PRESIDENTIAL
CLIMATE COMMISSION
TOWARDS A JUST TRANSITION

PRESIDENTIAL CLIMATE COMMISSION

TECHNICAL REPORT SUPPORTING THE RECOMMENDATIONS FOR SOUTH AFRICA'S ELECTRICITY SYSTEM

May 2023

ABOUT THE PRESIDENTIAL CLIMATE COMMISSION

The PCC is a multi-stakeholder body established by the President of the Republic of South Africa to advise on the country's climate change response and pathways to a low-carbon climate-resilient economy and society. In building this society, South Africa needs to ensure decent work for all, social inclusion, and the eradication of poverty. Those most vulnerable to climate change, including women, children, people with disabilities, the poor and the unemployed need to be protected, and workers' jobs and livelihoods also need protection. The PCC facilitates dialogue between social partners on these issues and, in particular, defining the type of society we want to achieve and detailed pathways for how to get there.

ABOUT THIS REPORT

This report presents the technical analyses that underpins the PCC's recommendations for South Africa's electricity system. The analyses, and subsequent recommendations, are based on significant research, evidence, and stakeholder engagement with all social partners, set against the current national policy framework, notably the National Development Plan, the Just Transition Framework, and South Africa's climate commitments (the NDC).

This technical report forms part of a series of three reports, all available on the PCC website, that should be read together:

1. The Electricity Planning Recommendations Report, which describes the recommendations of the PCC to the President of the Republic and Cabinet based on our research and engagement with stakeholders.
2. The Stakeholder Perspectives Report, which presents the unfiltered perspectives of the stakeholders consulted in preparing the PCC recommendations on electricity planning.
3. The Technical Report (this report), which holds the summary of the PCC's technical research work that informed the consultations and recommendations report.

This body of work focuses on South Africa's electricity system (i.e., electrical energy/power). While climate change will drive low carbon transitions across the broader economy and wider energy sector (e.g., transport and liquid fuels), the current focus is on electricity, largely due to the current electricity crisis and the concurrent review of the Integrated Resource Plan (IRP) 2019. The supporting technical report provides an objective critique of existing electricity plans/studies. Over time, the scope of research and recommendations will expand to include other energy sub-sectors. Terms like "energy efficiency" and the "Just Energy Transition" should therefore be understood within the context of the electricity sector.

Where the reader may disagree with the conclusions reached in this document, or where readers feel key pieces of information have been missed, the Commission welcomes additional research and insight. Such information should be sent to mitigation@climatecommission.org.za. The Commission will investigate all recommendations and questions that are substantiated with well researched, data-driven evidence.

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Abbreviations

CCUS	Carbon Capture Utilisation and Storage
DFIs	Development Finance Institutions
DMRE	Department of Mineral Resources and Energy
DPE	Department of Public Enterprises
EAF	Energy Availability Factor
EPP	Electricity Pricing Policy
FIT	Feed-in-tariff
GHG	Greenhouse Gas
IPPO	Independent Power Producers Office
IPP	Independent Power Producer
IRP	Integrated Resource Plan
ITSMO	Independent transmission, system, and market operator
JET-IP	Just Energy Transition Investment Plan
JETP	Just Energy Transition Partnership
LCOE	Legalised Cost of Electricity
LEDS	South Africa's Low Emissions Development Strategy
MES	Minimum Emissions Standards
MYPD	Multi-Year Price Determination
NDC	Nationally Determined Contribution
PCC	Presidential Climate Commission
RE	Renewable Energy
REFIT	Renewable Energy Feed-in Tariff
SMME	Small, micro, and medium enterprises
UNFCCC	United Nations Framework Convention on Climate Change
VRE	Variable Renewable Energy

1. Introduction

1.1. Background

The Presidential Climate Commission (PCC) agreed, in the February 2022 PCC Strategy Session, to make recommendations on how best to include the carbon-constraint in energy planning and governance. The PCC agreed to:

1. Make recommendations on an energy mix and energy governance structure that enables South Africa to achieve the emissions trajectory set out in our Nationally Determined Contribution (NDC) commitments (the Carbon Budget).
2. Base recommendations on best available science and modelling that considers all aspects of a Just Energy Transition – affordability, stability, reliability, environmental sustainability, job creation and decarbonisation.
3. Approach this in a participatory and inclusive way, enabling engagement by all social partners and allowing for greater transparency and accountability.

1.2. Report objectives

The PCC aims to set out recommendations to policymakers on critical decisions that need to be made in the short to medium term, to ensure a Just Energy Transition, specifically within the electricity sector, as well as recommending long-term pathways. This includes recommendations for developing future electricity systems in the long term that are reliable, stable, and affordable, and help to meet South Africa's international climate commitments while catalysing sustainable, low carbon economic development and job creation.

In this context, this report presents the technical analyses that support the recommendations, providing an overview of the electricity planning landscape, including key considerations: risks, co-benefits, and trade-offs associated with electricity regulations, policy and governance, air quality and water usage, the pace of coal transition, local beneficiation and re-industrialisation, and requirements for a Just Energy Transition.

This report also considers existing plans and interventions to deal with the current electricity crisis, and how decisions taken in the short term have implications for long-term aspirations. Recommendations will also frame the required shift of the electricity system in the context of a Just Energy Transition, which is based on the Cabinet-approved Just Transition Framework.

1.3. Methodology

The Technical Report provides a critique of several electricity planning studies and scenarios[1] against criteria related to (i) energy equity, (ii) energy security, (iii) environmental sustainability, and (iv) socio-economic sustainability. The aim was to identify an electricity generation pathway that best balanced these four energy planning requirements for ensuring a Just Energy Transition in South Africa.

The PCC also conducted a series of stakeholder consultations on the Electricity Planning Recommendations (including both the "Recommendations Report" and this "Technical Report"), the

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[1] NBI, BSG and BUSA. 2022. Decarbonising South Africa's Power System.; ESRG UCT. 2022. Exploring Net Zero pathways for South Africa. An initial study. CSIR and Meridian Economics. 2020. Technical Report: Systems analysis to support increasingly ambitious CO_2 emissions scenarios in the South African electricity system. ; World Bank. 2022. South Africa Country Climate and Development Report.; DMRE. 2019. Integrated Resource Plan 2019.; PCC. 2021. South Africa's NDC targets 2025 and 2030.

Just Energy Transition Investment Plan (JET-IP[2]) and additional expert consultations. Stakeholder feedback from these consultations was incorporated into the Electricity Planning Recommendations, with references throughout the Technical Report. A more detailed account of stakeholder inputs was captured in a complimentary report: "Stakeholder Perspectives on the PCC Recommendations on Electricity Planning in South Africa".

The technical analyses presented in this Technical Report and the stakeholder consultations resulted in a Recommendations Report. The Recommendations Report sets out the preferred long-term pathway and supported short-term initiatives required to ensure an electricity mix based on the best available evidence and imperatives for a Just Energy Transition.

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[2] The Presidency, Republic of South Africa. 2022. South Africa's Just Energy Transition Investment Plan (JET-IP).

2. The Just Energy Transition and South Africa's national interest

2.1. The National Development Plan

South Africa's National Development Plan (NDP) 2030[3] sets out the national interest through ambitious economic development targets for addressing unemployment, poverty, and inequality – referred to as the triple challenge. It also identifies several "enabling milestones", including the need to *"produce sufficient energy to support industry at competitive prices, ensuring access for poor households, while reducing carbon emissions"*.[4] The NDP, therefore, acknowledges the importance of an affordable, accessible, reliable, stable, and environmentally sustainable electricity supply as a critical enabler for addressing the triple challenge (see Text Box 1).

> *Vision 2030: "By 2030, South Africa's transition to an environmentally sustainable, climate-change resilient, low carbon economy and just society will be well under way."*

TEXT BOX 1: SOUTH AFRICA'S TRIPLE CHALLENGE

Despite good progress being made since 1994, South Africa continues to face three key socio-economic developmental challenges: unemployment, poverty, and inequality – referred to as the *triple challenge*. The overall unemployment rate is currently at ~32.7% (Q4 2022), with a small 2% improvement compared to the same time in 2021. Unemployment is also higher amongst women (35.5% compared to 30.4% for men) and youth (39.9% for ages 25-34 years old, compared to 32.7% across all ages).[5] Since the COVID-19 pandemic, it's likely that more than 55% of the population are living in poverty, and inequality continues to be a significant challenge. South Africa is well known for being one of the most unequal societies in the world, with a Gini Coefficient of 0.63 and where the top 10% of the population own 86% of aggregate wealth.[6]

2.1.1. The importance of electricity in addressing the triple challenge and the risk of climate change

Electricity is a critical input for most, if not all, formal and informal economic activities, and is strongly linked with economic development. Higher GDP, for example, is correlated with greater electricity use, access, reliability, and affordability.[7] While correlation does not imply causation, access to electricity remains critical for addressing the triple challenge. This is true at all scales and across all sectors of the economy, from large industries like mining, and manufacturing right through to small, medium, and micro enterprises (SMMEs), and the household economy. Electricity is also essential for delivering basic public services. The direct investment in electricity infrastructure also creates jobs and increases GDP. Sustainable Development Goal (SDG) 7[8] - "*ensure access to affordable, reliable and sustainable modern energy for all*" – articulates the developmental challenges most countries face and the importance of electricity in enabling economic development.

The NDP also acknowledges the risks of climate change to South Africa's developmental objectives and the importance of a low carbon economic transition. It highlights South Africa's vulnerability to climate change, and how it can negatively impact livelihoods, health, food, energy, and water security,

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[3] RSA. 2012. National Development Plan 2030: Our future - make it work.
[4] RSA. 2012. (pg. 34).
[5] Statistics South Africa. 2022. Quarterly Labour Force Survey. Quarter 4: 2022.
[6] World Bank. 2021. South Africa Overview.; Statistics South Africa. 2017. Poverty trends in South Africa: An examination of absolute poverty between 2006 and 2015.; Statistics South Africa. 2019. Inequality trends in South Africa: A multidimensional diagnostics of inequality
[7] Jack. 2022. How much do we know about the development impacts of energy infrastructure?
[8] The Global Goals. N.d. Affordable and clean energy.

particularly among the poor, women, and children.[9] These climate impacts risk exacerbating the triple challenge.

Decarbonising South Africa's energy sector, particularly the electricity sector, is a vital enabler for the broader low carbon transition. Given its carbon intensity, transitioning the electricity sector will help mitigate climate change, promote environmental sustainability, and support improved public health via reduced air pollution and future climate change-related risks. A low carbon electricity sector will also help avoid the international transition risks and open new markets and export opportunities (e.g., green hydrogen production for export to the EU).[10]

Without a reliable, stable, and affordable electricity supply, the economy can't diversify and grow, and risks contracting. This limits the opportunity to lift people out of poverty and eradicate unemployment and inequality. All sectors, including South Africa's citizens, will therefore benefit economically and environmentally from a secure, affordable, and low-carbon electricity sector.

From a technology deployment perspective, the electricity sector is regarded as a "low-hanging fruit", relative to other hard-to-abate sectors (e.g., transport, construction). Please refer to Section 7 for more information on the different electricity generation technologies.

The NDP recognises the opportunities that a low carbon transition presents for the country – opportunities for inclusive and sustainable economic development akin to those "*shown by the agricultural and industrial revolutions… with huge rewards for pioneers of new models*".[11] It also acknowledges, in its "Guiding principles for the transition",[12] the need for a managed transition that is just, ethical, and sustainable.

2.2. The PCC's Just Transition Framework

The NDP's guiding principles for a low carbon transition are echoed in the PCC's Just Transition Framework.[13] The Just Transition Framework explains that a Just Transition aims to mitigate and adapt to climate change, while simultaneously addressing South Africa's triple challenge – to "leave no one behind" (see Text Box 2 below for the definition of a Just Transition according to the PCC Just Transition Framework). Transitioning to a low carbon economy (i.e., decarbonisation, adaptation, and resilience), in a just and inclusive manner, is a critical pathway for simultaneously addressing South Africa's developmental needs, while building resilience to both climate change and transition risks.

TEXT BOX 2: THE PPC'S DEFINITION OF A JUST TRANSITION[14]

"A Just Transition aims to achieve a quality life for all South Africans, in the context of increasing the ability to adapt to the adverse impacts of climate, fostering climate resilience, and reaching Net Zero greenhouse gas emissions by 2050, in line with best available science.

A Just Transition contributes to the goals of decent work for all, social inclusion, and the eradication of poverty. A Just Transition puts people at the centre of decision making, especially those most impacted, the poor, women, people with disabilities, and the youth — empowering and equipping them for new opportunities of the future.

A Just Transition builds the resilience of the economy and people through affordable, decentralised, diversely owned renewable energy systems; conservation of natural resources; equitable access of water

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[9] RSA. 2012.
[10] NBI, BCG and BUSA. 2021. World Bank. 2022.
[11] RSA. 2012. (pg 91)
[12] RSA. 2012.(pg 200).
[13] PCC. 2022.
[14] PCC. 2022. (pg. 7).

> *resources; an environment that is not harmful to one's health and well-being; and sustainable, equitable, inclusive land-use for all, especially for the most vulnerable."*

The PCC's Just Transition Framework[15] provides coordination and coherence to Just Transition planning in South Africa. It sets out a shared vision for the Just Transition, principles to guide the transition, and policies and governance arrangements to give effect to the transition. The Framework is for all social partners in South Africa, across all sectors. There is, however, no "one size fits all" approach to the Just Transition. Social partners across different sectors will need to design their own policies and programmes in line with their specific conditions, responsibilities, and realms of influence, based on the vision, principles and interventions articulated in the Framework.

Just Transition Principles of procedural, distributive, and restorative justice must be integrated into electricity planning and decision-making. This will be critical for ensuring the electricity transition alleviates, rather than exacerbates, poverty, inequality, and unemployment reduction. Planning for a Just Energy Transition is more than just an exercise in infrastructure development. It necessitates action to address the social and governance risks associated with the transition while maintaining reliability, stability, affordability, and environmental sustainability associated with electricity supply. It also requires decisions on the fair distribution of the costs and benefits arising from the development and function of future electricity systems.

Given the Just Transition's centrality to ensuring economic development and dealing with the triple challenge, the remainder of this section provides an overview of the risks associated with climate change and the failure to achieve a Just Transition to a low carbon economy. It then contextualises the Just Energy Transition within the broader Just Transition, highlighting key requirements for electricity planning to enable a Just Energy Transition. This section also speaks to the key issues raised by stakeholders throughout consultations, highlighting their values and ambition for the Just Energy Transition.

2.3. Biophysical climate change risks

Climate change presents a significant threat to the South African economy and risks exacerbating the triple challenge and other environmental risks (e.g., water scarcity). Climate change will lead to an increase in frequency and severity of extreme weather events (e.g., droughts, floods), extreme temperatures and sea level rise.[16]

These biophysical climate change risks can cause various direct and indirect negative socio-economic impacts, referred to as negative externalities. For example, severe droughts can reduce agricultural output, which in turn can lead to financial loses, job losses and compound food insecurity within a particular region. According to the IPCC ^{6t}h Assessment Report, Africa is already experiencing the negative socio-economic impacts from climate change and could face even more severe impacts if global average temperature continues to rise. Some of these current and future impacts are summarised in Table 1.

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[15] PCC. 2022. A framework for a Just Transition in South Africa.

[16] IPCC. 2021. Sixth Assessment Report, Chapter 9: Africa.

Table 1: Observed and projected socio-economic impacts from climate change in Africa.

Observed socio-economic impacts form climate change	Projected socio-economic impacts from climate change
Reduced economic output and growth for African countries compared to their northern hemisphere counterparts, with an estimated 13% reduction in GDP per capita since 1991 for African countries.	Global warming of 2.3°C by 2050 could lower GDP per capita by 12% across Sub-Saharan Africa, and 80% by 2100 with warming above 4°C.
A 34% reduction in agricultural output due to climate change, more than any other region	A further 25% – 75% reduction on agricultural output, depending on crop and scenario
Over 3.6 million weather-related displacements	With 1.7°C global warming by 2050, 17 – 40 million people could migrate internally in sub-Saharan Africa, increasing to 56 – 86 million for 2.5°C scenario.
A 5% reduction in GDP per capita for South Africa	An expected 50% reduction in GDP per capita for South Africa by 2100

Avoiding and reducing the severity of the socio-economic risks associated with climate change requires urgent action to both mitigate and adapt to climate change. This means reducing GHG emissions across all sectors of the South African economy, particularly from the carbon-intensive energy sector. It also requires various adaptation interventions (e.g., drought resilient crops and flood mitigation interventions) to help build resilience to already unavoidable impacts of climate change, particularly for vulnerable groups, such as the poor, women, and children.

2.4. Transition risks

While South Africa is vulnerable to the biophysical impacts of climate change, the economy is also vulnerable to a range of "transition risks" presented by the low carbon transition. Transition risks are defined as unintended socio-economic risks that result from climate change mitigation interventions, or "climate action".

Given the carbon-intensive nature of the electricity sector, South Africa's export products and commodities are also carbon-intensive. This exposes South Africa to international trade risks as key export markets implement their own climate interventions (Figure 1). For example, the EU is planning to implement a Carbon Border Adjustment Mechanism (CBAM) as part of the European Green Deal[17] and to increases its climate ambitions.[18] The CBAM is a tax instrument imposed on imports into the EU based on their carbon-content. When implemented, the CBAM would increase the cost of South African imports to the EU, reducing their international competitiveness. Furthermore, certain export products could face decreasing demand. For example, demand for Platinum Group Metals (PGMs), which are used in internal combustion engines, could decrease over time as export markets increase their demand for new electric vehicles.

