use versus flood irrigation. Government and NGOs have run programmes to introduce drip irrigation kits to small-scale farmers. Additionally, scheduling irrigation based on soil moisture sensors and weather forecasts (sometimes through mobile apps or extension advisories) helps optimize water use. A 2021 analysis found that rainwater harvesting and micro-irrigation are among the most adopted climate-smart water management technologies in Sub-Saharan Africa, including South Africa.[37] Large commercial farms are also investing in centre pivot systems with precision controls and even trials of automated irrigation driven by satellite imagery data (several agri-tech firms in SA offer remote sensing services to farmers to guide water and input use).

- Conservation agriculture: No-till or minimum tillage farming, along with crop rotation and cover cropping, is being promoted to improve soil moisture retention and soil carbon. South Africa has some adoption of conservation agriculture, especially in dry areas of Free State and Eastern Cape. The technology here is partly practice (changes in ploughing technique) and partly equipment (no-till planters). It has shown good results in enhancing resilience to drought by keeping soil structure intact. However, only a fraction of grain farmers practises it consistently – expansion is needed.

- Digital climate services for farmers: The South African Weather Service (SAWS) provides seasonal climate outlooks and severe weather warnings that are increasingly tailored to farmers. Through projects like Gauteng City-Region's Climate Portal and ARC's Agrometeorology unit, farmers can get localized early warnings (e.g. frosts, extreme heat, or heavy rain) enabling them to act (e.g. harvesting early, adjusting planting dates). Mobile phone-based advisory services (like the Rain4Africa project which delivered weather info via SMS) have also been piloted. These services are a form of soft technology that boosts resilience by improving decision-making.

Livestock and methane: Livestock (cattle, sheep, goats) produce methane through enteric fermentation. Technologies to reduce this include improved feeds and additives (e.g. feed supplements that reduce methane, like certain legume forages or even experimental treatments like 3-NOP or seaweed additives which research globally shows can cut methane significantly). In South Africa, research by CSIR and international partners is exploring feed additives suitable for local conditions (one challenge is most cattle are in extensive grazing, not feedlots, so solutions

[37] https://www.mdpi.com/2073-4441/16/19/2787

must work in grazing systems). Better breeding for productivity (fewer cows for same milk yield) also helps. These approaches are in early adoption. Manure management technology (biogas digesters on large dairies, improved kraal management) could also mitigate emissions and provide biogas energy – a couple of dairy farms in KZN and Western Cape have installed biogas digesters to convert manure to electricity, showcasing the potential.

Land use and forestry: South Africa has limited natural forest, but it has a commercial forestry sector (pine and eucalyptus plantations) and large tracts of rangeland. Restoration and tree planting (e.g. spekboom planting in the Cape thicket, or catchment restoration by removing invasive species and allowing regrowth of natives via Working for Water programme) act as carbon sinks and enhance resilience (improving water regulation, reducing erosion). Technologically, this involves better remote sensing to identify degraded lands, nursery techniques for climate-resilient seedlings, and community-based methods to plant and maintain vegetation. Government programmes are pursuing these at moderate scale. For example, blue carbon (coastal wetland restoration) is recognized as a niche opportunity; a study estimated significant carbon storage potential in rehabilitating mangroves and salt marshes, though projects are just starting. [38]

Water management technologies: Given South Africa's water scarcity and the likelihood of more intense droughts, water-related technologies are crucial:

- Water reuse and recycling: Several municipalities are implementing wastewater recycling for potable or industrial use. e.g., eThekwini (Durban) has the long-running Durban Water Recycling Plant that treats wastewater to industrial grade for a local paper mill and refinery, freeing up freshwater for other uses. During Cape Town's drought, plans for direct potable reuse were drawn (and small reuse schemes exist in Beaufort West and others). Technologies here include advanced treatment (ultrafiltration, reverse osmosis, UV disinfection) – these are imported systems typically, but local engineering firms integrate them.

- Desalination: Coastal cities are evaluating desalination as a last-resort water source. A few small desalination plants (±2–5 ML/day) were set up in 2018 in towns like Richards Bay and Saldanha Bay during drought emergencies. The technology (reverse osmosis units) was mostly containerized imports. Desalination is energy-intensive and costly, but the technology is proven – if renewable energy is used, it can be part of a climate-resilient water strategy. Research is ongoing at University of KwaZulu-Natal on lower-energy desal processes (forward osmosis, etc.), and the Western Cape has tested wave energy coupled desalination (a pilot WaveKelp device). For now, desal remains minor in SA's water mix.

- Precision monitoring and leak reduction: To manage water distribution efficiently, utilities are adopting smart water meters and pressure management. Cape Town installed tens of thousands of smart water meters that allow for quicker leak detection and user awareness. Johannesburg and others have advanced pressure management technology that has saved

[38] https://www.sciencedirect.com/science/article/abs/pii/S0048969722072424

billions of litres by reducing night-time pressures (and thus leaks/bursts). These are important urban technologies to stretch water supplies.

- Flood management: As climate change can bring intense storms, technologies like improved flood early warning systems are important. South Africa has invested in better radar and modelling for flood forecasting. For example, the South African Flash Flood Guidance system (SAFFG) is used by SAWS to warn communities. Efforts to integrate community alert apps and automated SMS warnings in flood-prone areas (e.g. in Durban after recent floods) are underway – a merging of technology and disaster management practice.

Cross-cutting adaptation technologies also worth noting are early warning systems and climate information systems on a national level. The National Framework for Climate Services (NFCS-SA)[39] has been established to coordinate climate observations, modelling, and user-oriented services. This includes upgrading meteorological technology (weather stations, radar, supercomputing for regional climate modelling) and creating platforms for disseminating advisories to sectors like agriculture, water, health. For instance, an initiative to develop a multi-stakeholder climate early warning and vulnerability network is referenced in adaptation plans. This would involve technology and data sharing between SAWS, agricultural extension, disaster management centres, etc., to ensure relevant warnings reach those who need them (e.g., a heatwave health alert to clinics, or a flood alert to municipal responders).

The agriculture and water sectors are integrating climate considerations with a range of technologies from high-tech (sensors, modelling) to low-tech (rainwater harvesting, conservation farming). The main gap here is often support for small-scale farmers – large commercial farms can afford drip irrigation or new seeds, but emerging farmers need financial, and extension support to adopt CSA technologies. Programmes like SmartAgri in Western Cape and others are trying to bridge this by providing toolkits and training on climate-smart technology. Another gap is scaling successful pilots – for example, many innovative farming practices are proven on model farms, but widescale behaviour change is needed to implement them across millions of hectares. This may require policy incentives (like subsidies for water-saving technology, insurance discounts for resilience measures, etc.).

On the mitigation side, South Africa could explore joining initiatives like the Global Methane Pledge[40] by targeting agriculture methane reductions, which might bring in technical support for feed additive technologies once they are mature.

3.6 Waste Management and Circular Economy Technologies

The waste sector is often overlooked in climate technology discussions, but it is important for both emissions (landfills emit methane; waste burning emits pollutants) and for resource efficiency

[39] https://nccis.environment.gov.za/climate-services
[40] https://www.globalmethanepledge.org/

(recycling saves energy and materials). South Africa has been making strides in moving towards a more circular economy, though challenges remain.

Waste-to-energy and landfill gas: A few projects in SA capture landfill gas (LFG) and use it for energy, which both reduces methane (a potent GHG) and yields electricity. Ethekwini Municipality (Durban) was a pioneer with two LFG-to-electricity projects (Mariannhill and Bisasar Road landfills) that generated a combined around 7 MW and earned carbon credits. Similarly, Johannesburg has LFG capture flaring at some sites and plans for energy use. These projects use proven technology: gas wells, blowers, generators – mostly imported but operated locally. Going forward, more landfill gas systems could be deployed, as many landfills still vent methane to atmosphere.

Apart from landfills, biogas digesters are being used on some farms (as mentioned for manure) and in some municipal contexts. For instance, Johannesburg's Northern Wastewater Treatment Works has a biogas plant co-digesting sewage sludge and organic waste to generate power for the plant. There's potential to replicate this at other large sewage works or agri-processing facilities (like sugar mills, which can use byproducts for biogas). The technology (anaerobic digesters, gas engines) is well-known; the issue is often economic constraints without incentives. With the new carbon tax, capturing biogas for energy can earn credits, which might spur more adoption.

South Africa has a relatively strong recycling industry for certain materials. For example, the paper recycling rate is around 60–67% in recent years,[41] and plastic recycling rate about 43% (2019/20)[42], which *"positions South Africa as a leader in mechanical recycling"* among emerging economies. These rates have been driven historically by a combination of voluntary industry efforts, the presence of an informal waste picker system, and producer responsibility organizations for materials like glass, cans, paper, etc. In 2021, the government made Extended Producer Responsibility (EPR) mandatory for sectors like packaging, electrical/electronic waste, and lighting. Under these new regulations, producers must ensure collection and recycling of a percentage of their products at end-of-life. This is expected to boost recycling technology and infrastructure – e.g. investments in plastics recycling plants, e-waste dismantling and metals recovery facilities. Already, companies are responding - more advanced plastic recycling plants are opening that can process mixed plastics into pellets for new products. A challenge is that much of SA's recycling (especially plastics) is mechanical and downcycles material; moving to higher-value recycling or chemical recycling for plastics could increase recycling rates further (there are early discussions on a plant for chemical recycling of plastics to fuel or monomers, but no large-scale plants are operational yet).