These trade risks pose various knock-on threats to the balance of payments, trade deficits, GDP, and employment across all key export sectors, potentially adding to the triple challenge.[19] It is, therefore,

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[17] Council of the EU. 2022. EU climate action: provisional agreement reached on Cross Border Adjustment Mechanism (CBAM). Monaisa. 2021. European Green Deal: The Carbon Border Adjustment Mechanisms and implications for South Africa and European Trade. TIPS. ; PCC. 2023. Carbon Border Adjustment Mechanisms and Implications for South Africa.; PCC. 2022. A framework for a Just Transition in South Africa.
[18] Norton Rose Fulbright. 2023. Potential conflicts between the European CBAM and the WTO rules.
[19] Monaisa. 2021. PCC. 2022.

imperative that South Africa recognises the need to reduce the carbon intensity of the economy, and the electricity sector.

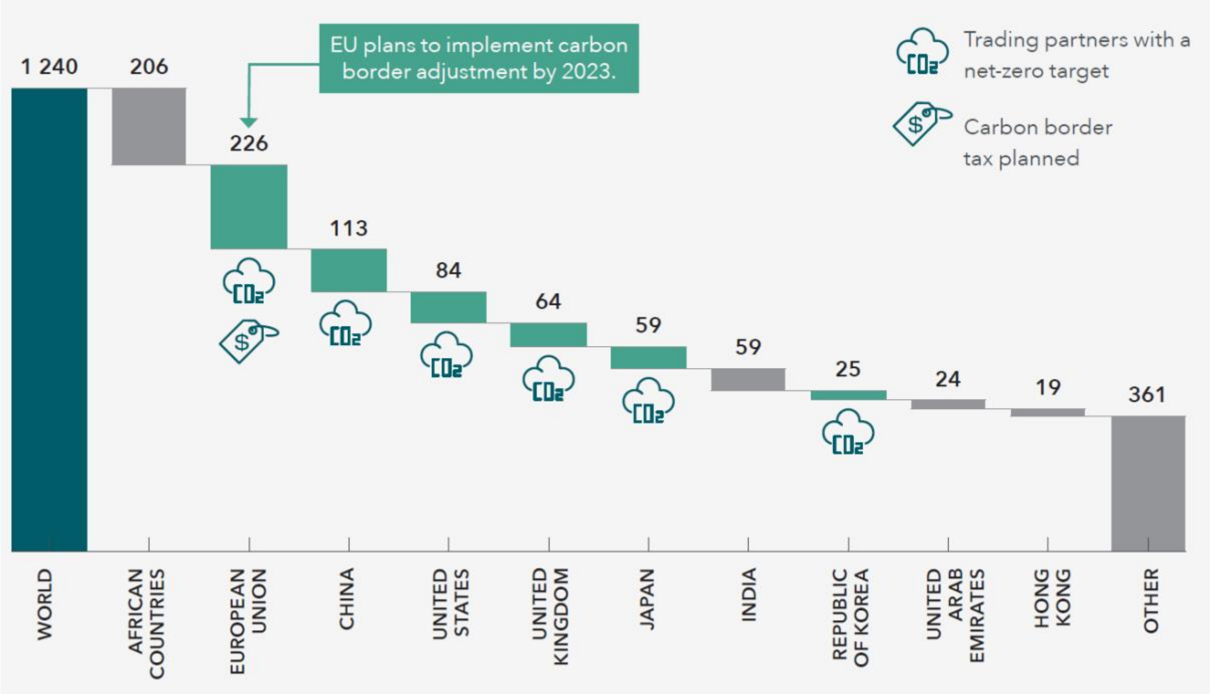

FIGURE 1: SOUTH AFRICA'S LEADING EXPORT PARTNERS BY TRADE VOLUME IN 2018 (R BILLION) [20]

However, efforts to reduce South Africa's GHG emissions also carry their own transition risks. For example, imposing economy-wide carbon taxes will lead to higher prices on carbon-intensive goods. In the absence of cheaper, lower-carbon alternatives, this could have a disproportionate impact on poorer households in the short term as the cost of the tax is passed onto customers.

Transitioning the electricity sector will also impose transition risks on the economy, particularly across the coal value chain. The coal mining sector provides approximately 400 000 jobs, with ~80 000 direct jobs and ~200 000 – 300 000 indirect and induced jobs in the broader coal value chain and economy. Given that each mine worker supports an average of 5 – 10 dependants, the coal value chain supports between 2 million and 4 million livelihoods.[21] Transitioning away from coal-based electricity will reduce demand for coal and therefore puts an estimated 2 million to 4 million coal-based livelihoods at risk.

2.5. The Just Energy Transition

2.5.1. An electricity planning framework for enabling a Just Energy Transition

The World Energy Council's[22] Energy Trilemma Framework (Figure 2) provides a useful tool for policymakers and decisionmakers to understand and assess competing future electricity mix options as part of their planning for a Just Energy Transition. The Framework outlines three, sometimes competing, requirements, or pillars, for future energy planning: (i) energy security (reliability and stability), (ii) energy equity (access and affordability), and (iii) environmental sustainability (GHG emissions, water, and air quality). Future electricity plans and technology mixes should aim to address all three Energy Trilemma requirements to enable a Just Energy Transition. However, this framework

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[20] Minerals Council South Africa. 2022. Facts and Figures 2021. NBI. 2021.
[21] Minerals Council South Africa. 2022. Facts and Figures 2021. NBI. 2021.
[22] World Energy Council. 2022. World Energy Trilemma Index

falls short in terms of socio-economic considerations associated with the energy transition, including mitigating transitions risks, and contributing to socio-economic opportunities associated with the transition.

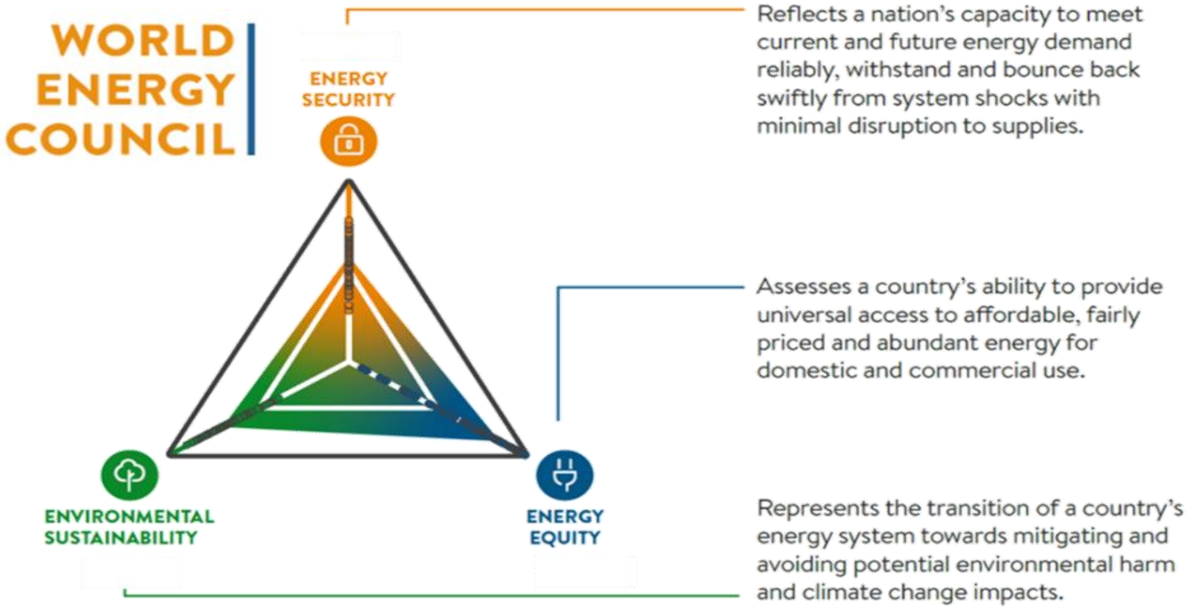

FIGURE 2: WORLD ENERGY COUNCIL'S ENERGY TRILEMMA FRAMEWORK[23]

The Department of Mineral Resource and Energy's (DMRE) draft "Road to Just Energy Transition Framework" (Figure 3)[24] provides an alternative framework for planning for a Just Energy Transition. This framework sets out key performance indicators (KPIs) for the Just Energy Transition across three main elements: (i) social side; (ii) supply side; and (iii) demand side.

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[23] World Energy Council. 2022.
[24] DMRE. 2021. Towards a Just Energy Transition Framework in the Minerals and Energy Sectors

FIGURE 3: DMRE ROAD TO JET FRAMEWORK

There are some similarities between in the DMRE's framework and the Energy Trilemma framework, including affordability and environmental elements related to climate change and air pollution. Where they differ, however, is in social protection, the need to reskill at-risk workers and reliability and accessibility of supply.

In South Africa, and other developing countries, we would balance the two frameworks by adding Social Sustainability to the World Energy Council's Energy Trilemma Framework. This addition should help to include justice elements that need consideration, like employment, labour migration and ownership, into electricity planning and decision-making. The criteria outlined in the Table 2 are also aligned to energy security requirements outlined in the NDP.

TABLE 2: AN ELECTRICITY PLANNING FRAMEWORK FOR ENABLING A JUST ENERGY TRANSITION

1. **Energy equity**	Provide low-cost and affordable electricity, including free basic electricity, to ensure access to electricity for all sectors and South Africans, particularly the poor and marginalised groups (e.g., women and youth)
2. **Energy security**	Meet electricity demand, now and in the future, by providing a reliable, stable, and resilient supply. This will help ensure physical access to electricity that is reliable, stable, and resilient to external shocks, climate-related or otherwise. Energy efficiency considerations for demand-side management are also a critical component for energy security.
3. **Socio-economic Sustainability**	Ensure the electricity sector, and the transition to a low carbon electricity mix, contributes positively to South Africa's developmental agenda by enabling net-positive job creation, livelihood opportunities, and reindustrialisation opportunities.
4. **Environmental Sustainability**	Ensure that the provision of electricity contributes positively to climate change mitigation, adaptation and resilience, air quality, food and water security, and a healthy environment that supports human health, sustainable livelihoods, and well-being.

2.5.2. Stakeholder requirements for a Just Energy Transition

The PPC hosted several stakeholder engagement sessions with labour, civil society, business, and government to unpack and discuss electricity planning. These sessions were hosted in-person and online. Table 3 attempts to capture some of the key considerations arising from stakeholder engagement sessions as they pertain to each of the four criteria for a Just Energy Transition. Taking these stakeholder values into consideration for the electricity scenario assessment (*outlined in Section 6*) and building their requirements into assessment criteria ensures that their voice has bearing on electricity planning and debate.

TABLE 3: THEMATIC CATEGORISATION OF STAKEHOLDER REQUIREMENTS FOR A JUST ENERGY TRANSITION

Energy equity	• Improvements in distribution and management of FBE. • Access to affordable electricity. • Concerns over additional public debt. • Calls for social / community ownership models and concerns over privatisation of electricity generation.
Energy security	• Concerns over the capacity of municipalities and national government to manage and enable a Just Energy Transition. • Calls for stable and reliable electricity supply to help address the triple challenge. • Concerns over corruption, accountability, and the capacity of the state to provide energy security. • Concerns over the privatisation of electricity supply. • Concerns in respect of the limitations of available grid capacity.
Socio-economic	• The Just Energy Transition is about workers and communities and needs to be people centred. The three justice principles of the PCC's Just Transition Framework are critical in this regard, particularly procedural fairness. • Skills development and education are key components of a Just Energy Transition. • Creation of decent jobs and protection of workers and vulnerable communities. • Need to unpack the social protection measures in the Just Energy Transition Investment Plan (JET IP). • Calls for localisation and green industrialisation. • Improved health and living conditions via reductions in environmental impacts (e.g., air quality, climate change impacts).
Environmental Sustainability	• Accelerated transition to a Net Zero emissions pathway. • Sustainable and inclusive land-use and special planning. • Improve water use efficiency and access to clean water. • Reduce air pollution and health impacts from poor air quality. • Mine rehabilitation and post-closure sustainability.

Stakeholder inputs were captured in detail in a complimentary report "Stakeholder Perspectives on the PCC Recommendations on Electricity Planning in South Africa".

3. The climate constraint on South Africa's electricity future

To avoid catastrophic climate change, the Intergovernmental Panel on Climate Change (IPCC) estimates that global average temperatures need to be stabilised at 1.5°C above pre-industrial levels. While the Paris Agreement puts forward a 2°C temperature target, it also notes the need for a 1.5°C ambition. According to the IPCC, achieving the 1.5°C temperature target by 2100 would require the global economy to stay with a global carbon budget of between 420 and 570 gigatonnes of carbon dioxide ($GtCO_2$). This means anthropogenic GHG emissions would need to decrease 43% by 2030 (from 2019 levels) and reach Net Zero GHG emissions by 2050 (with ~90% reduction in GHG emissions relative to 2019 levels).[25]

According to the IPCC Sixth Assessment Report,[26] decarbonising the energy sector, including electricity, is a critical requirement for limiting global warming to 1.5°C (Figure 4). Global modelled mitigation pathways reaching Net Zero GHG emissions include transitioning from fossil fuels without carbon capture and storage (CCS) to very low- or zero-carbon energy sources (e.g., renewable energy technologies, improved energy efficiency and/or fossil fuels with CCS[27]). In global modelled pathways that limit warming to 2°C or below, almost all electricity is supplied from zero or low-carbon sources in 2050. Modelled global pathways limiting global warming to 1.5°C (>50%) with no or limited overshoot, generally implement such changes faster than pathways limiting global warming to 2°C (>67%).[28]

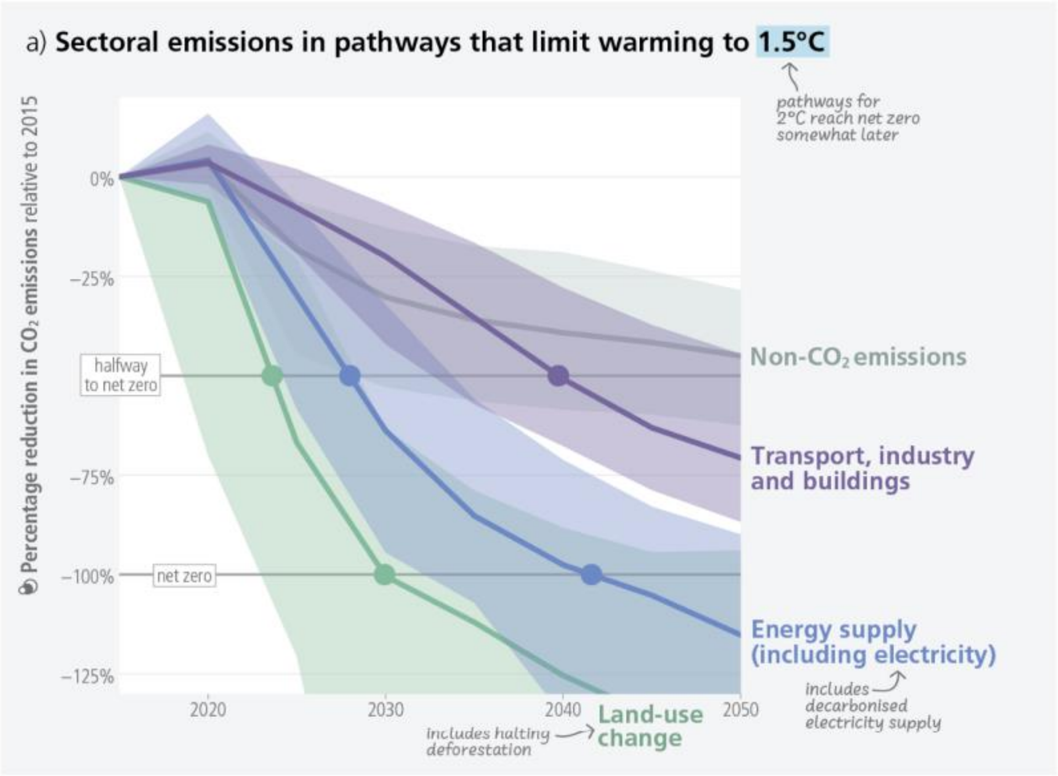

FIGURE 4: SECTORAL EMISSIONS PATHWAYS THAT LIMIT WARMING TO 1.5°C

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[25] IPCC. 2023. Synthesis Report of the IPCC Sixth Assessment Report (AR6). Pg 56.
[26] IPCC. 2023.
[27] While continued use of fossil fuels with CSS is a potential option, one needs to consider the implications it will have on electricity prices. Renewable energy is already cheaper than fossil fuels, such as coal, and adding expensive CCS technology to fossil fuels will only increase the price differential.
[28] IPCC. 2023.