A number of innovative approaches are emerging in the circular economy:

- Industrial symbiosis, where one company's waste becomes another's input: The Western Cape Industrial Symbiosis Programme (WISP) has facilitated dozens of such linkages, e.g. wood offcuts from a manufacturer used by another to make furniture or pallets. In Gauteng, a similar programme (Gauteng Industrial Symbiosis) exists. These initiatives

[41] https://thepaperstory.co.za/pamsa-announces-south-african-paper-production-and-recycling-statistics/
[42] https://www.esi-africa.com/southern-africa/south-africa-plastic-pollution-on-the-decline-but-more-to-be-done/

often require some technology or process tweak (like shredders, re-processors) to make waste usable and these yield both environmental and economic benefits.[43]

- Upcycling and new products: Entrepreneurs are using waste in new ways – e.g., eco-bricks made from plastic waste mixed with cement, or paving tiles made from recycled plastic (several start-ups exist). There are also innovators turning organic waste into animal feed through insect farming – for instance, AgriProtein in Cape Town breeds black soldier flies that consume food waste and produce larvae for animal feed and fertilizer, a technology that addresses waste and creates new value.

- Electronic waste (e-waste): E-waste is a growing stream with valuable metals. South Africa has a few formal e-waste recyclers (e.g. Desco, AST Recycling) using technologies like shredders, eddy current separators, and even small smelters to recover copper, gold, and other materials. The EPR regulations for electronics are expected to channel more e-waste to such facilities. This is an area where partnership with international technology providers is happening, because extracting precious metals at scale often require advanced technology (hydrometallurgy, etc.).

- Municipal solid waste treatment: Some municipalities are exploring alternatives to landfill:

    - Material recovery facilities (MRFs) to sort recyclables from mixed waste (Johannesburg has a large MRF at its Robinson Deep landfill, mainly manual sorting with conveyor belts).

    - Mechanical biological treatment (MBT): converting the organic fraction of waste into compost or into refuse-derived fuel (RDF). E.g., City of Cape Town ran trials on using RDF from waste as a fuel in cement kilns.

    - Waste incineration with energy recovery is not widely used (due to high capital cost and pollution concerns), but a few small medical waste incinerators with energy recovery exist. Large-scale waste-to-energy incineration hasn't taken off in SA, partly because recycling is preferred and community opposition to incinerators are often experienced.

The circular economy approach in South Africa is in its early days but gaining policy support. In 2020, the DTI (now DTIC) in collaboration with the EU launched the Circular Economy study and report to stimulate innovation in this area.[44] It is acknowledged that a circular economy can create jobs in reuse/remanufacturing while reducing emissions (for example, recycling metals uses far less energy than producing virgin metals, so it cuts industrial emissions).

In climate terms, better waste management reduces methane and offsets virgin production emissions. If South Africa can reach European-level recycling rates (over 50% for plastics, >70%

[43] https://greencape.co.za/sector/circular-economy/wisp/
[44] https://op.europa.eu/en/publication-detail/-/publication/62768223-3e88-11eb-b27b-01aa75ed71a1

for paper), it would significantly cut landfill emissions and create a supply of secondary materials for manufacturing. The main gaps here are consumer separation of waste (household adoption of recycling is still low outside of certain urban areas) and infrastructure (many areas lack collection services for recyclables, and only around 3 of 9 provinces have hazardous waste/e-waste processing facilities). Technology can help – for instance, some municipalities are trying reverse vending machines for recyclables or using applications to connect waste pickers and generators. Social and logistical innovations are as important as technical innovations in this sphere.

4 Gaps in Research, Innovation and Investment

Mapping the current landscape sheds light on where South Africa might be falling short in its climate technology trajectory. These gaps occur in knowledge, research and development (R&D), in the innovation ecosystem (commercializing and localizing technologies), and in investment and implementation on the ground. Recognizing these gaps is essential to formulate effective interventions.

4.1 Insufficient R&D investment and coordination

Multiple stakeholders and studies noted South Africa's public and private R&D expenditure on green technologies is inadequate. South Africa's overall R&D spend is around 0.8% of GDP, below the target of 1.5%. Within that, funding dedicated to climate-related innovation (renewables, batteries, agri-technology, etc.) is limited and often fragmented across agencies. This leads to a risk of remaining an importer of technology rather than developing home-grown solutions. There are pockets of excellence (HySA for hydrogen, CSIR work on energy and climate, universities' work on adaptation crops, etc.), but no large mission-driven programmes besides hydrogen.

The ASSAf report explicitly urged strengthening the National System of Innovation (NSI) to support green technologies, including human capital development. Yet, nearly a decade later, R&D in areas like energy storage, electric mobility, and advanced materials still struggles for funding.

Coordination is another gap – responsibilities are split (some handle research, other climate policy, while other focus on industry) and without a unified technology roadmap, efforts can overlap or leave gaps. There is opportunity for creating a focused "Climate Technology Innovation Programme or Roadmap" pooling funds from DSI, DFFE and international sources (like the Green Climate Fund) to accelerate home-grown innovation in priority fields.

4.2 "Valley of death" – from research to market

Even where South African researchers develop promising technologies, there is a gap in commercialization. For example, prototypes from universities or CSIR (say a new type of solar thermal collector or a climate-smart irrigation device) often do not reach mass production due to lack of venture capital, entrepreneurial support, or market pilots. The innovation ecosystem for hardware startups in clean technology is not very mature – contrast with countries where government provides grants for demonstration projects or firms, or where private venture capital flows into clean tech startups. South African technology SMEs often cite difficulty in obtaining funding beyond early prototype stage. Initiatives like the Technology Innovation Agency (TIA) exist to help bridge this, but their resources are limited relative to the need. This gap means local inventions can languish or be overtaken by imports.

4.3 Local manufacturing and localization gaps

A recurring theme is that many technologies are being deployed, but with imported equipment, meaning fewer local economic benefits and vulnerabilities in supply chains. For example, almost all solar PV panels and wind turbines in REIPPPP were imported (aside from towers and some assembly), and EVs being introduced are fully imported at high cost. This is a gap in leveraging the transition for industrial development. Local manufacturing of climate technologies is constrained by factors such as high capital cost, small domestic market size (thus difficulty achieving scale), skills gaps in advanced manufacturing, and policy uncertainty (e.g. inconsistent localization requirements in procurement). Local innovation and manufacturing should receive more focussed resourcing, as opposed to only implementation – yet since then, local renewable component manufacturers struggle when policies stall (e.g. a wind tower plant closed in 2016 when REIPPPP paused). There is an opportunity as global supply chains shift and with the JETP focus, for South Africa to target niches and localize supply of battery materials, fuel cell components, green hydrogen value chain equipment, or assembly of EVs. Achieving this requires addressing policy and incentive gaps.

4.4 Policy and regulatory barriers

While South Africa has many policies, gaps remain in specific regulations or incentives that could drive technology adoption.

Renewables: Past delays in updating the IRP and bureaucracy in licensing hampered growth. Recent removal of licensing for <100MW embedded generation is positive, but grid access rules still cause delays.

Electric vehicles: There is currently no consumer incentive (like a tax rebate) for EVs and import duties on EVs are high (25% vs 18% for ICE), making EVs very expensive. The draft EV strategy is not yet finalized into clear support measures. This policy gap results in slow EV uptake.

Building efficiency: Enforcement of building codes for efficiency (SANS 10400-XA) is weak; there's no mandatory energy performance certificate rollout except for large buildings (a regulation was introduced requiring display of energy performance for certain buildings, but compliance is nascent). Appliance efficiency standards exist for some products but not all (e.g., no fuel efficiency standards for vehicles yet).

Grid and market rules: Technology like battery storage or demand response could be deployed faster if electricity market rules allowed easier participation or if there were time-of-use tariffs and ancillary service payments. These regulatory enablers are only starting to emerge (NERSA is working on frameworks). Red tape can also slow pilot projects – e.g., experimental technologies might not fit existing standards and thus face permitting hurdles.

Procurement and standards for adaptation technology: On adaptation side, a gap is lack of updated design standards incorporating climate change (e.g., flood lines, wind loads for structures may need revising for future conditions), and lack of mainstreaming climate resilience in procurement (few tenders require climate-resilient designs or materials).

4.5 Human capacity and skills

Many advanced technologies require specialized skills to develop, deploy, and maintain. South Africa faces skills shortages in various engineering fields. For instance, transitioning auto manufacturing to EVs will require retraining workers in battery systems and high-voltage electronics; installing solar PV at scale needs more trained technicians (though this has grown as an occupation); managing biogas or hydrogen systems needs chemical engineers with new expertise. If skills gaps aren't addressed, it becomes a bottleneck, or solution providers end up importing labour along with technology. The education and training system thus needs to anticipate this – incorporating renewables, EVs, sustainable design into curricula, expanding vocational training for green jobs. Some positive shits include TVET colleges offering solar technician courses, and universities launching degrees in sustainable energy or climate change, but scaling up is needed. The NBI pathways stressed that jobs of the future will require a different workforce skill set[45] – hence proactive re-skilling (especially for workers transitioning from fossil-based sectors) is a gap to fill.

4.6 Financing gaps and cost of capital

Deploying technologies at scale demands investment – often up-front costs are high even if lifecycle costs are lower. In South Africa, clean technology projects can face higher financing costs due to perceived risks (policy uncertainty, Eskom's financial woes affecting IPPs, etc.). For smaller players or new technologies, it's even tougher – local banks may be hesitant to fund an unproven technology project. While there is significant international climate finance interest (witness the JETP, and institutions like DBSA trying to facilitate green funding), on-the-ground, many project developers and companies struggle to secure affordable finance to implement projects (like a farmer wanting to install a large solar pump system or a factory wanting to invest in efficient equipment). The Climate Finance Landscape (CPI 2023) report indicates current climate-related investment in South Africa is far below what is needed to meet NDC targets. Gaps include a lack of tailored financial products for green technology (e.g. EV leasing, energy efficiency loans that repay from savings, etc.), and limited use of public finance to de-risk new technology (like guarantees or first-loss facilities). There is opportunity to develop public-private green finance schemes - for example a Green Bank or expansion of DFIs (Development Bank, IDC) in co-funding innovative projects, or results-based subsidies (like paying per ton CO_2 reduced for certain projects) to improve project economics.

[45] https://www.greenbuildingafrica.co.za/nbi-report-south-africas-net-zero-transition-will-need-r6-trillion-in-investments-by-2050/

4.7 Data and awareness gaps

There is still a gap in data availability and awareness that hinders technology adoption. Many businesses and consumers are not fully aware of the newer solutions or their benefits. Knowledge platforms and decision-support tools are needed. The government's Climate Change M&E system and Annual Climate Change Reports are trying to improve data tracking[46], but these need to translate into accessible information for investors and the public. Also, success stories need amplification – companies and individuals are more willing to implement technology if they see peers succeeding. There is a human behaviour aspect to technology adoption – it is a process requiring trust and incentive – and this points to a gap in how technology is promoted in South Africa. Strong awareness campaigns (like what was done for solar water heaters in some cities, or rainwater harvesting during droughts) can make a difference.

5 Interventions to Accelerate Technological Innovation and Deployment

To bridge the gaps above and seize the opportunities of low-carbon, climate-resilient technologies, South Africa will need strategic interventions by government, industry, and civil society. Below are key recommended interventions, aligned with findings from the this stocktake study.

5.1 Boost R&D and innovation funding

South Africa should significantly scale up investment in climate-related research and development, ideally through the creation of a dedicated Climate Technology Innovation Fund. Such a fund could pool financial resources from the DSI, the Department of Trade, Industry and Competition (DTIC), international development partners, and the private sector to support research, pilot projects, and technology development in areas of strategic advantage. These may include innovations such as Fischer-Tropsch catalysts compatible with biomass or green hydrogen (building on Sasol's expertise), advanced battery technologies using South Africa's critical minerals, and climate-resilient biotechnology for agriculture.

In parallel, enhanced support to entities like the Technology Innovation Agency (TIA) and the Green Fund is needed to provide early-stage grants and seed capital to clean-tech start-ups, helping to bridge the "valley of death" between research and commercial deployment. As part of this effort, TIA could lead the development of a national Climate Technology Innovation Roadmap to guide priority setting, coordinate public and private R&D investment, and align South Africa's innovation agenda with its climate and industrial policy objectives. International research partnerships should also be pursued to foster knowledge exchange and attract pilot projects to local sites.

This innovation push should treat green technologies with the same strategic importance once afforded to high-risk, high-reward national initiatives like the Pebble Bed Modular Reactor or the

[46] https://www.dffe.gov.za/ccaq_research

satellite programme. Beyond climate and industrial benefits, such an initiative would also serve to cultivate a new generation of scientists and engineers, strengthening South Africa's long-term skills pipeline for a green economy and just transition.

5.2 Incentivize localization and local manufacturing

South Africa should create enabling conditions for both global and local companies to manufacture climate technologies domestically. This could involve introducing targeted tax incentives or temporary tax holidays for facilities producing components for renewable energy systems or EVs. Local content requirements in public procurement can also play a catalytic role - where government or state utilities procure electric busses, solar panels, or other clean technologies, a percentage of local content should be mandated. This must be paired with technical and financial support to help manufacturers meet the requirements.

To attract foreign direct investment, agencies such as InvestSA or the Department of Trade, Industry and Competition (DTIC) should proactively target strategic investors, such as battery gigafactory developers or solar panel manufacturers from China or India, offering them tailored support to establish operations in South Africa. Investment promotion efforts should highlight the country's access to critical mineral inputs and its position as a gateway to African markets. The Just Energy Transition Partnership (JETP) funding could potentially support aspects of this industrial development, particularly in the electric vehicle and green hydrogen sectors.

Support for local enterprises is equally important. Institutions like the Industrial Development Corporation (IDC) can play a role by offering concessional loans or co-investment to manufacturers producing green technologies. The focus should be on establishing a few high-impact anchor industries that can drive broader localisation. Examples include the vanadium electrolyte production facility underway in East London, a platinum-based fuel cell component manufacturing plant (such as IPM's membrane-electrode assembly facility), or the conversion of an existing automotive plant into an electric vehicle assembly line, potentially negotiated under the revised Automotive Production Development Programme (APDP).[47]

Investing in localisation not only stimulated job creation and skills development but also reduces import dependency, enhancing the long-term economic and political sustainability of South Africa's green transition.

5.3 Enhance financing mechanisms for implementation

Strong collaboration between government, financial institutions, and international partners is essential to develop financing mechanisms that lower the barriers to clean technology adoption for businesses and consumers. A range of complementary approaches can be pursued:

- Green bonds and concessional loans: Municipalities and state-owned entities like Eskom can issue green bonds to finance renewable energy deployment, grid upgrades, and other

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[47] https://naacam.org.za/automotive-production-and-development-programme-apdp/

climate-aligned infrastructure. Private sector actors, including property funds, are also beginning to issue green bonds to fund energy-efficient building retrofits. Government-backed credit enhancements, such as partial guarantees, could help lower borrowing costs and attract broader investor participation.

- On-bill financing and ESCO models: Utilities can play a role in funding the upfront costs of clean technologies, such as solar water heaters or energy-efficient appliances, with repayments recovered through monthly utility bills, offset by user savings. This approach has been used in programmes like City Power's solar geyser rollout in Johannesburg and could be expanded nationally.

- Blended finance for high-risk technologies: Concessional funding sources, including the Just Energy Transition Partnership (JETP) and the Green Climate Fund, can be used to de-risk early-stage or high-capex technologies. For example, providing first-loss capital for projects such as green hydrogen pilots or fleets of fuel cell-powered mining trucks could crowd in commercial investment and accelerate proof-of-concept. Successful pilots can then be scaled through private financing.

- Targeted incentives and smart subsidies: Time-bound subsidies can support the early adoption of proven but capital-intensive technologies. For example, a rebate for residential solar PV and battery storage, similar to the earlier solar water heater rebate, could drive mass adoption while reducing grid pressure. Similarly, a vehicle scrappage scheme paired with purchase incentives for EVs could help catalyse the domestic EV market. These subsidies should be tapered over time to avoid long-term fiscal burdens and to encourage market self-sufficiency.

- Environmental levies: Introducing targeted levies, such as a tax on waste sent to landfill, can help shift the economics in favour of recycling and waste-to-energy technologies. This approach has been effective in other countries and could stimulate circular economy solutions locally.

- Carbon market development: Strengthening South Africa's carbon credit ecosystem is vital to incentivising emissions reductions across sectors. Enhancing the integrity and accessibility of measurement, reporting, and verification (MRV) systems, alongside a credible national carbon registry, will improve alignment with the Carbon Tax Act. Platforms such as Verra's Verified Carbon Standard (VCS), Gold Standard, and emerging domestic registries present a clear opportunity to expand local carbon market participation while supporting international integration.

5.4 Human capital development

A coordinated Green Skills Development Plan is essential to support South Africa's transition to a low-carbon economy. This should include the systematic revision of curricula at universities and Technical and Vocational Education and Training (TVET) colleges to incorporate disciplines such as renewable energy engineering, battery storage technology, electric vehicle (EV) maintenance, and sustainable agriculture. Scholarships and bursaries should be made available to students pursuing studies in climate-critical fields, such as power systems engineering, climate science, and environmental economics, to ensure a pipeline of future expertise.

At the same time, the availability of practical, short-duration training must be expanded. Technical certifications, such as accredited solar PV installer programmes and energy auditor training (currently offered by organisations like SAESA and SAEEC), should be scaled up to reach more technicians nationwide. Companies should be encouraged to reskill existing workers for green sectors, particularly in regions dependent on coal and other high-emission industries. For example, employees at coal-fired power stations could be retrained as solar farm technicians or electricians, with government co-financing such initiatives as part of its Just Transition commitments.

International partnerships can also play a pivotal role in accelerating skills development. Exchange programmes with countries leading in key technologies, such as Germany for renewables, Norway for green hydrogen, or China for EV manufacturing, could offer South African professionals the opportunity to gain practical experience abroad. One example would be to place young engineers in overseas EV battery plants for year-long training placements.

Ultimately, the success of South Africa's climate and technology ambitions hinges on the availability of appropriately skilled professionals. Without this human capital, even the most well-crafted transition strategies will struggle to deliver. Investing in green skills development must therefore be treated as a national priority.

5.5 Strengthen institutions and coordination

Institutional alignment and clear mandates are critical to advancing South Africa's climate technology transition. TIA or the DSI could be designated to take on a central coordinating role in driving the development, deployment, and monitoring of climate-related technologies under the Just Transition. This would include oversight of the implementation of key strategies and alignment of innovation priorities across sectors.