South Africa is a signatory to the United Nations Framework Convention on Climate Change (UNFCCC) and to the Paris Agreement. South Africa is, therefore, committed to its fair share contribution to global climate action. South Africa's updated Nationally Determined Contribution (NDC) commits to reducing GHG emissions to between 350 and 420 megatons of carbon dioxide equivalent ($MtCO_2e$) by 2030.[29] The upper limit is consistent with a 2030 target required to meet a 2°C target while the lower limit is consistent with a 2030 target required to meet a 1.5°C target.[30]

Given the carbon-intensive nature of South Africa' electricity system, and our international climate commitments, it is critical that the energy system transitions to more renewable energy. This, therefore, highlights the importance of considering a climate constraint (i.e., a carbon budget reflective of our international commitments) in electricity planning and decision-making processes.

However, applying different carbon constraints on the electricity sector is not without its trade-offs. Table 4 provides an illustrative example of the likely trade-offs between two opposite carbon constraints: (i) a small carbon budget, representing high climate ambition, and (ii) a large carbon budget representing low climate ambition. Each carbon budget constraint, and pathway to Net Zero GHG emissions, clearly has significant trade-offs that need careful consideration during electricity planning and decision-making, particularly for enabling a Just Energy Transition.

TABLE 4: ILLUSTRATIVE EXAMPLES OF THE LIKELY TRADE-OF BETWEEN A HIGH AND LOW CARBON BUDGET / FARE SHARE CONTRIBUTION

	Small carbon budget / high climate ambition	Large carbon budget / low climate ambition
Net Zero ambition	Net Zero by 2050 or sooner.	Net Zero by 2060, maybe later.
RE deployment and coal Retirement	Rapid RE deployment and retirement of all coal-fired power stations by 2040 or soon.	Continued to use coal until 2050, maybe later, with slower deployment of RE.
Environmental	Significantly lower air pollution and water consumption due to cleaner RE technology. Avoids long-term catastrophic climate change.	More air pollution and water use. Greater risk of catastrophic climate change in the medium to long term.
Socio-Economic	Avoided negative environmental externalities, improved human health, and reduced socio-economic impacts from biophysical climate change risks.	Additional environmental stress could place increased pressure on the fiscus through higher public health costs, increased damaged to infrastructure, and reductions in economic output due to biophysical climate change impacts.

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[29] DFFE. 2021. South Africa's updated draft Nationally Determined Contribution (NDC).

[30] RSA. 2022. South Africa's Just Energy Transition Investment Plan (JET-IP)

	Small carbon budget / high climate ambition	Large carbon budget / low climate ambition
Transition Risk	Avoids trade risks from the EU's CBAM on the broader economy but places greater transition risk on the coal value chain. This would require faster action to ensure a Just Energy Transition. For example, reskilling programmes would need to be fast tracked and support a larger group of stakeholders to transition to new employment opportunities quickly.	Greater trade risks from the EU's CBAM, ignores the timing on international coal markets, potentially exposing the coal value chain to trade risks. More time to address employment risks across the cola value chain for enabling a Just Transition.
Economic Opportunity	Catalyse innovation, market development and a green industrial revolution, with new employment and economic growth opportunities.	Could reduce the direct cost of RE technology deployment, grid expansion, coal phase-out, and Just Transition interventions (e.g., reskilling programmes).
Transition costs	Would likely increase the direct cost of the transition in terms of RE deployment, expanding grid infrastructure and decommissioning coal-fired power stations before their technical/economic end-of-life. There is also the risk of stranding coal assets. There could, however, be greater opportunity for accessing international finance under an ambitious pathway.	Gives more time to raise finance (domestic and international) and put safeguards in place for at-risk coal value chain stakeholders. This pathway could, however, make it harder and more expensive to access international finance.

4. Policymaker challenges

4.1. Governance of the electricity sector

All South African society is impacted by the current electricity crisis and therefore by short- and long-term electricity plans. To ensure the sustainability of our economy and society, to ensure growth and development for all, it is imperative that there is a cooperative governance framework, ensuring that electricity planning is holistic, evidence-based and follows the least-cost, low carbon trajectory that will provide reliable, stable, and affordable electricity, and decent jobs.

There are currently several organs of state that have a role in the governance of the electricity sector. This section sets out what the current role is of each of these players, some of the interdependencies and some of the challenges and opportunities they face.

4.1.1. The Department of Mineral Resources and Energy (DMRE)

The DMRE is responsible for energy-related policy and planning in South Africa, including electricity. The Department drafts and implements legislation and regulations governing the electricity sector, including the Electricity Regulation Act (no. 4 of 2006) (ERA)[31], which is, at the time of writing, being amended. Key amendments to the Bill include:

- Introduction of the trading platform, multi-market, and the day-ahead market.
- Creation of the TSO to take responsibility for transmission planning.
- Creation of a Central Purchasing Agency within the TSO.
- Integrated resource plan must be revised at least every three years.

The DMRE is responsible for the drafting and implementation of the Integrated Resource Plan (IRP) to guide electricity planning and procurement for the country. There are several other Acts, Regulations, policies, and plans owned by the DMRE governing the electricity and wider energy sector, however, the ERA, IRP, and Gas Master Plan (under development) are the most relevant for this report. DMRE does not have the direct authority or mandate to regulate or manage all key considerations in respect of electricity planning. It is therefore reliant on other organs of state for input and information for planning purposes. It must also ensure that consideration is given to Regulations and policies that impact the electricity sector, but over which it has not authority and control.

4.1.2. Eskom

Eskom is the state-owned, vertically integrated (generation, transmission, and some distribution) monopoly utility. Eskom sits under the Department of Public Enterprises and has no mandate for energy policy and planning. However, as the monopoly Generator and System Operator, Eskom arguably has the best access to information required for robust electricity planning. Recognising this, Eskom is required to publish certain reports on an annual basis that provide crucial information for planners. These include the medium-term system adequacy outlook (MTSAO) report, which indicates the ability of the current and future known capacity to meet demand. Eskom also publishes the Generation Connection Capacity Assessment (GCCA) report, which indicates the available capacity for the connection of new generation at the main transmission system substation level. In addition, Eskom

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[31] DMRE, ERA. 2006

publishes a Transmission Development Plan which sets out the planned expansion and investment for the transmission infrastructure.

The process is underway to separate Eskom into three sub-organisations divided by function (generation, transmission, and distribution). Its System Operator and Transmission will become part of the recently legally separated National Transmission Company South Africa (NTCSA).

4.1.3. NERSA

NERSA is mandated to regulate electricity, piped gas, and petroleum pipelines industries in terms of the various Acts. This includes licencing, permitting, registration and pricing of electricity in the country. NERSA is also required to concur with Ministerial Determinations (published under Section 34 of the ERA[32]) for the procurement of new generation capacity by the State in line with the IRP. NERSA must regulate an electricity sector that is undergoing significant change. This challenge requires that NERSA must balance the application of the law and its rules with the need for dynamism and flexibility as the structure of the electricity sector evolves.

4.1.4. The Independent Power Producers Office (IPPO)

The IPPO was established to provide government with the support required to implement the Independent Power Producer Procurement Programme. The IPP Office has three interrelated focus areas:

- It is a key procurement vehicle for delivering on the national renewable energy capacity building objectives (REIPPP);
- It is responsible for securing electricity capacity from IPPs for non-renewable energy sources as determined by the Minister of Energy; and
- It is providing advisory services, related to programme / project planning, development, implementation, and financing focused on creating an enabling and stable market environment for IPPs.

Like the challenges faced by NERSA, the IPPO as an implementor of policy and regulation must contend with the restrictions of the law and rules, and the need for a more dynamic and flexible response required to transition the electricity sector.

4.1.5. Other National Departments

Several other national government departments also have roles to play in the governance of electricity, through planning or authorisations. For example, the Department of Forestry, Fisheries and the Environment (DFFE) is responsible for governance related to air quality, environmental impact assessments and climate change, both critical considerations for electricity planning. Further, the Department for Trade, Industry and Competition (DTIC) is responsible for developing sectoral industrial development plans, as well as determining the localisation requirements for state procurement. It was announced at a recent media briefing[33] held to explain the state of disaster (SOD) Regulations (see Section 6.2), that the DTIC would act as a one stop shop (OOS) for the streamlining of energy project applications. The OOS is intended to speed up the regulatory processes required for private investment in electricity generation, to "assist power-generating companies navigate the

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[32] Section 34 provides for the Minister of Energy to issue a determination for new electricity generation capacity to be built.

[33] News24.2023 SA Government briefs media on the National State of Disaster regarding electricity supply.

different processes that apply in law and increase turnaround times by assisting investors to submit applications through a single-window process to obtain all necessary government approvals."[34]

4.1.6. Presidential platforms

Within the Presidency there are currently four key platforms engaged in energy or energy-related (specifically electricity-related) policy and implementation initiatives. These are:

- Operation Vulindlela – tasked with unblocking policy and regulatory constraints to the implementation of network related economic recovery and growth initiatives identified for post-COVID recovery.
- National Energy Crisis Committee (NECOM) – established in July 2022 to oversee the implementation of an action plan to end load shedding and achieve energy security for South Africa through addressing the current supply shortfall; improve the performance of Eskom's existing fleet; dealing with rampant criminal acts and sabotage; and achieving medium- and long-term energy security in the context of the country's climate commitments and developmental goals.
- Presidential Climate Commission (PCC) – tasked with developing a framework for and ensuring the implementation of a Just Transition in South Africa, particularly in respect of the shift from a carbon intensive economy to a Net Zero economy by 2050. Though focussed primarily on climate change mitigation, as most emissions in South Africa are related to energy, there is a strong interrelation of the work of this body in influencing the energy policy landscape.
- Presidential Climate Finance Task Team (PCFTT) – formed following the establishment of the Just Energy Transition Partnership (JETP) at COP26. This body developed the Just Energy Transition Investment Plan (JET-IP) for further engagement, and negotiation with the International Partner Group (IPG) which comprises the governments of the UK, US, France, Germany, the EU, and other interested funders.

Operation Vulindlela and NECOM are tasked with overcoming many of the challenges presented by the current siloed approach. The initiatives of these two bodies are detailed further in Section 6.2 below.

4.2. Challenges facing policymakers for electricity planning

While it may be generally accepted that electricity planning should be based on sound technical and least-cost principles, policymakers must also consider several other issues. The energy trilemma of energy security, energy affordability and environmental sustainability must be addressed alongside access and Just Transition considerations (energy trilemma plus). The following subsections set out the challenges facing policymakers that have critical bearing on energy planning and the successful balance of the energy trilemma plus imperatives.

4.2.1. The electricity demand profile has changed and no longer matches supply

Historically, South Africa's demand profile was defined by energy-intensive industries. Many of these operated 24/7, creating a relatively flat profile and requiring a fairly static generation supply to meet demand. Over time, changes in economic activity and increased access to electricity have changed the demand profile to a curve with peak times in the mornings and evenings, primarily due to domestic demand. This profile requires more dynamic ramping up and down of generation to ensure that

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[34] Engineering News. 2023. DTIC's new energy one-stop shop to include 'unblocking teams' to speed up electricity investments.

demand peaks can be met. In addition, the assumptions that form the basis of the demand forecast must be considered. Generally, these are based on projected gross domestic product (GDP) forecasts and assumptions of the economic structure of the country. Sources of these input assumptions differ, compounding the challenge for policymakers.

4.2.2. Declining system adequacy trend vs. improvement targets

The current performance of the electricity supply system and assumptions of its future performance are also key inputs. Recent performance of particularly the coal-fired power plants has shown a declining performance trajectory (or energy availability factor (EAF)). Policymakers traditionally rely on data provided in the most recent MTSAO; however, the actual performance may be different at the time of modelling, stakeholder engagement or finalisation of the plan. In addition, policymakers may have to balance the historical declining trends against the improvement targets set by the shareholder and/or Board.

4.2.3. The technology landscape is rapidly evolving

Technological advancements and learning rates are moving quickly for many technologies giving policymakers more options to consider. Some technologies are proven, and commercially available, with low build and operational costs. Other technologies are still nascent – being tested and developed and not yet commercially available but showing promise for the future.

4.2.4. High levels of forecasting uncertainty make decision-making more difficult

Forecasting uncertainty presents a key challenge for policymakers, with levels of uncertainty increasing the further ahead one looks. Given the time horizon for infrastructure decisions, this uncertainty makes it more difficult for policymakers to take decisions with a good degree of confidence. This is true not just for technological options, but also for key input assumptions such as demand and economic growth.

4.2.5. Air Quality and other environmental compliance are delaying decision-making

Policymakers must consider the implications of regulations and decisions taken by other organs of state, as mentioned above. Environmental authorisations, or their absence, are increasingly impacting the timing and feasibility of new generation projects. In addition, non-compliance of existing generation plan impacts assumptions of the current and forecasted availability.

4.2.6. The carbon budget will impact the pace and scale of coal decommissioning

In line with South Africa’s commitment (NDC) to reduce its GHG emissions and to limit emissions in line with its fair share of global emissions, policymakers must include a carbon constraint for the electricity sector. The carbon budget determined for and applied to the electricity sector will drive, in large part, the pace and scale of new generation and technology choice as well as the decommissioning of current fossil fuel generation plants.

4.2.7. System costs and resilience

Beyond these technical considerations, policymakers must increasingly include other factors. For example, not just the LCOE at a technology level but also other associated costs at a system level, and how the build can be funded (loan) as well as who will pay (customer or taxpayer). Beyond funding, there are environmental considerations such as climate change, air quality, water scarcity and the need to ensure resilience in the electricity system.

4.3. Challenges for local government

Local government bodies face unique challenges regarding electricity planning, implementation, and management. Local government (municipalities) have the responsibility to distribute electricity. In many areas where metropolitan and district municipalities distribute electricity to their customers, this presents a significant revenue stream for them. However, some municipal stakeholders have reported that electricity supply is loss-making. Many municipalities are dysfunctional and lack requisite skills and capacity to properly manage, for example, the distribution of electricity, infrastructure maintenance and expansion, distribution of the free basic electricity grant to indigent households, and tariff structuring and revenue collection. In addition, non-payment from their customers and cable theft plague municipalities as well as Eskom. Municipalities are at the frontline of electricity supply and will play a key role in energy efficiency and other demand-side management initiatives, as well as regulating and incentivising the expansion of embedded generation and storage.

Municipalities have the difficult task of balancing the need to set cost-reflective tariffs to ensure that their cost of supply is recovered, thus enabling revenue for the maintenance, and required investment in infrastructure to continue to serve their communities – with the reality in many areas, that customers genuinely cannot afford to pay for electricity. Electricity pricing reform and a review of funding flows and the FBE is critical to ensure that all South Africans can access affordable and reliable electricity. Municipalities will require targeted support in preparing for the electricity transition.

5. Electricity planning

5.1. South Africa's current electricity crisis

Despite making great strides since 1994 to increase electricity access in the country, the country is facing a dire electricity crisis affecting all parts of the economy. The first wave of loadshedding started in 2008 and has become a regular occurrence since. The history of how South Africa has reached the current electricity crisis is multi-faceted and complex. A combination of delayed decisions, delays to building additional capacity, inadequate and delayed maintenance, changes in leadership, state capture and insufficient financial resources are some of the factors that have contributed to continuous and extended loadshedding.

These circumstances have led to the current Eskom fleet being over-run and undermaintained, which resulted in a current year-to-date (YTD) Energy Availability Factor (EAF[35] for Eskom's fleet of 52% (week 9 of 2023)[36] – much lower than the 75% assumption in the IRP2019 (as shown in Figure 5). This has led to an estimated capacity shortfall of 6 GW. In addition, these challenges are exacerbated by a constrained grid, and pressure on Eskom to comply with Minimum Emission Standards (MES).

5.1.1. Declining Energy Availability Factor

Eskom's EAF is declining year on year and would require significant intervention to reverse the declining trends and enable the stations to reach nameplate capacity. Eskom's 2022 Medium-term System Adequacy Outlook (MTSAO)[37] report states, in its most optimistic scenario, that the EAF will improve to 68% by 2027. However, the report shows that, without radical intervention, EAF forecasts based on historical trends suggest the average EAF will be 58% by 2027. Figure 5 illustrates the year-on-year decline in EAF, despite this, targets of a EAF of 75% have been set. In respect of plant performance, Eskom's MTSAO states that the System Operator "*expects a downward trend in plant performance to continue in the medium term, fuelled by increasing unplanned full and partial load losses, particularly given that the current calendar year to date EAF is 57.8% as at the week ending 16 October 2022*".

Therefore, a more likely low EAF, with an annual average of 58% is considered the base case of the MTSAO 2022. A higher EAF, averaging 67%, aligned with Eskom Generation's plan, was also considered for assessment. For the higher EAF to be realised, the MTSAO assumes that maintenance planned in Eskom's Reliability Maintenance Recovery Programme will be able to arrest the decline in the plant performance. The successful implementation of this programme is dependent on sufficient funding, skills, procurement, and efforts to curb plant sabotage. Many of these interventions are being delt with as part of planned and ongoing responses to the crisis, unpacked in more detail in Section 5.2.

Critically, policymakers should, in line with the MTSAO methodology, consider a high and low EAF to ensure that there is contingency to ensure the capacity gap does not widen if the plant performance cannot be recovered to high availability levels.

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[35] The availability factor of a power plant is the amount of time that it can produce electricity over a certain period, divided by the amount of the time in the period. It is an indicator of the available energy.