To support this mandate, a Climate Technology Coordination Committee could be established, with participation from key departments such as the DFF), the DTIC the DMRE, the DoT and other industry bodies and institutions. This structure would ensure strategic coherence, helping to align the various technology related strategies (hydrogen strategy, electric vehicle roadmap, and national energy planning) to unlock synergies and innovation, such as leveraging green hydrogen development to support renewable energy integration and decarbonising transport.

In parallel, regulatory processes should be streamlined to reduce administrative barriers and accelerate implementation. Establishing a central entity for permitting renewable energy projects, building on recent progress in exempting certain areas from environmental assessments, can help fast-track deployment. Additionally, regulatory sandboxes (a controlled environment created by regulators that allows companies or innovators to test new technologies, products, or services with real users, but under relaxed or adapted regulatory conditions and close oversight) could be introduced to enable the safe testing of emerging technologies such as autonomous electric shuttles or novel energy systems within controlled environments. These efforts would stimulate innovation while maintaining regulatory integrity.

5.6 Public awareness and behaviour change programmes

National public education and outreach campaigns are essential to accelerate the adoption of high-impact climate technologies. Targeted initiatives should be launched to raise awareness about specific solutions, such as solar water heaters or heat pumps, highlighting their economic and environmental benefits for households. Public demonstrations, coupled with bulk procurement programmes to lower costs, could reignite interest in solar water heating, which has stagnated following earlier national rollouts.

Widespread education on waste separation and recycling is also urgently needed to support the implementation of Extended Producer Responsibility (EPR) regulations. South Africa can draw on international best practices from countries like South Korea and Belgium, where sustained public awareness efforts, paired with user-friendly systems and incentives, have significantly boosted recycling rates.

Social influence plays a powerful role in shaping public behaviour. As noted by ASSAf, early adoption by trusted public figures, combined with effective media campaigns, can accelerate societal acceptance of new technologies. The government can also showcase tangible success stories, for instance, businesses that have achieved substantial cost savings through energy efficiency, or communities benefiting from reliable water access through reuse technologies. These real-world examples can build public confidence and support for climate technologies, helping to normalise their uptake across society.

5.7 Monitoring, evaluation and learning

Establishing a strong system to monitor and evaluate the deployment of climate technologies is essential for informed decision-making and continuous improvement. This includes institutionalising the Low Carbon Technology Stocktake as a recurring exercise, ideally every three to five years, to track progress, identify gaps, and recalibrate strategies where necessary. Systematic evaluation of past initiatives, including both successes and setbacks, should be built into this process. For example, analysing the reasons behind the limited success of the government's earlier solar water heater rollout, such as logistical and implementation challenges, can yield important lessons to strengthen future programmes. The ASSAf report rightly underscores the value of transparency and learning from failure as a core principle for effective innovation policy.

These monitoring and learning mechanisms are not standalone, they form part of a broader enabling environment that supports the full climate technology value chain, from research and development through to widespread deployment. Moreover, well-designed interventions offer multiple co-benefits: they can drive job creation, reduce inequality (for instance, through lower household energy bills), and improve public health by reducing pollution exposure.

With urgency now a defining imperative, as highlighted by the calls for "10x faster renewables" and "rapid electrification," South Africa has a window of opportunity to not only meet its climate goals, but also position its economy as a competitive player in the emerging low-carbon global market.

5.8 Strengthen policy signals and targets

Clear and ambitious targets, underpinned by enforceable policy measures, are essential to drive climate technology adoption at the scale and speed required. Government should update and extend its planning horizons, for example, by setting a renewable electricity target beyond 2030, such as a defined percentage by 2040, to provide long-term market certainty.

The Electric Vehicle (EV) policy should be finalised and implemented, with a clear package of enabling measures. These should include reduced import duties for EVs, direct purchase incentives such as tax credits or rebates, and consideration of a phase-out date for ICE vehicle sales, potentially by 2035, as proposed by the NBI. In the interim, the introduction of mandatory fuel economy standards would incentivise automakers to offer more efficient ICE models while the EV market matures.

In the built environment, energy efficiency codes must be enforced consistently and progressively tightened over time. The scope of mandatory Energy Performance Certificates should also be expanded to cover a broader range of building types, increasing market transparency and stimulating retrofitting activity.

Ultimately, regulations and policy signals should be aligned with South Africa's 2050 target. This requires the establishment of clear intermediate milestones, such as sector-specific targets for 2030 and 2040 (to be considered under the Sectoral Emissions Targets), that map out the expected timeline for technology adoption and emissions reductions. These milestones will provide essential guidance for investors, industry, and the public sector, ensuring that action today remains on track for long-term climate commitments.

6 Technologies Under Advanced R&D for Commercialisation and Localisation

This section zooms in on specific low-carbon and climate-resilient technologies that are being actively researched and developed in South Africa and appear to be at an **advanced stage** – meaning they have progressed through R&D and pilot phases and are on the cusp of commercialization or scale-up. These technologies are crucial because they represent areas where South Africa could establish a competitive advantage or meet strategic needs domestically, thus supporting the just transition. We also consider the localisation potential: can these technologies be produced or largely serviced from within South Africa, creating local value chains? The technologies are grouped by sector or theme:

6.1 Green Hydrogen and Fuel Cell Technologies

South Africa has made a strategic push into the hydrogen economy, capitalising on its abundant renewable energy resources, sun, wind, and available land, as well as its mineral wealth, particularly platinum, which is critical for fuel cell technologies. Several hydrogen-related innovations are now approaching commercial readiness.

One of the most advanced areas is **Proton Exchange Membrane (PEM)** fuel cells. Through the HySA Programme, South Africa has built strong capabilities in PEM fuel cell components, especially those using platinum catalysts. Companies such as HyPlat are manufacturing membrane electrode assemblies (MEAs) with South African platinum, successfully exporting to international clients and proving their global competitiveness. Isondo Precious Metals (IPM), supported by government, is in the process of establishing a facility to manufacture MEAs at scale using local platinum and membranes. A pilot production line has already been tested, and plans for commercial-scale operations are underway. If successful, HyPlat and IPM could position South Africa as a global supplier of fuel cell components, with growing demand in sectors such as vehicles, forklifts, and backup power. Commercialisation will depend on securing offtake agreements, and one opportunity lies in the domestic market, particularly replacing diesel generators at telecommunications towers or in mining operations. Companies like Mitochondria Energy have already demonstrated the feasibility of these applications. The localisation potential is significant, offering high-value manufacturing jobs and platinum beneficiation in line with global trends favouring hydrogen fuel cells for heavy-duty transport and stationary power[48].

Green hydrogen production via electrolysis is also advancing. Electrolysers are needed to produce hydrogen from water using renewable electricity, and while PEM and alkaline electrolyser units are currently imported, South African institutions are conducting R&D on catalyst improvements and systems integration. A notable local development is Klydon's patented hydrogen separation technology, originally developed for uranium enrichment, which could be adapted to upgrade hydrogen purity or produce valuable isotopes. Although not an electrolyser, this technology adds value within the hydrogen supply chain. Several pilot electrolysis projects are now in planning or early implementation. These include a 3.5 MW solar-to-hydrogen facility in Vredendal, intended to supply green hydrogen for industrial applications, and a pilot electrolyser project at Sasolburg, where Sasol and its partners aim to produce green hydrogen for sustainable aviation fuel production. Larger-scale initiatives such as the proposed Boegoebaai Hydrogen Hub in the Northern Cape are targeting commercial operation by 2030. With sufficient market demand, there may be opportunities for local assembly of electrolysers, beginning with balance-of-plant integration and potentially progressing to more substantial localisation of stack components.

Hydrogen-powered vehicles, particularly in the mining sector, represent another promising application. Anglo American's hydrogen-powered haul truck, developed in partnership with Engie and academic institutions including HySA and the CSIR, is a world-first in its class. This 2 MW vehicle has been operating at the Mogalakwena mine since 2022. Anglo American intends to convert additional trucks at this site, effectively establishing one of the first hydrogen-powered mining fleets[49]. The project has fostered a local supply chain, with Plug Power (USA) supplying some fuel cell modules, while much of the system integration occurred locally. The mine includes an on-site solar plant and an 8 MW electrolyser to produce hydrogen, demonstrating an integrated and scalable model. As Anglo commercialises the system within its own operations, and potentially

[48] https://www.thedtic.gov.za/wp-content/uploads/Full-Report-Green-Hydrogen-Commercialisation-Strategy.pdf
[49] https://www.angloamerican.com/media/press-releases/2022/06-05-2022

expands to other sites by 2024, this model could stimulate demand for fuel cell systems in other heavy-duty sectors such as port equipment and long-haul freight[50]. With rising local demand, there may be scope for domestic assembly of fuel cell systems under license, supported by the presence of heavy industry players who can serve as anchor customers[51].

Stationary fuel cells also hold promise for backup and distributed power applications. South Africa has trialled their use in facilities such as the Vodacom headquarters in Cape Town, where fuel cells provided standby power. During periods of load-shedding, hospitals and office parks have explored fuel cells as a cleaner and more reliable alternative to diesel generators. Companies such as Bambili Energy have partnered with international original equipment manufacturers, including Fuji, to deploy demonstration units. If uptake increases, local assembly of stationary systems could become viable. These systems typically rely on platinum catalysts and use components that can largely be sourced locally, with the exception of some specialised elements like membranes. Given South Africa's persistent electricity supply challenges, this segment of the market may be close to commercial viability, particularly if supported through leasing models or targeted government procurement for critical infrastructure.