[36] Eskom Data Portal

[37] Eskom. 2022.Medium-Term System Adequacy Outlook

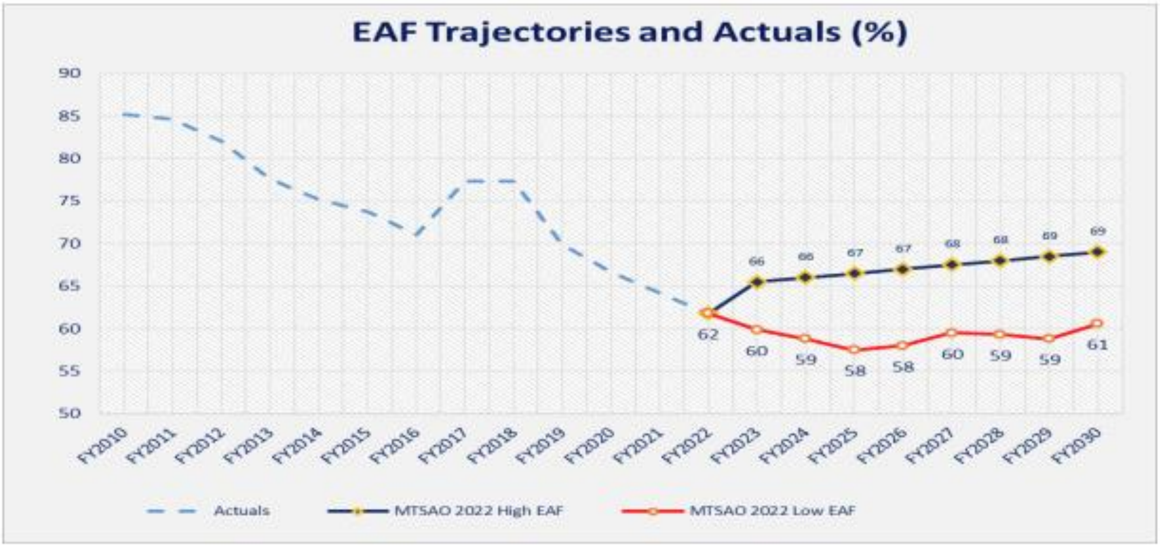

FIGURE 5: EAF TRAJECTORIES AND ACTUALS[38]

5.1.2. Grid Constraints

In addition to plant and maintenance considerations, large amounts of new capacity must be connected to address the current supply shortfall. The critical concern in this respect is that the transmission grid is severely constrained, especially in the western and southern parts of the country where most applications for new generation have been made, since this is where the best renewable resources are found. The terms of procurement favour the best price at point of generation, which means the Northern Cape for solar PV generation, and Western and Eastern Cape for wind generation. However, the grid is severely constrained in these areas and as such, several projects could not be connected to the grid. For example,[39] 4 GW of potential onshore wind projects submitted under the Renewable Energy Independent Power Producer Programme (REIPPP) Bid Window 6, could not be awarded any of the allocated capacity for wind projects under this procurement round. This is because it emerged during the bid evaluation process that no grid capacity was available to connect any proposed projects in these supply areas (Easter Cape and Western Cape).

Figure 6 provides an overview of the generation connection capacity in the country supply areas. It clearly illustrates that there is no connection capacity in the Northern Cape and very limited capacity in the Western and Eastern Cape.

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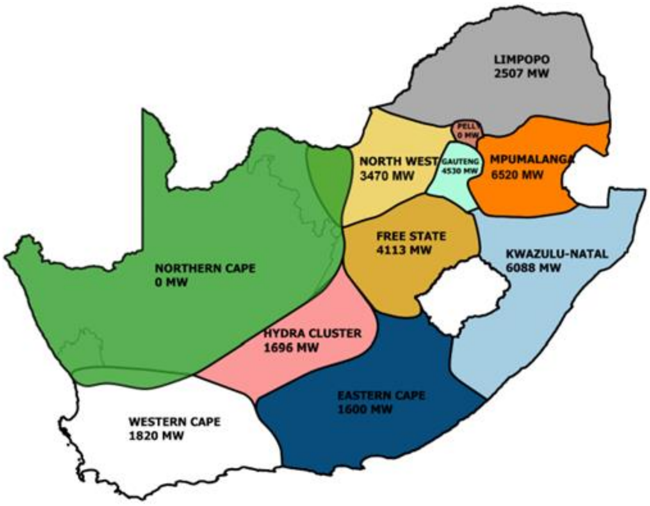
[38] Eskom.2022. Medium-Term System Adequacy Outlook

[39] DMRE. 2022. Media Statement: Signing of Preferred Bidder projects under the 5th Bid Window, and announcement of Preferred Bidders under the 6th Bid Window of the REIPPP. 2022



Supply region	Connection capacity (MW)
Northern Cape	0
Eastern Cape	1 600
Western Cape	1 820
Hydra Cluster	1 696
Free State	4 133
Gauteng	4 530
Limpopo	2 507
North West	3 470
Mpumalanga	6 520
KwaZulu Natal	6 088

FIGURE 6: GENERATION CONNECTION CAPACITY IN THE COUNTRY SUPPLY AREAS[40]

5.1.3. Minimum Emissions Standards (MES) Compliance

Another more immediate consideration for the current crisis is that nine of Eskom's 14 stations are currently non-compliant with Minimum Emissions Standards (MES), with the compliance rulings relating to these stations under appeal. The non-compliant stations are at risk of being forced to shut down, which would result in 16 GW – 30 GW of installed capacity being taken off the grid between 2025 and 2030, further exacerbating the electricity crisis. The IRP2019 included the assumption that postponement applications from Eskom to comply with the MES would be granted by the DFFE. It is recognised that it is difficult for policymakers to predict decisions by other Departments or regulators. Policymakers are also now faced with the challenge of deciding how to balance compliance, which will prevent detrimental health impacts, and energy security.

Policymakers must consider the legal determinations (court rulings) made based on strong arguments in favour of early decommissioning of coal-fired power plant to improve air quality. One of the strongest arguments in favour of accelerating the transition from coal fired power are the detrimental health impacts due poor air quality because of burning coal, which the High Court has held to be a violation of the Constitutional right to an environment not harmful to health or wellbeing[41]. A recent report suggests that air quality emissions resulting from coal powerplants, considering Eskom's planned retirement schedule and emission control retrofits, would be responsible for a projected 79 500 air pollution-related deaths from 2025 until their end-of-life. Full compliance with the MES at all plants that are scheduled to operate beyond 2030 would avoid a projected 2 300 deaths per year from air pollution and avoid economic costs of R42 billion (USD 2.9 billion) per year. Other avoided health impacts would include 140 000 asthma emergency room visits, 5 900 new cases of asthma in children, 57 000 preterm births, 35.0 million days of work absence, and 50 000 years lived with disability. The study estimated that requiring the application of best available control technology at all plants, instead of the current Minimum Emissions Standards, by 2030, would avoid 57 000 deaths from air pollution and economic costs of R1000 billion (USD 68.0 billion) compared to the Eskom plan[42].

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[40] Eskom. 2022. Generation Connection Capacity, GCCA

[41] Centre for Environmental Rights. 2023. Deadly air pollution case back in court.

[42] Centre for Research on Energy and Clean Air, 2023.

Despite the many challenges currently being faced by policymakers, there are several interventions currently underway (see Section 6.2 below) to alleviate the immediate challenges and provide a stable platform for sound long-term planning.

5.2. Planned and ongoing responses to the electricity crisis

Several planned and ongoing interventions to alleviate and address the electricity crises have been made and implemented.

5.2.1. Operation Vulindlela

Operation Vulindlela was established in October 2020 as a joint initiative of The Presidency and National Treasury to accelerate the implementation of structural reforms. Operation Vulindlela is driving reforms in the sector focusing on five key objectives: (i) fix Eskom and improve the availability of existing supply; (ii) enable and accelerate private investment in generation capacity; (iii) accelerate procurement of new capacity from renewables, gas, and battery storage; (iv) unleash businesses and households to invest in rooftop solar; and (v) fundamentally transform the electricity sector to achieve long-term energy security.

By fostering collaboration and coordination across Government in support of the reform agenda, Operation Vulindlela has achieved significant progress in a short space of time by paving the way for private investment in electricity generation, with reforms underway to establish a competitive electricity market. Highlighted below in Table 5 are reforms related to the electricity sector that are either underway or completed, as well as other achievement in the electricity sector, according to the operation Vulindlela Progress Update report of 2022/23 Q3[43]:

TABLE 5: REFORMS UNDERWAY AND COMPLETED, AND OTHER ACHIEVEMENTS OF OPERATION VULINDLELA IN THE ELECTRICITY SECTOR

Progress status	Intervention detail
Interventions underway, albeit delays in progress	• Implementing the energy action plan (updated by NECOM (see below), which now has the responsibility to implement the plan). • Enable municipalities to procure power from IPPs. Facilitating the procurement of independent power by municipalities, following the amendment to the Regulations on New Generation Capacity. The National Treasury has issued a Municipal Finance Management Act (MFMA) circular which provides guidance to municipalities in this regard.
Reform progress on track	• Finalise the Electricity Regulation Act to establish a competitive electricity market. Finalising the Electricity Regulation Amendment Bill. This Bill will establish a competitive electricity market for the first time, enabling multiple generators to complete on a level playing field. • Complete restructuring of Eskom. Driving progress on the unbundling of Eskom into separate entities for generation, transmission, and distribution, with the establishment of the National Transmission Company of South Africa as a separate subsidiary. The process of legal separation of the entity is underway, alongside work underway by National Treasury to address Eskom's debt. • Draft amendment to Schedule 2 of the Electricity Regulation Act published to remove the licensing threshold for generation facilities and enable private investment at a larger scale.
Reform complete, with no further work required	• Raising the licensing threshold for embedded generation projects from 1 MW to 100 MW, unlocking massive investment by the private sector. More than 100 projects, representing over 9000 MW of new generation capacity, are now at various stages of development.
Other key achievements	• Accelerating procurement of new generation capacity, with three projects from the risk mitigation programme having entered construction and six projects

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[43] NT. 2022. Progress Update: Two Years of Progress in Accelerating Economic Reform

Progress status	Intervention detail
	proceeding to financial close from Bid Window 5, representing 784 MW of new generation capacity. • Increasing the capacity procured through Bid Window 6 of the renewable energy programme from 2600 MW to 4200 MW. The procurement round closed in October and was oversubscribed. • Publishing a new Ministerial determination for the procurement of over 18000 MW of new generation capacity from wind, solar PV, and battery storage. • Developing a standard offer programme for Eskom to procure up to 1000 MW of additional capacity from existing generators, contingent on market response. • Eskom has signed agreements for the commercial use and lease of its land with four Independent Power Producers (IPPs). This will facilitate the development of up to 2 000 MW of generation capacity, with sufficient grid capacity already in place.

5.2.2. National Energy Crisis Committee

In July 2022, the President announced the creation of the National Energy Crisis Committee (NECOM), which would be tasked with bringing a permanent end to load shedding. The recent update from the Committee indicates progress in key areas that could help alleviate the crisis over the next couple of years. NECOM made the following recommendations in response to the electricity crisis and part of the Energy Crisis Action Plan (Table 6).

TABLE 6: SOLUTIONS TO ADDRESS THE ENERGY CRISIS AS PROPOSED BY NECOM.

Recommendation	Update (January 2023)
Fix Eskom and improve the availability of existing supply	• Increase budget for maintenance; keep to maintenance schedules; and enhance the quality of maintenance. • Ongoing engagement to allow for more agile procurement of maintenance spares and equipment. • Ensure coal contract delivery to specifications and remove poor-quality coal from the system. • Ongoing cooperation to reduce crime and corruption. • Work with public and private stakeholders to drive Energy Efficiency imperatives.
Accelerate private investment in generation capacity	• Continue to streamline and where necessary remove regulatory barriers. • Establish a one-stop shop for energy projects. • Reduce onerous timeframes and processes.
Accelerate new generation capacity	• Purchase surplus capacity from existing producers. • Continue to use available Eskom land. • Import power from neighbouring countries through the Southern Africa Power Pool. • Increase the capacity allocation in BW6.
Enable business and householders to produce electricity	• Incentivise greater uptake of rooftop solar (see SONA and Budget Speech) • Feed-in tariffs and wheeling.
Fundamentally transform the electricity sector	• Set up an independent transmission company and invest in grid strengthening and expansion. • Collocate batteries with generation to maximise grid utilisation. • Aggregate consumer systems in cities to drive additional generation and storage.

5.2.3. Interventions announced at the SONA and Budget Speech

More recent interventions to help alleviate the electricity crisis announced at the State of the Nation Address (SONA) included declaring the energy crisis a national state of disaster to provide practical measures to support businesses in the food production, storage, and retail supply chain, and enable the government to accelerate energy projects and limit regulatory requirements. A Solar Panel Tax incentive was also announced to accelerate deployment of rooftop solar by households and businesses with the aim of bringing additional generation capacity to the grid. Individuals will be able to claim a rebate to the value of 25% of the cost of new and unused solar photovoltaic (PV) panels, up to a maximum of R15 000 per individual.[44] From 1 March 2023, businesses will qualify for a 125% tax deduction on qualifying investment costs for a 2-year window period[45].

During the budget speech on 22 February 2023, it was announced that government will take over R254 billion of Eskom's debt. The debt relief will ease pressure on the Eskom's balance sheet and is intended to enable investment in transmission and distribution infrastructure. It will also allow Eskom to conduct the maintenance required to improve the EAF. Because of the structure of the debt relief, Eskom will not need further borrowing during the relief period. The arrangement is accompanied by strict conditions to safeguard public funds.[46] These conditions include[47]:

- Requiring Eskom to prioritise capital expenditure in transmission and distribution during the debt-relief period, meaning that Eskom cannot undertake capital expenditure in generation. And, no new borrowing is allowed for the three years of the relief, though exemptions can be applied for. This could present challenges for Eskom's Just Energy Transition programme given the proposed plans for repowering and repurposing along the same lines as Komati, as well as the need to borrow for transmission and for decommissioning costs.
- Eskom cannot utilise non-core asset sales for capital or operation needs – it must go to reducing debt.
- Eskom guarantees will decline as the relief is rolled out and guaranteed debt matures. The intention is for new debt after the relief period to be unguaranteed.
- That the debt relief be used to settle debt and interest payments only. This reinforces that tariff increases are still required to keep underlying operations expenditure in balance.
- For the company to focus on maintenance of the existing generation fleet to improve availability of electricity.
- That Eskom implement the recommendations emanating from an independent assessment of its operations, which has been commissioned by the National Treasury.

Furthermore, in line with the announcement made during the SONA, the President appointed Dr Kgosientsho Ramokgopa as the Minister in the Presidency responsible for Electricity, in his Cabinet Announcement on 6 March 2023.

5.2.4. State of Disaster

In line with the announcement in the SONA and the subsequent declaration of a state of disaster, Regulations were issued in terms of the Disaster Management Act (Act no. 57 of 2002) to support efforts to deal with the electricity crisis. The aim of these Regulations is, inter alia, "*to assist, protect and provide relief to the public; to protect property; to prevent and combat disruption; and to deal with the destructive nature and other effects of the disaster by –*

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[44] NT. 2023. Solar panel tax incentives for individuals.

[45] RSA. 2023. Government introduces renewable energy, solar tax incentive.

[46] NT. 2023. Budget Speech 2023.

[47] Adapted from Intellidex Budget 2023 Review

i) *Minimising the impact of load shedding on livelihoods, the economy, policing functions, national security, security services, education services, health services, water services, food security, communications, and municipal services, amongst others;*

ii) *Reducing and managing the impact of load shedding on service delivery to support lifesaving and specified essential infrastructure;*

iii) *Providing measures to enable the connection of new generation of electricity; and*

iv) *Providing measures to improve Eskom's plant performance."*

Note that these regulations were subsequently repealed.

5.2.5. MES Panel

In August 2022, the Minister of Forestry, Fisheries and the Environment established the National Environmental Consultative and Advisory Forum in terms of Section 3A [48] of the National Environmental Management Act. The purpose of this panel is to advise the Minister on matters arising from the applications for the suspension and postponement of compliance with the MES and issuance of provisional Atmospheric Emission Licences, including applications made by Eskom. The Terms of Reference (ToR)[49] for the panel recognise the complex and sometimes conflicting nature of the issues at play and require the consultative processes to deal will matters which have a bearing on the environment in particular air quality, health of the people, as well as matters relating to the *security of energy supply* [emphasis added] and sustainable development within the country.

In line with the challenges highlighted in Section 5.1.3 above, it is understood that the panel is seeking to analyse and quantify the costs and benefits of MES compliance with a view to inform recommendations to the Minister in respect of the current appeals. The outcome of this process will impact future electricity planning.

5.3. Existing electricity plans and studies

5.3.1. The Integrated Resource Plan 2019

The Integrated Resource Plan 2019 (IRP2019)[50] is the key, cabinet-approved plan for the power sector. It is intended to direct the expansion of electricity generation over a given period and to identify and inform the investments required in the electricity sector to meet forecasted demand. These are also based on requirements for least-cost, security of supply and environmental sustainability, minimising GHG emissions and water use.

The process to develop the IRP2019 started with the development and compilation of input assumptions, leading to the least-cost base scenario. Various policy adjustments were then made to the IRP2019, including:

i) Imposing annual build limits for solar (1 000 MW) and wind (1 600 MW);
ii) The inclusion of 2 500 MW of large hydro from Grand Inga;
iii) Inclusion of 1 500 MW of new build coal; and
iv) Annual allocations of 200 MW for new generation for own use.

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[48] DFFE. 2009. National Environmental Management Act. Section 3A of this act provides that the Minister may establish any forum or advisory committee and determine its composition and functions.

[49] DFFE 2022, National Environmental Consultative and Advisory Forum

[50] DMRE. 2019. Integrated Resource Plan 2019.

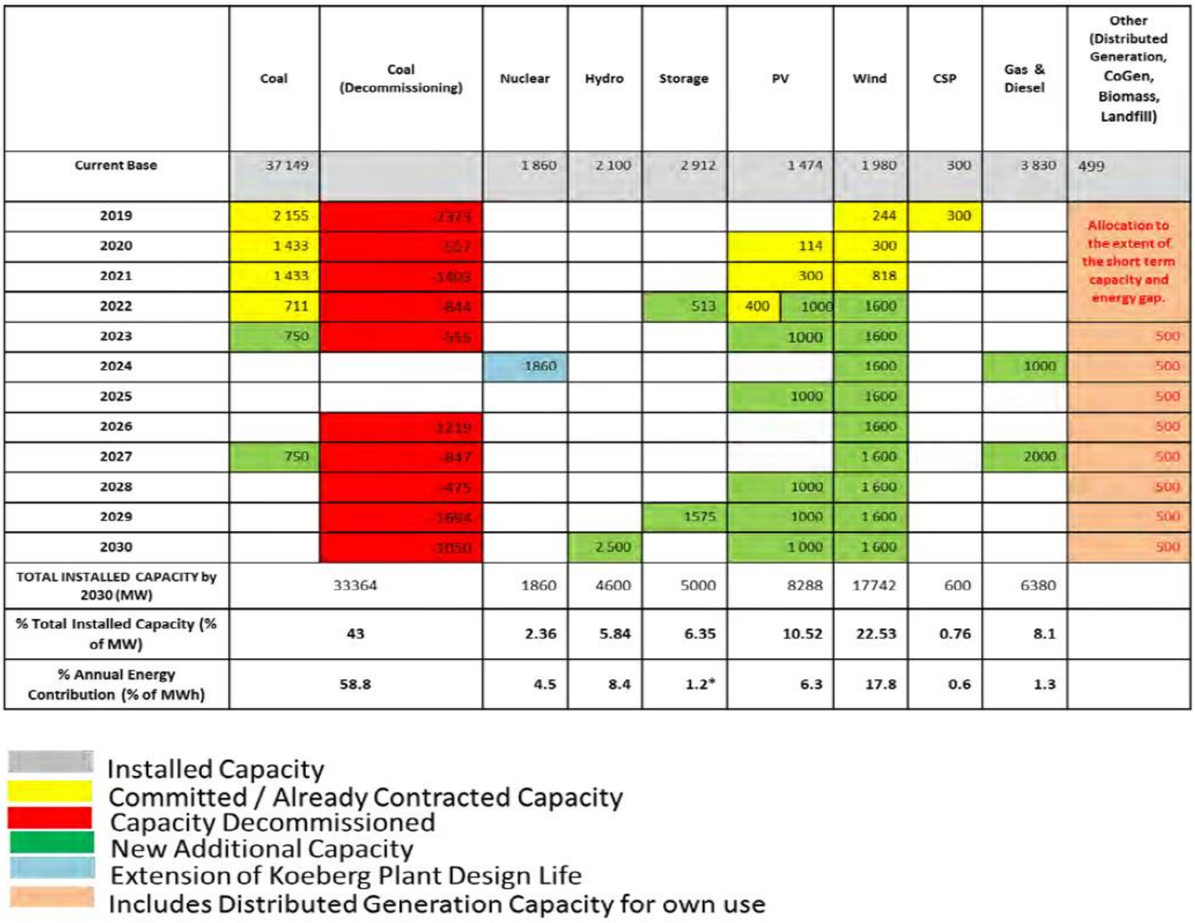
Each revision is followed by an extensive public consultations process on the assumptions, after which additional changes are considered and incorporated. The IRP2019 was promulgated in 2019 and is in the process of being updated (the update of which this Recommendations Report is intended, in part, to inform). The IRP provides key decisions until 2030, which is provided in Table 7.

TABLE 7: SUMMARY OF KEY DECISIONS OF THE IRP 2019

Category	Decision
Immediate term security supply	• Decision 1: Undertake a power purchase programme to assist with the acquisition of capacity needed to supplement Eskom's declining plant performance and to reduce the extensive utilisation of diesel peaking generators in the immediate to medium term. Lead-time is therefore key. • Decision 2: Koeberg power plant design life must be extended by another 20 years by undertaking the necessary technical and regulatory work. • Decision 3: Support Eskom to comply with MES over time, considering the energy security imperative and the risk of adverse economic impact.
Energy mix and Just Transition	• Decision 4: For coherent policy development in support of the development of a Just Transition plan, consolidate into a single team the various initiatives being undertaken on Just Transition.
Wind and PV	• Decision 5: Retention of the current annual build limits on renewables (wind and solar PV) pending the finalisation of a Just Transition plan.
Coal	• Decision 6: South Africa should not sterilise the development of its coal resources for purposes of power generation, instead all new coal power projects must be based on high efficiency, low emission technologies and other cleaner coal technologies.
Gas to power	• Decision 7: To support the development of gas infrastructure and in addition to the new gas to power capacity, convert existing diesel-fired power plants (peakers) to gas.
Nuclear	• Decision 8: Commence preparations for a nuclear build programme to the extent of 2500 MW at a pace and scale that the country can afford because it is a no-regret option in the long term. • Extension of the life of the Koeberg nuclear plant by 20 years, and launch of nuclear build programme, with the aim to deploy an additional 2500 MW of nuclear energy.
Regional power projects	• Decision 9: In support of regional electricity interconnection including hydropower and gas, South Africa will participate in strategic power projects that enable the development of cross border infrastructure needed for the regional energy trading.
Energy storage	• No decision taken.

The capacity allocation plan of the IRP2019, incorporating the results of technical analysis simulations and above key decisions, are provided in Table 8 below.

TABLE 8: IRP 2019[51]



	Coal	Coal (Decommissioning)	Nuclear	Hydro	Storage	PV	Wind	CSP	Gas & Diesel	Other (Distributed Generation, CoGen, Biomass, Landfill)
Current Base	37 149		1 860	2 100	2 912	1 474	1 980	300	3 830	499
2019	2 155	-2373					244	300		Allocation to the extent of the short term capacity and energy gap.
2020	1 433	-557				114	300			
2021	1 433	-1403				300	818			
2022	711	-844			513	400 1000	1600			
2023	750	-555				1000	1600			500
2024			1860				1600		1000	500
2025						1000	1600			500
2026		-1219					1600			500
2027	750	-847					1 600		2000	500
2028		-475				1000	1 600			500
2029		-1694			1575	1000	1 600			500
2030		-1050		2 500		1 000	1 600			500
TOTAL INSTALLED CAPACITY by 2030 (MW)	33364		1860	4600	5000	8288	17742	600	6380	
% Total Installed Capacity (% of MW)	43		2.36	5.84	6.35	10.52	22.53	0.76	8.1	
% Annual Energy Contribution (% of MWh)	58.8		4.5	8.4	1.2*	6.3	17.8	0.6	1.3	

⬜ Installed Capacity
🟨 Committed / Already Contracted Capacity
🟥 Capacity Decommissioned
🟩 New Additional Capacity
🟦 Extension of Koeberg Plant Design Life
🟧 Includes Distributed Generation Capacity for own use

- 2030 Coal Installed Capacity is less capacity decommissioned between years 2020 and 2030
- Koeberg power station rated / installed capacity will revert to 1926 MW (original design capacity) following design life extension work.
- Other / Distributed generation includes all generation facilities in circumstances in which the facility is operated solely to supply electricity to an end-use customer within the same property with the facility
- Short term capacity gap is estimated at 2000 MW

Some of the underlying assumptions applied to develop the IRP 2019 require review, as the IRP 2019 was developed in a context where the necessary speed of climate action was not as well understood; the plan pre-dates the updated Nationally Determined Contribution for 2025 and 2030 as well as the development of a national Just Transition Framework and DMRE's JET Framework. Other assumptions that require review include EAF of the existing coal fleet plants, demand assumptions, artificial build constraints, and cost of technologies.

Continued reliance on a plan based on outdated underlying assumptions has far-reaching implications. For example, outdated assumptions of the EAF mean that the capacity allocations and timings are inadequate to address the growing supply gap.

In a sector with fast changing technologies and development, it is challenging for policymakers to predict all assumptions accurately for the period. It may be beneficial to allow for more frequent planning and revision to ensure that the proposed plan considers the most recent sector developments, technological maturity, and learning rates. It may also be advantageous to include alternative pathways in the plan to account for uncertainties. For example, as per the MTSAO, plan for a high EAF and a low EAF; if experience inclines more towards on or another, allocations can be adjusted to respond accordingly.

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[51] DMRE. 2019.

5.3.2. Studies modelling long-term electricity decarbonisation pathways in South Africa

Several studies have modelled future electricity decarbonisation pathways for South Africa. Those assessed in this report include the NBI, BUSA and Boston Consulting Group (BCG)[52], the University of Cape Town's Energy Systems Research Group (ESRG)[53], the World Bank[54], the CSIR and Meridian Economics[55]. Each of these studies identified potential electricity pathways that could meet South Africa's future energy demand while achieving its NDC commitments under different assumptions. The aim was to quantify critical metrics that affect strategic decision-making, such as supply capacity and generation mix, cumulative GHG emissions, and costs/affordability of electricity between different supply system options.

An overview of each study and associated pathways/scenarios are provided in the Table 9 below, with additional detail provided in Appendix A. The sections below provide an analysis of where key results and outcomes from the selected studies align and where they diverge.

TABLE 9: OVERVIEW OF ELECTRICITY DECARBONISATION SCENARIOS FROM SELECTED STUDIES

Study/report name	Organisation	Overview	Pathway / Scenario name	Description of pathway/scenario
Decarbonising South Africa's Power System	NBI, BCG and BUSA	Study undertaken by the National Business Initiative (NBI) Boston Consulting Group (BCG) and Business Unity South Africa (BUSA to explore Net Zero pathways and implications for certain South African sector.	Lowest emissions with gas and DACCS	The 'low emissions pathway' retires all coal by 2042, including Medupi and Kusile. Residual emissions removed by DACCS. Pathway follows a ~3.5 $GtCO_2e$ carbon budget for the electricity sector.
			Lowest emissions with Green H2	Same as 'lowest emissions pathway – gas and DACCS' but reaches zero emissions via substituting natural gas with green H2 in GTP plants[56]. Pathway follows a ~3.5 Gt CO_2e carbon budget for the electricity sector. Early coal retirement and coal off by 2042.
			IRP pathway with gas and DACCS	The 'IRP constrained pathway' is anchored in a coal decommissioning schedule in line with the timeline presented in the IRP 2019. However, the pathway features a linear ramp-down of Medupi, Kusile, and any new-build coal plants between 2049 and 2050 to reach Net Zero emissions in the power sector mid-century. Includes deployment of DACCS to compensate for residual emissions from use of gas in Gas to Power (GTP) peakers.
			IRP pathway with green H2	Same as 'IRP pathway – gas' but reaches zero emissions via substituting natural gas with green H2 in GTP plants.
Systems analysis to		Research undertaken by Meridian Economics supported by	IRP 2019 (DMRE)	Refers to the Promulgated IRP 2019, published by DMRE in 2019. Includes annual capacities of new generation options required between 2022 and 2030 to meet forecasted demand and considers all input assumptions defined in

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[52] NBI, BUSA and BCG. 2021. Decarbonising South Africa's Power System

[53] ESRG. 2022. Exploring Net Zero pathways for South Africa. An Initial study

[54] The World Bank. 2022. South Africa Country Climate Development Report

[55] CSIR and Meridian Economics. 2020. Systems analysis to support increasingly ambitious CO_2 emissions scenarios in the South African electricity system.

[56] Substitution for green hydrogen will require increased renewable capacity.

Study/report name	Organisation	Overview	Pathway / Scenario name	Description of pathway/scenario
support increasingly ambitious CO2 emissions scenarios in the South African electricity system	CSIR and Meridian Economics	modelling done at the CSIR which provides targeted research to provide commentary on current policy positions and challenge widely held beliefs about South Africa's energy systems and the transition to renewables.		the IRP 2019 (e.g., technology costs, EAF, coal decommissioning dates, carbon constraints etc.). The IRP 2019 extends to 2030 only, therefore, CSIR extended time horizon to 2050 and optimised new-build investment needs utilising the same input assumptions.
			Reference (Currently Policy)	To compare scenarios, a reference scenario was created using the IRP 2019 as a basis but with the following changes: updated technology costs, lower demand forecast and lower existing fleet EAF, and no annual new build limits on solar PV and wind from 2030 onwards. The carbon constraint includes the peak-plateau-decline, existing coal fleet assumes a 50-year life as well as new build forced in according to the IRP policy adjustments.
			Least-cost	the same input assumptions as the Reference scenario but with no carbon emissions constraint, no forced-in new-build technologies and no annual new-build constraints on any technologies. Endogenous coal decommissioning.
			Modest RE pathway	This scenario assumes the same input assumptions as the Least-cost scenario with the only changes being dynamically smoothed minimum new-build limits on solar PV and wind specifically. Endogenous coal decommissioning.
			Ambitious RE	This scenario assumes the same input assumptions as the Least-cost scenario with the only changes being dynamic minimum new-build limits on solar PV and wind specifically. Endogenous coal decommissioning.
			Ambitious RE pathway & coal off by 2040	Similar to Ambitious RE industrialisation scenario, wind and solar PV annual new build is smoothed over the planning horizon as per the same minimum build constraints. In addition, this scenario enforces that all coal-fired capacity is decommissioned by 2040, to further reduce carbon emissions.
			2 GtCO$_2$ budget	Same input assumptions as Least-cost but with a total carbon budget constraint of 2 Gt applied between 2020 and 2050.
South Africa Country and Climate Development Report (CCDR)	The World Bank	Provides recommendations to help policy makers prioritize among a range of options, recognizing uncertainties about future climate change impacts and the availability of technologies and financing.	Net zero reference scenario	The Net Zero reference scenario is a pathway that follows the updated NDC targets by 2030 and the government's ambitions for 2050 as presented in its Low-Emission Development Strategy and JTF. The Net Zero reference scenario assumes a cumulative GHG emissions budget of 9 gigatons (Gt) CO2-eq over the period 2021–2050, which is aligned with the upper level of the updated NDC until 2030.
Exploring Net Zero pathways for South Africa	University of Cape Town's Energy Systems Research Group	Extension of the analytical work that informed the update of South Africa's NDC in 2021, with the goal of undertaking some initial analysis on the options for, and implications of, a greenhouse gas emissions pathways to Net Zero CO2 emissions in 2050.	Reference	No greenhouse gas emission constraint and assumed minimal policies to reduce GHG emissions.
			Net Zero 20 MT sink	Assumes moderate policy interventions and programmes to reduce CO2e emissions and enhance CO2 sinks, resulting in a 12 Mt sink. The scenario is modelled across various cumulative economy wide GHG emissions budgets of 6, 7, 8, 9 Gt CO$_2$e/year.
			Net Zero 45 MT	Assumes comprehensive set of mitigation policies in the land and agriculture sector, resulting in a 45 Mt sink. The scenario is modelled across various cumulative economy wide GHG emissions budgets of 6, 7, 8, 9 Gt CO$_2$e/year.

5.3.3. Areas of alignment between selected studies

The results of the studies, and their various electricity pathways, have several areas of alignment, which are each discussed in turn below. These relate to:

- Least cost technology pathways are dominated by renewable energy and do not include new build coal or new build nuclear;
- The most cost-effective way to meet mitigation commitments and pursue more ambitious carbon constraints is through decommissioning and/or reducing outputs from coal fleets; and
- Costs increase with more ambitious decarbonisation scenarios, but only marginally.

5.3.3.1. Least-cost systems are predominantly comprised of renewable energy and do not include new build new coal or new build nuclear

Decarbonising South Africa's Power System (NBI, BCG and BUSA, 2021)

The report assessed three energy sources available at scale to close the supply gap and fulfil the energy security needs of the country. These were: (i) renewable energy[57]; (ii) coal with carbon capture and storage (CCUS)[58]; and (iii) conventional nuclear energy[59]. These energy sources formed the basis of the archetypes that were assessed to determine the dominant technology in a least-cost scenario for a 2050 power system. Each of these archetypes comprise a range of supply technologies but are characterised by the technology that accounts for most of the power generation in that system making it the 'dominant' technology.

The analysis of the three archetypes indicated that by 2050, a renewables-dominated power system, together with a combination of gas and batteries for flexibility, is the most cost-competitive system for South Africa to supply electricity at least-cost. This archetype therefore formed the basis of the four pathways presented in the study. This system leverages battery storage for short-term variability management, uses gas for peaking and mid-merit, and has Medupi and Kusile in operation until 2050. The study indicated that this renewable energy supply mix would cost 100 cents per kWh in 2050 in real 2020 terms, while coal and nuclear systems cost 129 c/kWh and 116 c/kWh, respectively.