6.2 Energy Storage Technologies (Beyond Li-Ion)

While lithium-ion batteries remain the dominant technology globally, and will continue to play a major role in South Africa's energy landscape, as evidenced by Eskom's Battery Energy Storage System (BESS) projects, the country is also pursuing innovation in alternative storage technologies where it holds a strategic advantage.

One of the most promising areas is **Vanadium Redox Flow Batteries (VRFBs)**. South Africa is advancing domestic production of vanadium electrolyte[52], a critical input, and positioning itself within the global VRFB supply chain. Bushveld Energy, a key player in this space, is constructing an electrolyte production facility in the East London Industrial Development Zone, with commissioning expected in 2024[53]. While the company currently partners with international VRFB providers such as Invinity and CellCube for cell stacks, its strategy includes localising balance-of-system components such as pumps and tanks over time. A successful 8 MWh VRFB installation at the Vametco mine, coupled with a solar mini-grid, has already demonstrated the viability of the technology under South African conditions. Eskom is exploring VRFBs for long-duration storage applications, which could create substantial domestic demand. If uptake accelerates, full local manufacturing of VRFB systems may become commercially viable. TIPS confirms that much of the VRFB system, including tanks, electronic controls, and bipolar plates, can be manufactured in

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[50] https://www.miningweekly.com/article/greater-fuel-cell-adoption-would-be-a-massive-boost-for-south-africas-platinum-group-metals-2022-04-13

[51] https://im-mining.com/2022/05/06/nugen-mining-truck-a-smart-step-for-anglo-american-giant-leap-for-south-africas-hydrogen-economy/

[52] https://www.tips.org.za/research-archive/sustainable-growth/green-economy/item/4638-localising-vanadium-battery-production-for-south-africa-s-energy-security

[53] https://www.engineeringnews.co.za/article/bushveld-energy-and-partners-deploy-eskoms-first-vanadium-redox-flow-battery-2017-11-21

South Africa, with only membranes and cell stacks initially imported. As the technology evolves, South Africa's strong research base could contribute to cost reductions, for instance by developing affordable membranes through local material science innovations. VRFBs are thus at the cusp of transitioning from pilot demonstrations to early commercial deployment, with South Africa actively positioned along the value chain.

Other emerging technologies are also being explored. **Sodium-ion batteries**, which use more abundant and less critical materials than lithium-ion systems, are receiving attention from research groups at the CSIR and various universities. While not yet commercially advanced in the South African context, global breakthroughs could present a future opportunity for local licensing and manufacturing, leveraging the country's access to raw materials such as sodium salts and existing industrial infrastructure.

Battery recycling technologies are becoming increasingly relevant as battery use scales up. South Africa's metallurgical expertise presents an opportunity to lead in this space. Researchers at Mintek and the University of Cape Town are developing processes to recover valuable metals from spent lithium-ion batteries, with a pilot recycling facility under consideration. As the first generation of electric vehicle and stationary storage batteries approach end-of-life, early investment in recycling could secure South Africa a leadership role in servicing the broader Southern African region[54].

Thermal energy storage is another niche where South Africa has accumulated experience, particularly through CSP projects. Stellenbosch University's Solar Thermal Energy Research Group has developed low-cost storage prototypes, including latent heat storage modules as part of the Helio100 project. Although CSP deployment has slowed, this expertise could be repurposed for applications such as industrial process heat or off-grid storage for agriculture. Early-stage commercialisation efforts are underway by start-ups such as Enertronica, which is developing thermal storage solutions for agri-processing. This segment remains at the R&D to pilot phase, with the market still taking shape.

Energy storage is essential to support renewable energy integration and the electrification of transport. Local manufacturing, whether in vanadium electrolyte production, battery pack assembly, recycling, or thermal storage systems, offers both economic opportunity and strategic resilience. Projects such as Bushveld's VRFB developments and BlueNova's growth in lithium-ion battery assembly demonstrate that South Africa is already making tangible progress in this space.

6.3 Electric Vehicles and Components

The transition to electric mobility presents several key opportunities for technology localisation in South Africa, and the country is already taking early steps to capitalise on them.

Electric busses and mini-busses offer some of the most immediate prospects. South African vehicle body manufacturers, such as Busmark, have the technical capability to assemble electric

[54] https://naamsa.net/wp-content/uploads/2024/12/20240725-IDC-Overview-Value-Proposition-Project-Dev-Process-Battery-Projects-240725.pdf

busses if provided with component kits. One early innovation came from the Cape Peninsula University of Technology (CPUT), which developed a solar-powered electric minibus as a concept project. Since then, small-scale commercialisation has occurred through companies like Mellowcabs in Stellenbosch, which produces electric micro-cabs used at resorts and campuses. More ambitiously, the idea of converting conventional mini-busses to electric, modelled on Kenya's Opibus initiative, is gaining interest in South Africa. Local startups are exploring how to retrofit existing Toyota mini-busses with imported electric drivetrains, a move that could localise both installation and maintenance jobs.

On the bus side, the Green Automotive Industry Alliance (GAIA), led by Busmark and others, has established facilities for electric bus production in South Africa. However, the success of these efforts now hinges on confirmed procurement orders from municipalities or public transport operators. While the underlying technology is advanced, further progress depends on policy support and demand activation.

EV battery assembly and charging infrastructure are also areas of emerging local capacity. Companies such as Metair/Prime Batteries and BlueNova are assembling battery packs for EVs and industrial machinery. These efforts are already commercial, though currently at modest scale. Notably, Metair has retrofitted mining locomotives with its battery systems. As EV production scales locally, the same firms could produce battery packs for the domestic auto market. Simultaneously, the charging infrastructure sector is beginning to take shape. GridCars, based in Pretoria, manufactures some EV charger components and has installed a nationwide charging network[55]. With rising EV adoption, local production of chargers, potentially using imported subcomponents, could become a viable and competitive industry. Other companies such as Sinetech are also entering this space.

Vehicle components and conversion kits represent another avenue for localisation. South Africa's established automotive supply chain already exports wiring harnesses and could pivot to producing EV-specific components such as electronic control units or battery casings. Some elements, like axles and chassis, are shared between ICE and EV platforms, making the transition more feasible. While manufacturing electric motors locally may pose greater challenges, there is scope for strategic partnerships with global EV firms to support component production. The Department of Trade, Industry and Competition (DTIC) is actively promoting an EV Accelerator initiative, which seeks to match South African manufacturing capabilities, such as precision machining, with the needs of the global EV market.

South Africa's prior attempt to create a homegrown EV, the Optimal Energy Joule, offers valuable lessons. Despite reaching the pre-production phase in the 2000s, the project collapsed due to inadequate funding and policy support. Learning from this, today's strategy focuses on attracting global OEMs to localise EV production. For instance, Ford is investing $1.05 billion in its Silverton plant to manufacture next-generation vehicles, potentially including a plug-in hybrid version of the Ranger pickup for export. If realised, such projects could bring EV manufacturing to South Africa

[55] https://www.gridcars.net/

and enable local suppliers to participate under licensing arrangements, thereby deepening domestic capabilities.

Although electric vehicle uptake in South Africa remains relatively low, the domestic industry is actively preparing to transition. Technical expertise in vehicle conversion and battery assembly already exists, and charging infrastructure is expanding. The main barrier to commercial-scale production is not technological readiness, but alignment of policy signals and market demand. With over 100,000 jobs linked to the automotive sector, ensuring a successful shift to electric mobility is a national economic imperative. If current momentum is maintained, South Africa could see its first locally assembled electric vehicle within the next five years, potentially including prototypes like an electric bakkie being explored by Toyota South Africa.

6.4 Renewable Energy Integration and Smart Grid Tech

As South Africa expands its renewable energy capacity, integrating and managing these variable resources is becoming increasingly important. A range of grid-supporting and enabling technologies are being piloted and deployed, positioning the country to modernise its electricity system while fostering local innovation.

Smart grids and advanced metering are progressing steadily. Eskom and various municipalities have rolled out smart prepayment meters and initiated advanced metering for large users. One notable innovation is the FuseForward smart grid platform, developed in collaboration with CSIR, which is being piloted in eThekwini to improve load management and integrate distributed solar generation. Eskom's Virtual Power Plant (VPP) project marks another milestone: this system aggregates dozens of small-scale rooftop solar and battery installations across 70 sites (totalling 1 MW) to behave like a unified flexible resource. The VPP relies on IoT devices and localised control software, developed by South African tech firms in partnership with international suppliers, and could significantly enhance grid flexibility if scaled.

Electric mobility infrastructure is also advancing. Technologies like Zimi Charge[56] (TRL 7), GridCars (TRL 9), and Zero Carbon Charge (TRL 9) reflect the growing maturity of South Africa's smart charging and vehicle-to-grid capabilities. However, realising their full potential will require substantial investment in grid reinforcement and bidirectional charging infrastructure, particularly to enable widespread use of decentralised renewable energy.

Grid decarbonisation technologies are being introduced as well. The installation of South Africa's first SF_6-free switchgear at Eskom's Dalwes substation demonstrates technical readiness for climate-aligned transmission infrastructure. Yet, in contrast to the EU's F-Gas Regulation[57], South Africa lacks a dedicated policy framework to accelerate adoption of SF_6-free alternatives, a gap that warrants urgent attention.