Systems analysis to support increasingly ambitious CO_2 emissions scenarios in the South African electricity system (CSIR and Meridian Economics, 2020)

A key result from the study is that regardless of CO_2 ambition, low-cost renewable energy is expected to play an increasingly important role while more expensive renewables (e.g., CSP) and other new-build low carbon technologies, like nuclear and coal with CCUS, are not selected as part of the least-cost technology mix.

New-build coal capacity is only built when either forced-in (such as for the IRP 2019 and Reference scenarios) or when annual new-build constraints are placed on other technologies. The study indicated that clean coal technologies, specifically coal with Carbon Capture and Storage (CCS) and Integrated Coal Gasification Combined Cycle (IGCC) did not form part of the least-cost energy mix due to these technologies' high capital cost. To illustrate the high cost associated with CCUS, new-build pulverised fuel (PF) and fluidised bed combustion (FBC) coal investment costs is c. R43 500 to R52 450/kW, while

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[57] ~130 GW of RE (52 GW wind and 78 GW solar), 29 GW gas (Open Cycle Gas Turbine [OCGT] and Combined Cycle Gas Turbine [CCGT]), and 15 GW of battery storage.

[58] The coal and CCUS system consist predominantly of coal (~35 GW), with gas for peaking (~21 GW) and limited RE (~32 GW wind and solar combined).

[59] The nuclear dominant system consists of 20 GW of nuclear, supported by 10 GW coal, peaking and mid-merit gas (~20 GW) and ~50 GW of wind and solar.

coal PF with CCS was c. R84 000/kW in 2018 and will be c. R70 900/kW by 2030. Supplementing this information with the known expected future low utilisation of the coal fleet as well as other cheaper to build energy and capacity expansion technologies results in coal with CCS to not form part of least-cost energy mixes, especially as CO_2 ambition increases. Similarly, IGCC is very capital intensive at c. R67 500/kW, revealing a similar reason as to why IGCC is also not part of least-cost energy mixes with increasing CO_2 ambition.

Across all scenarios explored in the study, no new-build nuclear generation capacity is selected as part of a least-cost energy mix. This is due to the techno-economic characteristics of new-build nuclear capacity, which is capital intensive. Thus, low-cost build and flexible capacity would be preferred in an optimised power system to supplement the already least-cost variable nature of capacity.

New-build solar PV and wind capacity is consistently part of all scenarios, albeit with different absolute deployment levels. The Modest and Ambitious RE Industrialisation scenarios aimed to smooth the wind and solar PV annual new build over the planning horizon. This is intended to represent a more sustainable and achievable build-out programme considering the already known outcomes from the Least-cost scenario.

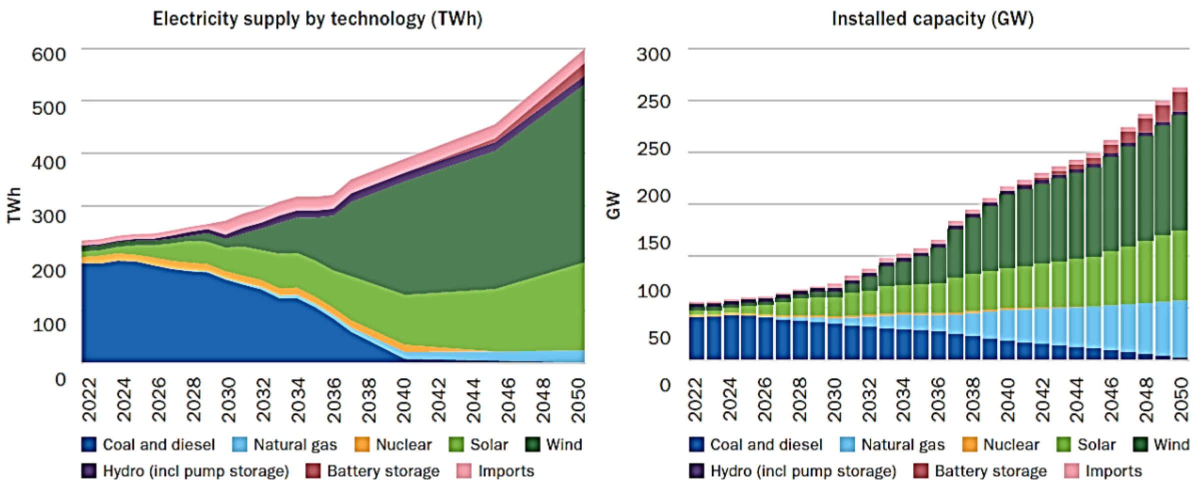
South Africa Country Climate and Development Report (CCDR) (World Bank. 2022)

The analysis in the CCDR indicates that although a Net Zero reference scenario is only one of the possible combinations of technologies to achieve the low carbon transition across the economy, it emphasises that the least-cost solution entails growth in renewables, complemented by storage and natural gas.

The CCDR provides a high-level overview of what a Net Zero power sector could look like over the next three decades (Figure 7). Such a system could include:

- By 2050, wind and solar could account for 85% of electricity generated and 67% of capacity installed.
- In alignment with IRP2019, the decommissioning of 10 – 12 GW of coal power plants by 2030, to mostly be replaced by new investments in solar and wind energy.
- Complementary use of pumped storage, battery storage and gas turbines (running on natural gas) to fill the demand gap for electricity and contributing some 30% of the total installed capacity by 2050. Battery storage will play a growing role, particularly as the cost of technology declines in future.

No explicit mention of nuclear is made in the report, however as indicated in the chart below, the assumption that was applied was that nuclear will supply electricity up to 2045, which is in line with the expected lifetime of Koeberg, should it be extended through refurbishment.



Source: SATIM

Figure 7: Net Zero reference scenario for the electricity sector by electricity supply technology (TWh) and installed capacity (GW)[60]

Exploring Net Zero pathways for South Africa (UCT ESRG. 2023)

The analysis performed by the ESRG for the Net Zero pathways indicated that the new capacity which is added to the electricity system is predominantly solar PV and wind capacity, with OCGT (natural gas fired) and batteries providing ancillary services. New build coal or nuclear is not selected as a least-cost option.

The results and conclusion from the studies agree that the bulk of the least-cost mix should be comprised of predominantly renewable energy with peaking support (e.g., battery storage, pumped hydro, and natural gas) providing flexibility to the systems and fill the gap between demand and supply. Even without climate change constraints, the results provided by the models underpinning these studies did not select new build coal or new build nuclear as least-costs options. The studies did however assume a continuation of nuclear energy should Koeberg's lifetime be extended beyond 2024.

5.3.3.2. The most cost-effective way to meet mitigation commitments and pursue more ambitious carbon constraints is through decommissioning and/or reducing outputs from coal fleets

Decarbonising South Africa's Power System (NBI, BCG and BUSA. 2021)

This study explored how the remaining emissions from the selected renewable energy dominant system, predominantly emanating from the remaining coal capacity from Kusile and Medupi running until 2050, could be removed to reach a Net Zero emission system by 2050. The study considered the following technology options:

- Retrofitting coal plants with CCUS;
- Replacing coal with baseload gas;
- Overbuilding RE and storage; and
- Replacing coal with flexible nuclear like Small Modular Reactors (SMR).

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[60] World Bank. 2022.

Of these options, the RE overbuild was indicated to be the cheapest with a cost of 101 c/kWh, compared to 110 c/kWh for retrofitting the coal, 107 c/kWh for baseload gas, and 109 c/kWh for SMR. In the 'lowest emission scenario', all coal should be off by 2042, largely driven by the need to meet the Carbon Budget. The IRP aligned pathway follows the decommissioning of coal in accordance with the IRP, with Medupi and Kusile operational until 2050 to meet Net Zero by 2050. The pathway equates to a 9 Gt economy wide carbon budget.

South Africa Country Climate and Development Report (CCDR) (World Bank. 2022)

The scenario within the CCDR report modelled all coal off by 2040, considering an economy wide 9Gt carbon budget, which drives the need to remove coal by 2040.

Systems analysis to support increasingly ambitious CO_2 emissions scenarios in the South African electricity system (CSIR and Meridian Economics, 2020)

The study considered a range of pathways with increasingly ambitious CO_2 constraints, where the more ambitious pathways saw a reduced output from coal plants, and included one scenario of coal off by 2040, which aligned with the lowest carbon budget, as illustrated in Figure 8. The reference scenario runs the coal fleet until the end of life and the other scenarios follow endogenous decommissioning (Figure 8). It should be noted that the date chosen for coal closure is a representative scenario for testing a "what if" hypothesis, but it could be repeated for any year where the option to decommission all coal is chosen.

The study also indicated that the role of coal-fired power stations is expected to shift towards providing flexibility in a future South African power system with increased variable renewable energy part of the energy mix. Flexibility becomes increasingly important in scenarios where increased levels of solar PV and wind are integrated. This is especially notable in earlier years of the time horizon (pre-2030) as significant levels of coal capacity still exists and should be utilised as much as technically feasible but no more than economically optimal. The feasibility as well as cost implications of an increasingly flexible coal fleet to operate at low capacity factors will need to be carefully considered as increased variable renewable energy is integrated.

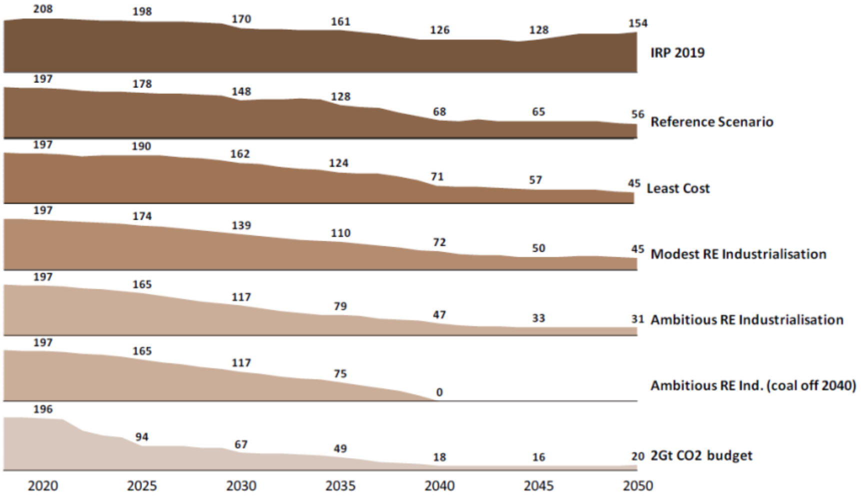

FIGURE 8: ELECTRICITY PRODUCTION FROM COAL (TWH/YEAR) ACROSS PATHWAYS[61]

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[61] CSIR and Meridian. 2022.

The Net Zero scenario within the CCDR report modelled all coal off by 2040, considering an economy wide 9 Gt carbon budget, which drives the need to remove coal by 2040.

Exploring Net Zero pathways for South Africa (ESRG, 2023)

The results of this study again reiterate that the most economically efficient pathway to meet more stringent carbon constraints, as well as the Net Zero target, is large-scale investment in wind and solar PV generation. Coal capacity is curtailed in response to the GHG constraint.

Similarly, this analysis indicated that the pace of coal closure is driven by the Carbon Budget, and depending on how ambitious the carbon constraint is, the amount of power generated by coal is reduced. Figure 9 illustrates the smaller proportion the power generated from coal contributes to the generation mix depending on the carbon constraints applied. The charts below range from a 6 Gt to 9 Gt carbon budget.

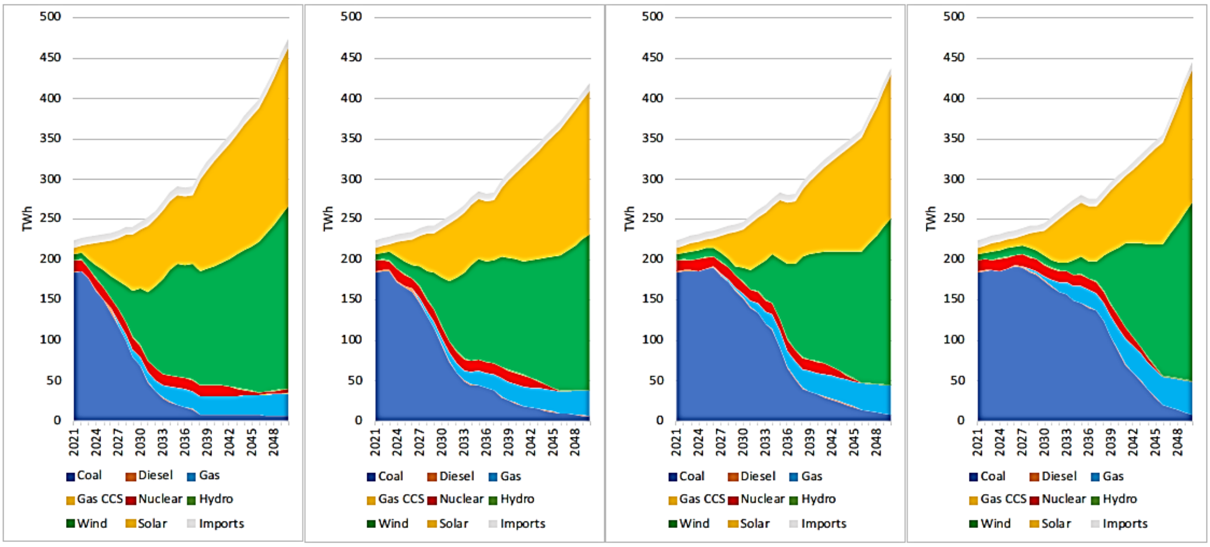

FIGURE 9: ELECTRICITY PRODUCTION BY SOURCE IN THE NET ZERO 45 MT SINK CASES WITH GHG BUDGETS OF 6-9 GT (LEFT TO RIGHT)[62]

With increasing carbon ambition, the speed at which South Africa can deploy the least-cost mix dominated by low carbon technologies becomes important. The results of the studies are consistent in that the most cost-effective way to meet mitigation targets is through increasing renewable energy build out and through reducing output of and/or retiring coal plants earlier. When more ambitious CO_2 reduction scenarios were modelled, additional renewable energy was selected by the models as least-cost options, together with decommissioning coal plants earlier or reducing the output of coal plants. Capacity from coal is curtailed in response to the carbon budget applied.

Refurbishments of coal plants with technologies such as carbon capture and storage (CCS) are too costly. When considering the decommissioning plan for the current coal-fired power plants based on end of technical life, once the retrofit with abatement technologies is complete, most coal plants in South Africa will be near decommissioning or operate for a very short period. Accordingly, this is not a cost-optimal solution.

To reduce coal generation, several factors must be considered, including Just Transition imperatives, economic and energy security impacts, and the pace and scale of RE build programme.

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[62] ESRG. 2022.

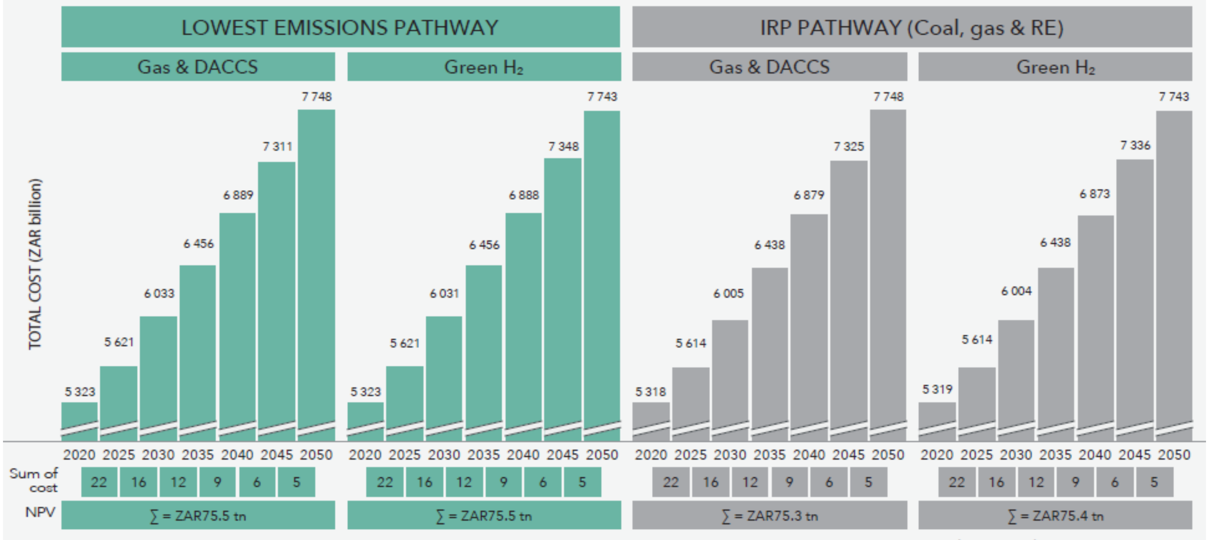
The exact pace of coal closure, whether following the IRP2019 or decommissioning coal plants earlier, and decisions around when coal should be completely off is, as discussed further below, an area of divergence between the studies, and consensus has not been reached.