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[56] https://techpoint.africa/news/zimi-320000-ev-power-grid/

[57] https://ec.europa.eu/commission/presscorner/detail/en/ip_24_463

Digital forecasting and AI tools are becoming integral to managing variable generation. South African universities, alongside the SA Weather Service, have developed machine learning-based models tailored to local meteorological conditions. The Energy Research Centre at UCT, for example, has built a solar PV forecasting tool using satellite imagery, enabling better day-ahead planning and more accurate market participation for grid operators and solar asset managers.

Renewable microgrids for remote and underserved communities offer another high-impact solution. A successful pilot in the Eastern Cape electrified a rural village using a solar-battery microgrid equipped with smart meters and autonomous controls, designed by CSIR in collaboration with Eskom. These containerised solutions, now marketed to farms, lodges, and small towns, are ready for deployment and present strong localisation potential in system assembly, installation, and software development[58]. Companies such as Zuhura Solutions and ENGIE are active in this emerging market, which aligns well with South Africa's universal energy access goals.

Concentrated Solar Power (CSP) with storage remains a technically promising, though underutilised, technology. Local CSP innovation, such as the Helio100 mini-heliostat field developed at Stellenbosch University and a Stirling dish prototype from Stirling Energy, has reached advanced R&D stages. While PV's declining costs have limited CSP uptake, these systems still offer valuable dispatchable power options, especially for off-grid mining operations or industrial heat applications.

Emerging renewable technologies are also being explored. Floating solar PV is undergoing pilot testing on Western Cape reservoirs to assess benefits such as reduced evaporation and additional generation capacity. Meanwhile, South African universities have developed early-stage prototypes of wave and tidal energy converters suitable for local coastal conditions. These marine technologies are still in the R&D phase but could see commercial deployment in the 2030s if viability is demonstrated.

These advances indicate that South Africa is not only scaling up renewables, but also building the technological foundation to support a resilient, decentralised, and intelligent power grid. These developments will be essential to ensure energy reliability and flexibility as more intermittent and distributed sources are integrated into the system.

6.5 Resource Efficiency and Circular Economy Innovations

A recurring theme across these emerging technologies is the strong potential for localisation. South Africa's established capabilities in heavy industry, mining, and manufacturing create a solid foundation for domestic production of many components, provided there is targeted support and strategic alignment. For instance:

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[58] https://www.pv-tech.org/south-africa-raises-licensing-exemption-threshold-for-embedded-generation/

- Fuel cells and MEA manufacturing can leverage South Africa's metallurgical and chemical expertise, particularly its platinum resources and related membrane technologies, as is already being demonstrated locally.
- Battery pack assembly draws on the country's automotive and electronics capabilities. Small firms are already producing battery packs, and with scaling, these could supply future EV production lines.
- Electric busses and vehicle conversions tap into South Africa's mature coach-building and automotive sectors. Local companies have demonstrated prototypes and are ready for commercialisation with the right demand signals.
- Vanadium redox flow batteries (VRFBs) benefit from the country's strong mining and chemical industry base. Domestic production of vanadium electrolyte is already underway, and further value-chain localisation, such as assembling full battery systems, is within reach.
- Even in less obvious sectors like solar PV manufacturing, South Africa has the potential to scale. With domestic silicon smelters and historical panel assembly capacity (e.g., ARTsolar in Durban), a resurgence in local production is plausible, especially as shipping costs and global supply chain disruptions make regional production more attractive for bulky goods like PV panels.

Achieving meaningful localisation, however, hinges on predictable and sustained demand, either through a strong domestic market or export agreements, as well as structural enablers like competitive energy pricing, reliable infrastructure, and skilled labour. While South Africa may not compete with global leaders like China in low-cost mass production, it can target high-value and niche segments, such as platinum-based fuel cells, bespoke battery chemistries utilising local minerals, or decentralised solar-powered water systems tailored for African contexts.

Industrial policy instruments, particularly the sector-specific Master Plans, are beginning to prioritise green technologies. The Automotive Master Plan now includes EV production and related components, while the Mining Master Plan promotes local beneficiation of battery minerals, signalling alignment with green reindustrialisation.

Opportunities also exist in the resource efficiency and built environment sectors, where products such as insulation materials, energy-efficient building components, and smart meters offer localisation potential. A notable example is Cape Town's polyethylene insulation manufacturing sector, which scaled up in response to RDP housing retrofits. Similarly, Sedgeley Energy in KwaZulu-Natal has developed locally tailored solar water heaters and was able to ramp up production during previous national programmes.

6.6 Carbon Capture and Storage Technologies

Carbon capture and storage (CCS) is another area of focus for South Africa, with practical capability now emerging, centred on the Council for Geoscience's pilot research site at Leandra, Mpumalanga[59]. The site follows a multi-year characterisation programme and was formally inaugurated in 2024 to progress design and injection preparations. Globally, CCS technologies vary in maturity across capture, transport and storage, with several elements proven at scale while others remain at prototype or demonstration stage. In South Africa the technology is still at an early stage, and the Leandra pilot represents a significant step toward understanding technical and geological aspects under local conditions. Further research and demonstration projects will be needed to move from pilot to commercial readiness, alongside policy and market enablers.

The most advanced engineered pathway under active investigation is mineral carbonation of mine and industrial tailings[60]. A notable example is the South African Tailings for use in Carbon Capture, Utilisation and Storage Project, led by the Universities of Pretoria, Southampton, and Cape Town since 2019, which is cataloguing mafic and ultramafic mine tailings across the country for their potential to permanently sequester CO_2 This work includes compiling national databases, GIS resources, and sequestration potential estimates, providing a foundation for pilot studies and possible large-scale projects. Direct Air Capture with Carbon Storage is recognised as carbon dioxide removal (CDR) only when paired with durable storage, but there are currently no local projects operating. Similarly, Bioenergy with Carbon Capture and Storage has no deployments in South Africa. CCS activity remains pre-commercial, with efforts focused on proving durability, lowering costs, and identifying pathways that could also support circular economy uses for tailings, such as valorisation, artificial soil engineering, and materials production.

South Africa stands on the cusp of commercialising a portfolio of promising technologies, ranging from advanced systems like fuel cells, hydrogen, and batteries, to practical, socially impactful solutions such as electric mobility, precision agriculture, and circular economy innovations. Strategic investment and coherent industrial policy can unlock domestic production capacity, reduce import dependency, and maximise the economic and employment benefits of the climate transition, ensuring these gains are broadly shared in support of a just transition.

7 Regional and International Context

Although this study focuses on South Africa, it is valuable to place the country's low-carbon technology adoption in a broader regional and global context.

Regionally, South Africa remains a front-runner in several areas. It has the largest installed renewable energy capacity on the continent, driven by the REIPPPP programme, and a relatively advanced scientific and industrial base in fields such as hydrogen, nuclear energy, and automotive manufacturing. Its automotive sector, in particular, positions it uniquely for an EV transition, as no other African country manufactures vehicles at scale. However, other African nations are making significant strides that offer lessons and competitive pressure. Morocco has rapidly expanded its renewable portfolio, now supplying around 35% of its capacity, and developed local solar manufacturing, including the world's largest CSP plant. Kenya is emerging as a leader in

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[59] https://www.geoscience.org.za/media/news/minister-gwede-mantashe-inaugurates-south-africas-first-pilot-ccus-research-site-in-mpumalanga/

[60] https://www.up.ac.za/sat4ccus

geothermal energy and e-mobility, with electric busses and motorbikes already being piloted extensively. Namibia and Mauritius are also advancing ambitious green hydrogen initiatives, with Namibia leveraging superior solar potential and land availability to position itself as a future exporter of green hydrogen. To maintain its lead, South Africa must accelerate its deployment of clean technologies and explore regional collaborations, such as building a Southern African battery supply chain, drawing on cobalt and lithium from the DRC and copper from Zambia, or leveraging the SADC power pool to integrate large-scale renewables across borders.

Globally, the pace of transition is accelerating. Major economies are investing heavily in green technologies, with initiatives such as the US Inflation Reduction Act, the EU Green Deal, and China's dominance in EVs and solar manufacturing reshaping global markets. For South Africa, this presents both risks and opportunities. If the country lags in technology adoption, its exports may face rising trade barriers such as carbon border tariffs, and local industries could lose competitiveness. Conversely, by capitalising on its resource base and industrial strengths, South Africa could attract global investment and carve out niche roles in areas such as green fuel production or mineral beneficiation with clean technologies. Climate Action Tracker has highlighted that South Africa's climate policies remain insufficient to align with the 1.5°C pathway, underscoring the need for accelerated deployment of low-carbon technologies to complement its more ambitious updated NDC.

Encouragingly, international partnerships and financial support are emerging. The $8.5 billion Just Energy Transition Partnership (JETP) provides a framework for mobilising concessional finance and technical assistance, while bilateral collaborations, such as those with Germany on green hydrogen and with Japan on EV development, are opening pathways for knowledge transfer and co-investment. South Africa can also learn from global examples of just transition planning. For instance, Germany's coal phase-out programmes offer a model for repurposing coal-fired power stations, as demonstrated by the Komati power station, which is being converted into a solar and battery hub with World Bank support. Leveraging such partnerships and aligning them with national priorities will be critical for South Africa to remain competitive in the global low-carbon economy.