5.3.3.3. Costs increase with more ambitious decarbonisation scenarios, but only marginally

Decarbonising South Africa’s Power System (NBI, BCG and BUSA, 2021)

The study compared an ‘IRP constrained pathway’ with a ‘low emissions pathway, each with two variances, for costs. The ‘IRP constrained pathway’, includes coal ramp-down in line with the IRP at the cost of higher emissions. The ‘low emissions pathway’ includes accelerated decommissioning of coal with all coal off by ~2042.

The results of this study indicated that the cost trajectories and trends are similar across the pathways, but the low emissions path yield 2 – 8% higher electricity costs in the first 15 – 20 years. The cost increase is higher in the low emissions pathway due to the earlier coal decommissioning, as well as due to earlier build out of renewables when learning curves technology costs are still improving. The real costs subsequently decline from ~2030 or 2035 given the growing share of increasingly cheaper wind and solar energy in the system. When comparing new-build CAPEX and total cost, both pathways yield similar total costs at c. R75.5 trillion total cost for the 30-year period from 2020 – 2050. The total cost (ZAR billion) for the respective scenarios is provided in Figure 10.



Source: Plexos model, NBI-BCG project team.

FIGURE 10: COMPARISON OF TOTAL COST OF PATHWAYS, NBI, 2021

Systems analysis to support increasingly ambitious CO_2 emissions scenarios in the South African electricity system (CSIR and Meridian Economics, 2020)

The study includes six scenarios, each with different carbon budgets, as well as an IRP 2019 scenario. Each of these scenarios were costed, and a percentage in difference between costs were compared against the reference scenario. The results in Figure 11 indicate an increase in system costs as emissions reduce.

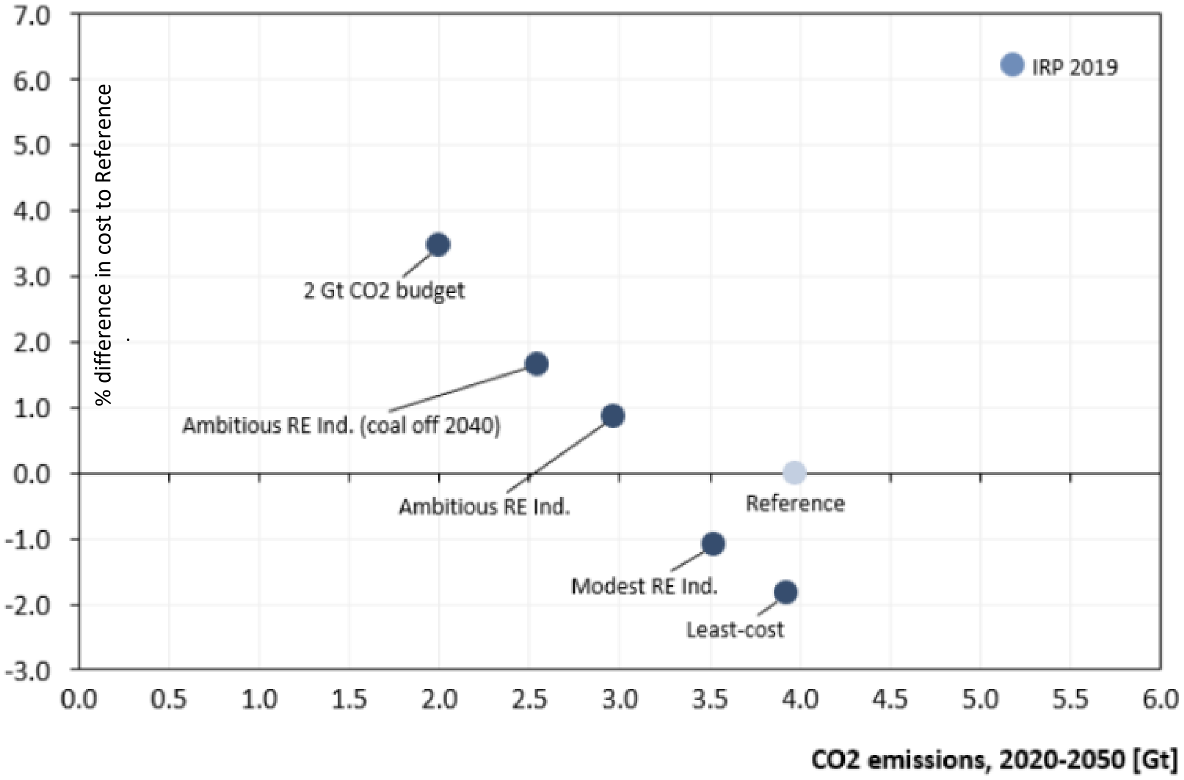


FIGURE 11: TOTAL SYSTEM COST PER PATHWAY, DISCOUNTED (2020-2050) (% DIFFERENCE TO REFERENCE)[63]

Although system costs rise as climate ambitions rise, the cost increase is considered marginal, with the most ambitious scenario costing 3.5% more than the reference scenario (R124 billion) and allowing a shift from 4 $GtCO_2$ (Reference scenario) to 2 $GtCO_2$ (CO_2 Ambition scenario). Similarly, moving from 4 $GtCO_2$ (Reference scenario) to 3.5 $GtCO_2$ (Modest RE Industrialisation) as an intermediate step would save costs with a 1.1% (R39 billion) reduction in system costs, whereas moving to 3 $GtCO_2$ (Ambitious RE Industrialisation) would only result in a 1% increase in system costs (R31 – R59 billion).[64]

Therefore, even if an earlier than optimal and smoothed renewable energy build out programme is imposed, or an ambitious power sector carbon constraint is considered, GHG emissions reduction comes at a relatively small premium. Furthermore, the assumption of conservative technology costs for renewable energy technologies strengthens this finding in scenarios with increased climate ambition and resulting renewable energy penetration.

Exploring Net Zero pathways for South Africa (ESRG, 2023)

The study compared the total undiscounted systems costs covering the energy and industry sectors across the scenarios with a 45 $MtCO_2$ sink across the 6 – 9 $GtCO_2$ budget compared to the reference case. The costs consist of the annualised capital costs of infrastructure and the fixed and variable costs of operating the infrastructure, which includes supply side and demand side technology, as well as the costs of fuel supply. Figure 12 presents the percentage change in total undiscounted system costs for the energy and industry sectors relative to the reference case, which rise to around 6% higher in the most ambitious budget case.

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[63] CSIR and Meridian. 2020.

[64] The IRP 2019 scenario's cost cannot be used as a comparison to the other scenarios, as the assumptions of technology cost and demand forecast are not the same. The Reference scenario was therefore made to be used a comparison.

The rapid increase in cost from year 2045 is because of a massive increase in the rate at which new capacity is added in the last two years before 2050 to meet the net zero constraint as, in the analysis, there are no constraints for the addition of new capacity. The study however acknowledges that there are technical and financial constraints to adding such sudden and large amounts of additional capacity, which should be tested in future analyses. This highlights the importance of smoothing annual new build to better reflect a realistic scenario.

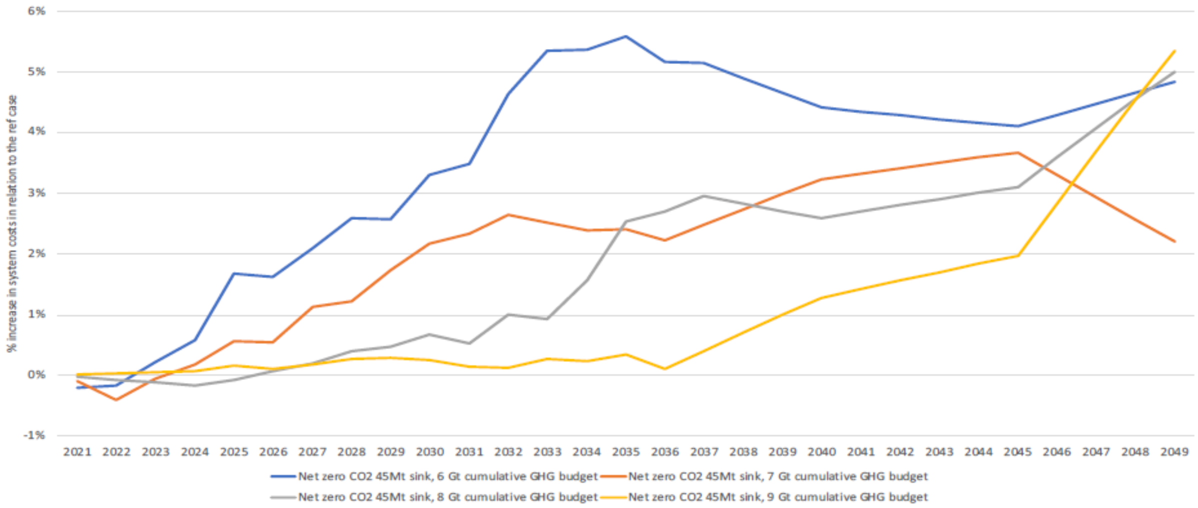

FIGURE 12: PERCENTAGE INCREASE IN TOTAL UNDISCOUNTED SYSTEM COSTS (ENERGY AND IPPU) RELATIVE TO THE REFERENCE CASE[65]

The outcome of the studies indicates that pursuing a power system with more ambitious carbon constraints, compared to a least-cost scenario, comes at a marginal cost increase. The increase in cost is largely driven by deploying renewable energy ahead of learning curves and closing coal early. A path for power sector decarbonisation therefore has minimal trade-offs and substantial power sector benefits, such as affordability and positive environmental impact.

5.3.4. Areas of divergences between selected studies

This section explores points of divergences and dissensus of study outcomes. The causes of the divergences or dissensus are largely driven by the assumptions applied around input parameters in the models used. To understand why there may be differences in results, it is important to understand what drives energy modelling results. This includes assumptions around:

- Demand forecast: How much electricity the country will need, driven by GDP levels and economic structure.
- Eskom's coal fleet performance: How much the plants can theoretically produce and how this changes over time, as well as parameters like minimum annual use (load factor) and expected lifetime.
- Type of model: Power sector only, all sector – demand sectors like transport/industry can alter the pace of power sector decarbonisation.
- Air quality compliance: Whether and how studies deal with air pollution compliance, CAPEX, OPEX, and life of plant.
- Costs and availability of alternative options: What prices for new RE will be realised? How much can be built and how quickly? Is gas available? Is capital available and at what cost?

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[65] ESRG. 2022.

- Carbon budgets: What South Africa can emit as part of its fair share of global emissions budgets for a given limit on temperature rise (e.g., budgets for 2°C vs. 1.5°C and probability of meeting those limits; as well as method for calculating the national share). This drives the pace of RE implementation and coal ramp down.

The key differences between the studies'' results are summarised in Table 10 and relate to:

- the pace of coal closure/early retirement or operating coal plants at reduced outputs;
- the amount of gas required to provide flexibility and meet demand gaps in transitioning systems; and
- the inclusion of green hydrogen and other technologies to remove residual emissions.

The outcomes of the studies are detailed in the subsequent sections.

Table 10: Summary of divergences across selected studies

Study/report name (organisation)	Pathway/ Scenario name	Carbon budget	Installed VRE capacity 2030	Coal retirement scenario	Gas	Green Hydrogen and CCS
Decarbonising South Africa's Power System (NBI, BCG and BUSA)	Lowest emission GAS and DACCS	~3.5 GtCO$_2$e electricity sector	~56 GW	Early coal retirement and Coal off by 2042	Included as part of energy mix, expected demand to be ~218PJ/a by 2030	DACCS to eliminate remaining emissions
	Lowest emission Green H2	~3.5 GtCO$_2$e electricity sector	~56 GW	Early coal retirement and Coal off by 2042	Included but replaced with Green H2 after 2040	Replaces gas after 2040
	IRP pathway–- gas	~4.4 GtCO$_2$e electricity sector	~26 GW	Follows IRP coal retirement trajectory and 2050 coal off	Included as part of energy mix, expected demand to be ~218 PJ/a by 2030	DACCS to eliminate remaining emissions
	IRP pathway–- Green H2	~4.3 GtCO$_2$e electricity sector	~26 GW	Follows IRP coal retirement trajectory and 2050 coal off	Included but replaced with Green H2 after 2040	Replaces gas after 2040
Systems analysis to support increasingly ambitious CO$_2$ emissions scenarios in the South African electricity system (CSIR and Meridian Economics)	IRP 2019 (DMRE)	~5.2 GtCO$_2$e electricity sector	~35 GW	50-year life ~170 TWh/yr (2030) ~154 TWh/yr (2050)	~27 PJ (2030) ~270 PJ (2050)	Green hydrogen not included
	Reference (Current Policy)	~4 GtCO$_2$e electricity sector	~35 GW	50-year life ~148 TWh/yr (2030) ~56 TWh/yr (2050)	~28 PJ (2030) ~135 PJ (2050)	Green hydrogen not included
	Least-cost	~3.9 GtCO$_2$e electricity sector	~34 GW	Endogenous decommissioning ~162 TWh/yr (2030) ~45 TWh/yr (2050)	~42 PJ (2030) ~142 PJ (2050)	Green hydrogen not included
	Modest RE industrialisation	~3.5 GtCO$_2$e electricity sector	~48 GW	Endogenous decommissioning ~139 TWh/yr (2030) ~45 TWh/yr (2050)	~42 PJ (2030) ~91 PJ (2050)	Green hydrogen not included
	Ambitious RE industrialisation	~3 GtCO$_2$e electricity sector	~61 GW	Endogenous decommissioning ~117 TWh/yr (2030) ~31 TWh/yr (2050)	~40 PJ (2030) ~131 PJ (2050)	Green hydrogen not included
	Ambitious RE ind. & coal off by 2040	~2.5 GtCO$_2$e electricity sector	~61 GW	Endogenous decommissioning, all off by 2040 ~117 TWh/yr (2030) 0 TWh/yr (2050)	~40 PJ (2030) ~203 PJ (2050)	Green hydrogen not included
	2 Gt CO2 budget	~2 GtCO$_2$e electricity sector	~71 GW	Endogenous decommissioning ~67 TWh/yr (2030) ~20 TWh/yr (2050)	~42 PJ (2030) ~130 PJ (2050)	Green hydrogen not included
South Africa Country and Climate Development Report (World Bank)	Net Zero reference scenario	~9 Gt CO$_2$e economy-wide	24 GW	Coal off by 2040	Included, no quantity provided	Green hydrogen not explicitly included, but acknowledged as a key technology for the transition
Exploring Net Zero pathways for South Africa (UCT, ESRG)	Reference	Four different scenarios, ranging from 6-9 GtCO$_2$e economy wide budget	19 GW (min)	Output of coal reduces dependent on carbon budget applied	12% of electricity generated	No hydrogen in the GHG constrained cases for electricity generation. CCS to play a role
	Net Zero 20 Mt carbon sink	Four different scenarios, ranging from 6-9 GtCO$_2$e economy wide budget	19 GW	Output of coal reduces dependent on carbon budget applied	Not provided for 20 Mt sink scenario	No hydrogen in the GHG constrained cases for electricity generation. CCS to play a role
	Net Zero 45 Mt carbon sink	Four different scenarios, ranging from 6-9 GtCO$_2$e economy wide budget	~21 - 62 GW depending on carbon budget	Output of coal reduces dependent on carbon budget applied	5.3% - 6.3% across carbon budget constraints, with some retrofitted with CCS at a later stage	No hydrogen in the GHG constrained cases for electricity generation. CCS to play a role

5.3.4.1. Pace of coal closure and operating capacity of coal fleets

There are differences between studies and pathways regarding whether coal plants should operate at a lower capacity to support system flexibility, or whether coal should be retired earlier and the exact date of decommissioning. The divergence is largely driven by the carbon budget applied in the scenario. The studies from NBI, BUSA and BCG and CCDR report each provide one scenario, with coal off the system by 2042 and 2040 respectively. Other studies, such as those by CSIR/Meridian Economics and ESRG, modelled a range of scenarios illustrating that, as a more stringent carbon budget applied, coal is decommissioned earlier or operated at lower capacity. This illustrates the fact that there are currently a range of possible options, largely driven by the carbon constraint, and a lack of consensus on the optimal choice in this area.

It should be noted that a study is currently under development to support the development of an independent and socially engaged Coal-Fired Power Plant (CFPP) decommissioning plan(s). This study would include testing the potential for early decommissioning or feasibility of running coal plants at a low annual load factor, such as 35% and lower, and assessing the potential avoided costs for refurbishment and retrofits, while ensuring energy security is maintained during the transition and beyond. The plan(s) will be based on the outcomes of a prioritisation framework based on a multi-criteria assessment, and a techno-economic modelling exercise. The preliminary results of this study will be presented to technical experts as well as to stakeholders through an open and transparent engagement process facilitated by the PCC.

5.3.4.2. The amount of natural gas required to support an energy transition

Decarbonising South Africa's power sector will require a transformation of today's coal power dominated system into a renewable energy dominated electricity system. Deployment of solar and wind generation capacity at scale will increase the need for energy storage and peaking capacity to address variability of renewable energy sources. Natural gas is proposed as a generation source that can support the flexibility requirements of the RE dominant system, as well as meet demand during period of RE unavailability.

Across all studies and scenarios, there is alignment that natural gas has a role to play in transitioning the power system. Leveraging natural gas as part of the energy mix in gas-to-power plants for peaking is proposed to manage seasonal variability, supporting grid flexibility and to lower system cost in early years, especially when other technologies such as battery storage are still expensive. Gas-to-power plant technologies include open-cycle gas turbine (OCGT)[66] and combined-cycle gas turbine (CCGT).[67] Across the studies however there isn't consensus as to how much natural gas will be required, and whether South Africa's existing supply sources and infrastructure can meet demand for natural gas.