8 Conclusions

South Africa stands at a critical juncture in its pursuit of a low-carbon, climate-resilient future. This report has mapped a growing ecosystem of technological innovation, revealing clear signals of progress: utility-scale renewables are steadily expanding, energy-efficient and green buildings are entering the mainstream, hydrogen fuel cells and battery systems are emerging from local labs, and digital tools are enhancing agricultural and water resilience. Importantly, the country is no longer starting from scratch. It has developed solid policy frameworks, from the National Climate Change Response White Paper to the Just Transition Framework, and has articulated clear ambitions through its NDC and Long-Term Low Emissions Development Strategy. The urgent task now is implementation at speed and scale. Several overarching conclusions emerge:

8.1 Untapped Potential and Emerging Strengths

South Africa possesses vast and largely underutilized solar and wind resources, significant industrial capacity, and a technically skilled workforce. Proven technologies such as solar PV, wind power, heat pumps, and efficient appliances are readily available and increasingly cost-effective, yet they remain under-deployed. Bridging the gap between the current roughly 9% renewable share and the >50% required by the 2030s is both feasible and essential. Simultaneously, the country is positioning itself in future-facing sectors such as green hydrogen, EVs, and energy storage. With deliberate policy and investment, these could catalyse a new generation of green industries and unlock economic diversification as the country shifts away from coal.

8.2 Addressable Gaps in Policy, Finance, and Skills

Despite promising pockets of innovation, bottlenecks in implementation persist, stemming from regulatory uncertainty, limited R&D funding, fragmented institutional coordination, and skills mismatches. These are not insurmountable. For instance, targeted incentives could unlock domestic EV assembly, while expanding localisation support would enable small-scale battery and charger manufacturers to scale. Strategic public procurement, such as green public transport and building retrofits, could send market signals that activate demand. Echoing long-standing recommendations from bodies like ASSAf, South Africa must shift from being a passive technology importer to an active developer and manufacturer of green technologies.

8.3 Just Transition as a Unifying Imperative

Throughout the landscape explored in this report, the central thread is clear: a successful climate response must be socially inclusive. Technologies like distributed renewables, water-smart agriculture, and microgrids can empower poor and marginalised communities, if designed with equity in mind. A just transition must prioritise job creation, reskilling, and equitable access to new opportunities. The potential for regional revitalisation is significant, particularly in coal-dependent provinces like Mpumalanga, where repurposed power plants and new energy hubs are already being piloted. The transition must not deepen inequality, it must be a vehicle to reduce it. This is not only a moral imperative but a practical one: without public buy-in and socio-economic benefits, transition risks will stall progress.

8.4 Harnessing International Momentum and Partnerships

South Africa need not face the transition alone. The global technological race, from the US Inflation Reduction Act to China's renewable manufacturing surge, offers both competitive pressure and collaborative opportunity. Partnerships under the Just Energy Transition Partnership (JETP) signal growing international recognition of South Africa's strategic role. Projects like Komati's solar and battery repowering showcase the type of innovation and international cooperation that can be scaled. Future bilateral partnerships, such as with Germany on hydrogen or Japan on EVs, must be leveraged not just for capital, but for knowledge transfer and industrial upgrading. However, global credibility depends on delivery: how JETP funds are used will serve as a benchmark for future support.

8.5 The Twin Challenge of Mitigation and Adaptation

Climate impacts are no longer future risks, they are current realities. Droughts, floods, and heatwaves are disrupting communities and economies, demanding parallel investment in resilience. Technologies like AI-powered forecasting, desalination, precision agriculture, and landscape restoration offer tangible tools to build adaptive capacity. Adaptation is not a secondary issue, it is central to ensuring food security, water access, and continued development under a changing climate. These adaptation technologies often have high localisation potential and can be aligned with economic resilience outcomes, reinforcing their importance in the just transition agenda.

South Africa's technology landscape is both promising and precarious. The technologies required for a low-carbon and climate-resilient future largely exist; where they don't, local researchers and entrepreneurs are charting the way forward. What is now required is rapid deployment, localisation of manufacturing and services, and equitable distribution of benefits. With coordinated action across government, industry, labour, academia, and communities, the country can turn the innovations profiled in this report into tangible outcomes. Within the next five to ten years, essentially the remainder of this decisive decade, South Africa can shift from planning to delivery, from prototype to production, from fragmentation to integration.

The vision is within reach: solar panels powering homes once reliant on coal, electric mini-busses gliding through city streets, precision tools transforming agriculture, microgrids lighting up rural villages, and a new generation of green jobs revitalising communities. A just, climate-resilient, and competitive South African economy is not a distant dream, it is a strategic and achievable goal.

8.6 Advancing to a Carbon Neutral Future

This study provides an evidence-based mapping of South Africa's current and emerging green technologies, highlighting both what is already available and what is still required to achieve a carbon neutral economy. Many assessed technologies, such as large-scale renewable electricity generation, industrial energy efficiency measures, and certain circular economy interventions, are already commercially deployed domestically, supported by established supply chains and proven operational performance. Others, including advanced storage, low-carbon fuels, and certain process-specific decarbonisation options, are nearing commercial viability but require targeted policy support, financing, and infrastructure to be deployed at scale.

Achieving carbon neutrality will require a dual approach: rapidly scaling the deployment of existing viable technologies, while accelerating the commercialisation and uptake of those that are currently emerging or underdeveloped in the South African market. Some critical solutions identified in this report remain at lower technology readiness levels or are absent entirely from domestic supply chains, signalling the need for investment in R&D, demonstration projects, and international technology collaboration.

The PCC's recommendations for the updated 2030 – 2035 NDC's sectoral contribution ranges provide a basis for interpreting the findings form this study. In many cases, technologies with high readiness levels in this stocktake already align with the PCC's recommended near-term priorities, particularly in renewable energy deployment, industrial efficiency, and sustainable mobility.

However, in other areas, such as green hydrogen, certain industrial process decarbonisation measures, and nature-based carbon removal, current deployment levels and innovation readiness fall short of the PCC's identified needs. This underscores the importance of targeted investment, coordinated policy support, and accelerated demonstration projects to close the gap.

The findings can support a range of decarbonisation pathways, including those outlined by the PCC and reflected in national planning processes. While many different trajectories can be considered, the enabling factors, constraints, and technology readiness insights presented here remain relevant across all potential scenarios. This study does not prescribe a single net-zero pathway or conduct a sufficiency test against any single pathway; however, by outlining the current technology landscape, identifying those nearing viability, and flagging where new solutions will be required, this report provides a critical evidence base to guide strategic investments, targeted policies, and partnerships that close the gap between today's capabilities and South Africa's long-term net-zero ambition.

9 APPENDIX A: MCA

The tables below provide the MCA weightings and present summaries of the Multi-Criteria Analysis (MCA) output, highlighting the top-ranked low-carbon and climate-resilient technologies based on their performance across the prioritisation criteria.

Criteria	Scoring Indicators	Weighting	Weighted Score	Weighting	Weighted Score
Mitigation	GHG Emissions Reduction/ Avoidance Potential	20%	0,200	10%	0,100
Adaptation	Technology Resilience to Climate Change Potential to Support Adaptation	10%	0,050	20%	0,100
Environmental Impact	Resource Efficiency Circular Economy Support	5%	0,025	5%	0,025
Just Transition Support	Skills Availability in the Workforce Equity, Inclusion and Social Benefits Job Creation Potential Local Value Chain Development Economic Resilience	30%	0,250	30%	0,250
Policy and Regulatory	Alignment with Policies Regulatory Barriers	5%	0,100	5%	0,100
Technical Readiness and	Scalability Potential Catalytic Opportunities	5%	0,050	5%	0,050
Commercial Viability	Capital intensiveness Operational costs Investment attractiveness	5%	0,033	5%	0,033
Infrastructure Requirements	Compatibility with existing Development needs Service delivery Green industrialisation	15%	0,075	15%	0,075
Adoption Risks	Technical Risks Acceptance and Adoption Risks International Review	5%	0,050	5%	0,050
Technology Score			83,3		78,3

Figure 2: MCA Weightings

Table 1: Technologies MCA output ranked for mitigation and adaptation

Technologies	Sector	TRL	Mitigation Score	Adaptation Score	Mitigation Rank	Adaptation Rank
Municipal and Agricultural Waste Conversion	Waste	9	95.0	95.0	1	1
Ecosystem Restoration and Afforestation	AFOLU	9	92.5	92.5	2	2
Biogas Production	Energy	8	91.7	91.7	3	3
Biochar Production	Agri	7	89.0	89.0	4	4
SF_6-Free Switchgear	IPPU	9	87.1	87.1	5	5
Waste-to-Sustainable Aviation Fuel	Waste	5	84.6	84.6	6	6
Hempcrete and Hemp-based Construction Materials	IPPU	6	84.2	84.2	7	7
Vanadium Redox Flow Batteries	Energy	8	83.3	83.3	8	8
Electric Vehicle Charging Infrastructure	Energy	8	82.5	82.5	9	9
Lead-acid Battery Electric Vehicles	Energy	9	82.5	77.5	10	14
Atmospheric Water Generators Powered by PV	Energy	4	81.1	81.1	11	10

Technologies	Sector	TRL	Mitigation Score	Adaptation Score	Mitigation Rank	Adaptation Rank
Utility-scale Solar and Wind	Energy	9	80.1	80.1	12	11
Solar-powered Desalination	Energy	7	79.8	79.8	13	12
Battery Assembly	Energy	9	79.0	79.0	14	13
Direct Lithium Extraction & Rare-Earth Recycling	IPPU	4	76.1	76.1	15	15
Wave Energy	Energy	5	72.9	67.9	16	21
Small Modular Reactors	Energy	7	72.3	72.3	17	16
Flue Gas Carbon Capture and Use	IPPU	5	70.8	60.8	18	27
Solid-State EV Batteries	Energy	5	70.7	70.7	19	17
Silicon Isotope Technologies	IPPU	5	69.0	69.0	20	18
Lithium-ion and Smart Modular Batteries	Energy	9	68.6	68.6	21	19
Hydrogen Direct-Reduced Iron	IPPU	4	68.2	68.2	22	20
Green Steel	IPPU	6	67.5	62.5	23	24
Mineral Beneficiation & Critical-Minerals Value Chains	IPPU	6	67.3	62.3	24	25
Acid Mine Drainage Remediation	Waste	2	66.5	61.5	25	26
Advanced Geothermal & Closed-Loop Heat Mining	Energy	4	66.3	66.3	26	22
Green Hydrogen	Energy	6	64.4	64.4	27	23
Carbon Capture and Use	IPPU	6	55.3	50.3	28	28
Hydrogen Fuel Cell Trucks in Mining	Energy	8	55.1	50.1	29	29
Trolley Assist Systems	Energy	9	53.3	48.3	30	30
Plastic Pyrolysis to Fuel	Waste	7	41.9	46.9	31	31

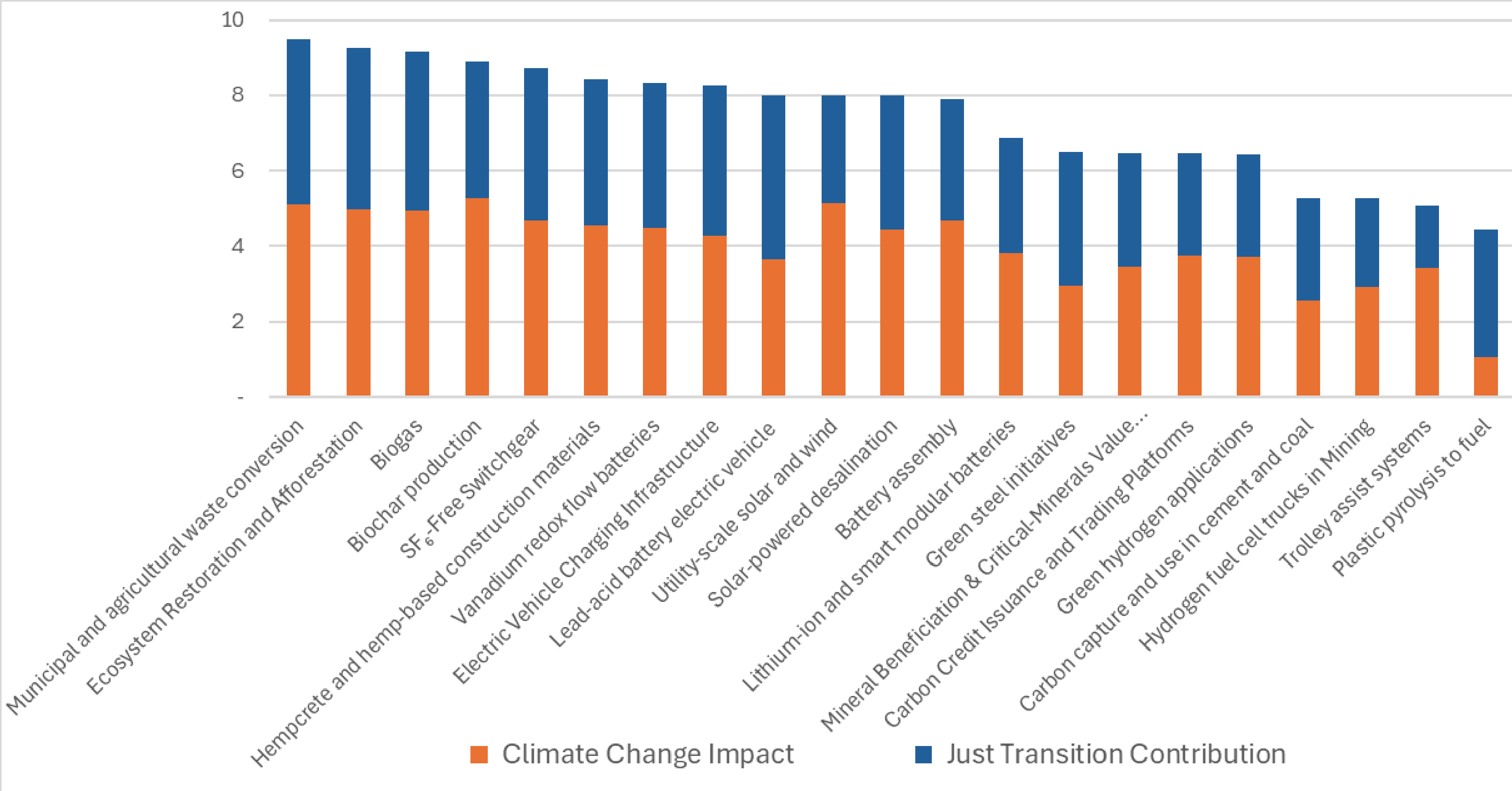

Figure 3: TRL 6 - 9 MCA Output: Just Transition Focus (equal mitigation/adaptation weighting)

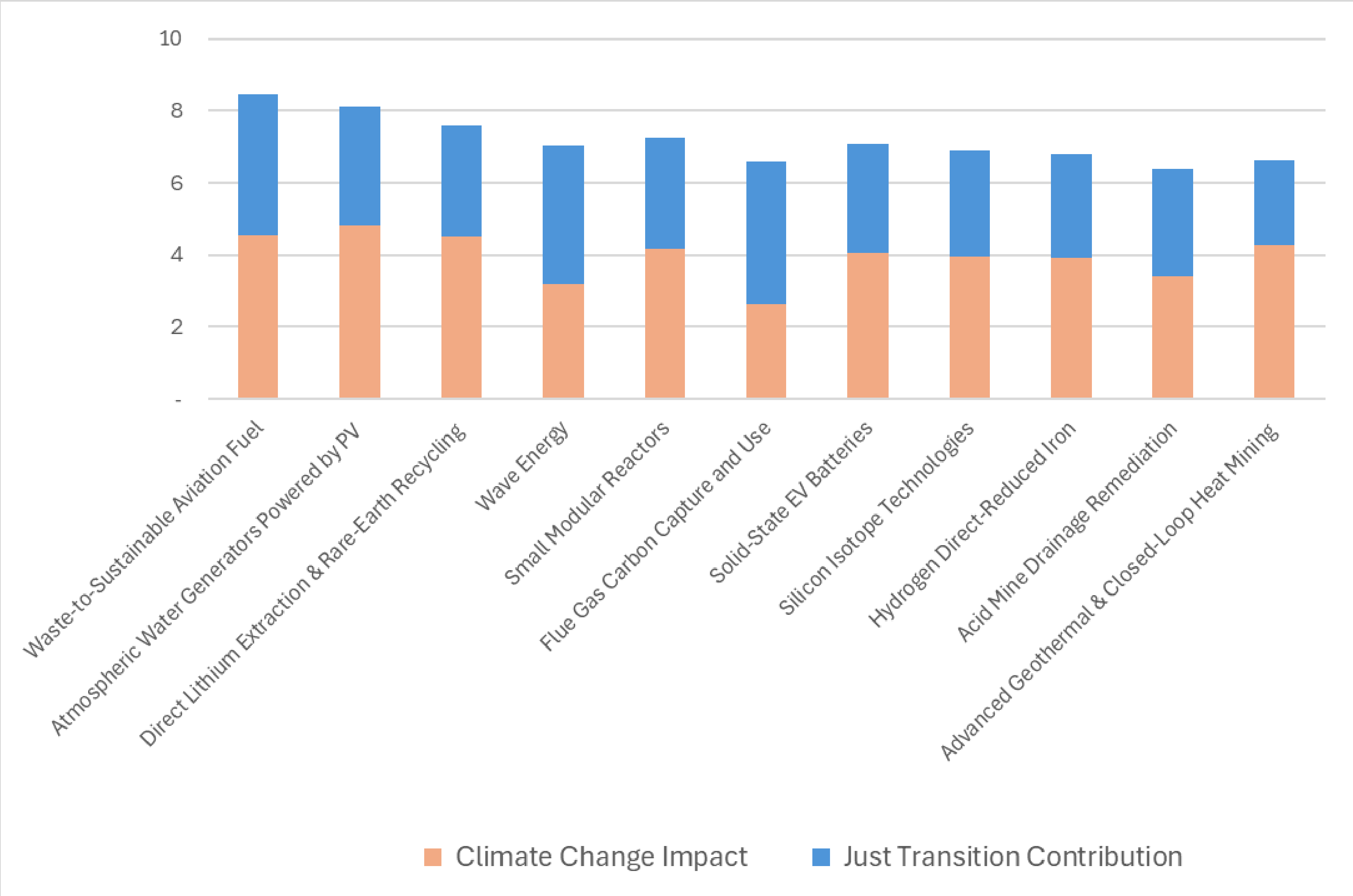

Figure 4: TRL 1 - 5 MCA Output: Just Transition Focus (equal mitigation/adaptation weighting)