TEXT BOX 3: SOUTH AFRICA'S CURRENT GAS DEMAND AND SUPPLY

Currently South Africa's primary gas demand is in Gauteng (50 PJ), Mpumalanga (110 PJ) and KwaZulu-Natal (KZN) (20 PJ). These areas are supplied by gas from Pande-Temane gas reserve in Mozambique (~160 PJ) via the Republic of Mozambique Pipeline Company (ROMPCO) pipeline, as

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[66] Gas turbines which are more suited for low level of utilisation, such as for peaking. OCGTs have lower CAPEX requirements, but higher OPEX costs relative to CCGTs. South Africa has six OCGTs which all run on diesel.

[67] Gas turbines which are more suited for supply equivalent to or greater than mid-merit utilisation. South Africa currently does not have any CCGT capacity installed.

well as Methane Rich Gas from Sasol operations (~20 PJ) to Kwa-Zulu Natal via the Lilly pipeline. The reserves of the Pande-Temane gas fields are declining, and supply is expected to be constrained from about 2025 onwards, presenting a supply risk if additional gas cannot be sourced at an affordable price. [68]

Decarbonising South Africa's Power System (NBI, BUSA and BCG, 2022)

The study views gas as a transition fuel which will be critical in the journey to transition to a Net Zero power system and sees it initially growing as an enabler to the integration of wind and solar into the power system at scale, whereafter gas will then be gradually replaced by other technologies to reach Net Zero emissions.

The study estimated that demand for natural gas in gas-to-power (GTP) plants are expected be ~218 PJ/a by 2030, for peaking and mid-merit load. The study argues that GTP is the most cost-competitive technology option for peaking and long-term seasonal variability management, if the gas price remains constant at a range of USD7 – 9/GJ. Gas prices are commodity prices and therefore variable and poses forex exposure risk on balance on payments.

The study identified several key areas that necessitate further research to properly gauge natural gas supply and demand as well as the requirement for additional infrastructure. These areas include:

- "What are likely demand scenarios for natural gas in South Africa, from a sectoral and geographic perspective?"
- "What are natural gas supply options for South Africa's power sector – and potential other sectors – and what are infrastructure requirements?"
- "If South Africa leverages natural gas for the power sector and potentially also the decarbonisation in other sectors, how can a gas lock-in be avoided and ensure that gas only serves as a 'transitional fuel'?"

Systems analysis to support increasingly ambitious CO_2 emissions scenarios in the South African electricity system (CSIR and Meridian Economics, 2020)

The study also envisages that gas will provide flexible capacity in the power sector. Natural gas is consistently included as part of the generation mix across all scenarios, deployed as a flexible resource to ensure grid stability and meet demand. Although significant capacity is deployed in all scenarios, it does not form a dominant part of the energy mix (only 1 – 5% of energy except in IRP 2019 with 9%) and would contribute relatively little to generation and thus demand. This is because of this capacity being utilised for capacity during exceptional periods of RE unavailability to ensure sufficient system adequacy.

The study indicated that annual natural gas offtake is expected to remain relatively low, increasing from 25 PJ to 30 – 40 PJ by 2030. Thereafter, increased natural gas offtake of 40 – 90 PJ by 2040 and 90 – 140 PJ by 2050. An exception is when all coal capacity is decommissioned by 2040 forcing an increased annual natural gas offtake of up to 130 PJ by 2040 and 200 PJ by 2050. Similarly, in the IRP 2019 scenario, projections indicate natural gas annual offtake is expected to rise towards 180 PJ by 2040 and 270 PJ by 2050. Figure 13 illustrates the various expected gas demand across the different scenarios.

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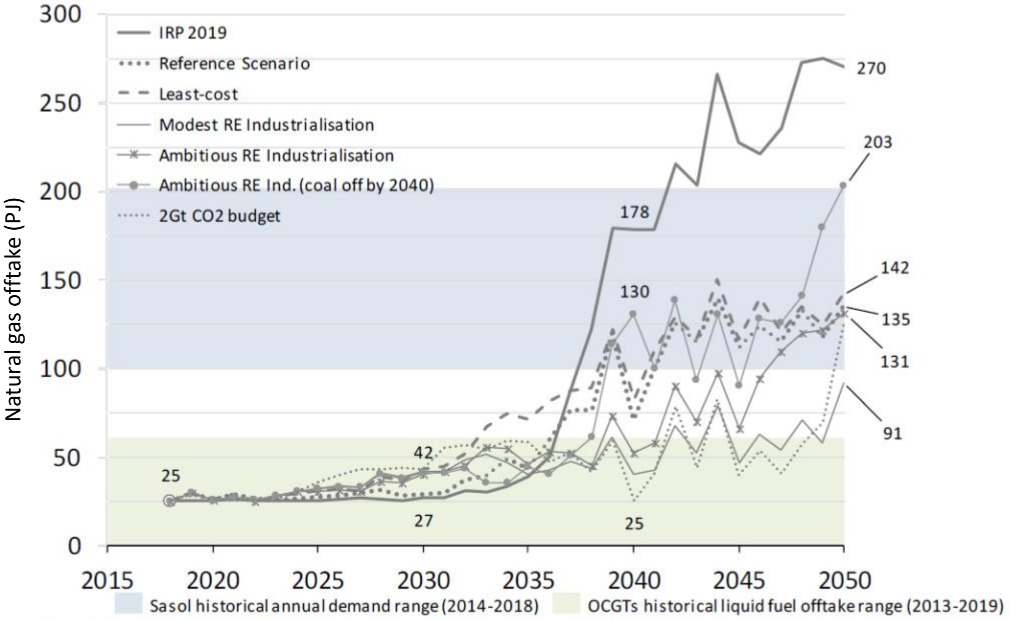
[68] NBI. 2021. The Role of gas in South Africa's Pathway to Net Zero.



Notes: Natural Gas Price = 150 R/GJ (proxy for "expensive" natural gas); IRP 2019 not directly comparable due to higher demand forecast assumption
Sources: CSIR analysis

FIGURE 13: ANNUAL NATURAL GAS OFFTAKE PER SCENARIO (PJ)[69]

Exploring Net Zero pathways for South Africa (ESRG. 2023)

The study indicated that in the reference case the amount of electricity generated from natural gas over the period 2021 – 2050 is 12%, compared to c. 6% in the GHG-constrained cases, and as discussed below, some of this gas generation is retrofitted with CCS later in the period. The study did not provide natural gas utilisation using the PJ unit of measure across all sectors, and therefore cannot be used as a fair comparison to the other studies. A key conclusion of the study was that more sensitivity analyses need to be undertaken on the natural gas price, which will also affect the use (or not) of gas in the electricity sector up to 2050.

TEXT BOX 4:KEY DRIVER OF DEMAND AND ALTERNATIVE FUTURE SUPPLY OPTIONS FOR GAS

Future gas demand in South Africa may be driven by the following sectors: i) power sector in gas-to-power plants; ii) Synfuels (chemicals and petrochemical sector) to transition away from a reliance on high emitting carbon sources such as coal as feedstock; and iii) Broader industry shifting away from coal and diesel to natural gas as source of power and heat.

The source of gas is a key determinant of its complexity, affordability, viability in the short and long term, and environmental and social impacts. Key alternative to supplement current supply of gas received from the Republic of Mozambique Pipeline Company (ROMPCO) pipeline can broadly be categorised to include: i) extending current ROMPCO pipeline to other gas reserves in Mozambique; ii) LNG from Floating Storage Regasification Unit (FSRU)[70] from various supply sources across Southern Africa, and iii) local off-shore and on-shore reserves.[71]

Determining long-term demand and preferred or optimal pathway to supply gas to South Africa is complex and needs to factor in several consideration in the decision making, these include: Impacts

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[69] CSIR and Meridian. 2020.

[70] Ships which transport, store and regasify Liquified Natural Gas (LNG) on board. FSRUs typically require either an offshore terminal, with an undersea pipeline, to transport regasified LNG to shore, or an onshore receiving terminal.

[71] NBI. 2021. The Role of gas in South Africa's Pathway to Net Zero.

on trade balance, complexity of supply (i.e., political, commercial and technical); broader socio-economic impacts such as job creation, cost effectiveness of supply and affordability, where the gas demand is in the country, climate and other environmental and social impacts, and risk of stranded gas assets and the technical and financial feasibility of potentially repurposing infrastructure e.g., green hydrogen, and existing and future alternatives to gas-to-power that could be more economically appealing while having fewer negative social and environmental effects, amongst other considerations.

It is beyond the scope of this report to provide an analysis of how much demand would necessitate investment into alternative gas supply sources, and further studies should investigate this.

More research is needed to determine the need for gas and how much gas will contribute to the energy transition. The amount of gas demand, and whether additional supply may be required need to not only consider the power sector, but future gas demand from other sectors. Consideration should be given to trade impacts, environmental and social impacts, socio-economic impacts, the risks of carbon lock-in and stranded assets, and economic feasibility and affordability (especially the impact of variables such as gas price) when determining the source of the gas supply. To provide clarity on short to long-term demand and preferred supply pathway of gas for South Africa, it will require a nationally orchestrated approach that coordinates key supply and demand decisions. Until then, the precautionary approach should be applied in relation to gas-to-power i.e., that major investments in gas infrastructure and exploration be postponed as long as possible while there is still a lot of scepticism and disagreement about how much of a role gas will play in the energy transition.

5.3.4.3. Role of green hydrogen and other emerging technologies to reach Net Zero

According to some studies, although at a much later stage and to a lesser extent than other technologies (such as renewables and natural gas), green hydrogen and other emerging technologies could support the transition of South Africa's electricity sector. The extent to which these technologies will contribute varies across studies, and the fact that many of them are still in their infancy (such as green hydrogen and carbon capture and storage) adds to the uncertainty.

Decarbonising South Africa’s Power System (NBI, BUSA and BCG, 2022)

To remove remaining emissions in the long term, the study includes two options as part of the lowest emissions pathway scenario. The first option includes natural gas in the energy mix until 2050, with emissions offset by CCUS or Direct Air Capture and Storage (DACCS) if suitable storage sites are identified. The second option substitutes green hydrogen for natural gas. Both decarbonisation options will be implemented by the 2040s.

Systems analysis to support increasingly ambitious CO_2 emissions scenarios in the South African electricity system (CSIR and Meridian Economics, 2020)

The study's scenarios did not include green hydrogen, but it does allow for the use of 'other storage,' such as batteries, across all scenarios, ranging from 11.7 to 12.8 GW installed capacity. All the scenarios modelled still have emissions in the system post-2050 to various degrees, depending on the scenario.

South Africa Country and Climate Development Report (World Bank, 2022)

According to the CCDR report, new technologies such as battery storage and green hydrogen are expected to play an important role in South Africa's low carbon transition and in offsetting hard-to-abate emissions. In the scenario presented, battery storage will play a growing role beginning in 2040 and will account for a minor portion of the energy mix by 2050. Although green hydrogen is acknowledged to play an important role in the energy mix, it is not explicitly included in the proposed electricity mix, therefore rather indicating a role in the energy sector as a whole and other industries.

Exploring Net Zero pathways for South Africa (ESRG, 2023)

The study indicated that there is no hydrogen utilisation in the GHG constrained cases for electricity generation and that the predominant industries that will use hydrogen would rather be for steel production, heavy freight transport (road), chemicals (including ammonia) and other thermal applications in industry.

The study did, however, indicate that CCUS will play a role in removing residual GHG emissions in the electricity sector that are from the remaining coal plants in operation (i.e., Kusile and Medupi) and the use of OCGT plants, which have not been retrofitted.

Interventions may be required from 2040 onward to reach Net Zero but will be dependent on technology maturity and cost. These include technologies such as Direct Air Carbon Capture and Storage (DACCS), green hydrogen and small modular reactors (SMR). These technologies are still at an early development stage, have many uncertainties regarding technology options, maturity and cost and require active support to reach commercial use. Given the uncertainty linked to these, a decision on the optimal last-mile decarbonisation strategy will likely only be made from 2030 – 2035 and onwards.

5.4. Just Energy Transition investment needs

South Africa’s Just Energy Transition will require significant investment. According to JET-IP[72], the energy sector will require an initial investment of approximately R1.5 trillion over the course of five years (2023 – 2027) to meet the NDC’s upper target range. This includes investments in four priority areas across South Africa's energy sector: (i) electricity; (ii) new energy vehicles (NEVs); (iii) green hydrogen, and (iv) cross-cutting skills development.

In the electricity sector alone, the JET-IP investment amounts to R711 billion by 2027, approximately half of the total investment need. Investment in the electricity sector can be broadly classified into (i) investment for RE build; (ii) expansion and strengthening of transmission grid and distribution infrastructure; (iii) investment in flexibility requirements (electricity storage and gas); and (iv) decommissioning/early retirement of coal plants and climate justice/supporting coal mining affected workers and communities.

Looking ahead to 2050, the investment needs to transition the energy system alone have been estimated by various organisations, ranging from R4 trillion to R14 trillion (Table 11). This estimate is dependent on the pathway taken, the carbon budget, the economy's capacity to transition, the type of modelled investments, and the rate at which it transitions.

TABLE 11: ESTIMATED INVESTMENT NEED FOR THE ENERGY TRANSITION

Organisation	2030	2050	Scope	Carbon Budget
System-IQ	R1.3 trillion	R4.0 trillion	Energy sector only	2.5 $GtCO_2$
NBI[73]	R1.0 trillion	R5.9 trillion	Economy wide	10 $GtCO_2$

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[72] RSA. 2022.
[73] NBI. 2021.

World Bank[74]	n/a	R7 trillion	Economy wide	9 $GtCO_2$

6. Methodology for assessing technologies and electricity pathways

The following provides an overview of the methodology used to:

(i) Critique individual electricity technologies to better understand their relative advantages/disadvantages and what these could mean at a system-level.

(ii) Critique different electricity scenarios/pathways to better understand their relative advantages and disadvantage at a system-level (i.e., when technologies are used in combination and at different time horizons).

Step 1: Assessment of electricity technologies

The first step provides a techno-economic assessment of a selection of electricity technologies in line with those included in the existing electricity plans and studies. Each of the technologies were assessed against a set of criteria related to their resource availability, deployment requirements, security and reliability, environmental impacts, cost and affordability, and any other notable considerations that might present risks or co-benefits from the use of these technologies. This assessment aimed to identify each technology's relative advantages and disadvantages. These are related specifically to the use phase of the technology's lifespan.

Assessment criteria included:

- Resource / feedstock availability in South Africa.
- Build-time.
- Cost / affordability (LCOE).
- Reliability and stability.
- Direct use-phase GHG emissions.
- Water use.
- Air pollution / quality.

Step 2: Clustering electricity scenarios

All electricity scenarios, pathways and plans discussed in the previous section were grouped into three broad clusters based on their key similarities. The three clusters include: (i) reference scenario cluster; (ii) moderate decarbonisation cluster; and (iii) ambitious decarbonisation cluster. Table 12 provides a short description of each cluster.

TABLE 12: ELECTRICITY PLANNING SCENARIO CLUSTERS

	Reference cluster	Moderate decarbonisation cluster	Ambitious decarbonisation cluster
Description	Scenarios that are based on the IRP 2019 and which represent a business-as-usual scenario. These include any extensions, or models based on the IRP 2019, using updated assumptions.	These include pathways that follow a modest RE build and follow endogenous decommissioning of coal.	Scenarios that model high-climate ambition pathways.

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[74] World Bank. 2022.

Step 3: Assessment of electricity scenario clusters

The "electricity planning framework for enabling a Just Transition" (discussed in Section 2.3.1, page 14) was used to objectively critique each of the electricity scenario clusters outlined in Table 12. The framework draws on the World Energy Council's Energy Trilemma, the DMRE's Road to JET Framework and energy security requirements of the NDP.[75] Table 13 provides an overview of the metrics used across each of the four main elements of the electricity planning framework.

TABLE 13: JUST ENERGY TRANSITION CRITERIA FOR CRITIQUING ELECTRICITY SCENARIO CLUSTERS

Key elements for electricity planning	Assessment metrics
1. Energy equity	• Access to electricity. • Cost / affordability of electricity (LCOE).
2. Energy security	• Reliability and stability of electricity supply.
3. Environmental sustainability	• GHG emissions as per overall carbon budget. • Water-use. • Air quality (noting the significant impacts on human health and the environment).
4. Socio-economic sustainability	• Climate and transition risk exposure (international trade and domestic value chain risks). • Net job creation across the economy. • Economic development opportunities (e.g., green industrialisation opportunities).

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[75] World Energy Council. 2022.; DMRE. 2021.; NDP 2012.

7. Results: Assessment of electricity technologies and pathway clusters

7.1. Electricity technology assessment

Each electricity technology has advantages and disadvantages. These need to be taken into consideration during electricity planning and scenario modelling to ensure a future electricity mix that meets the criteria for a Just Energy Transition.

Table 14 and Table 15 provide a summary the technology assessment results, highlighting the advantages and disadvantages associated with key electricity technology choices. (Please refer to Appendix B for more detail on the technology assessment.)

The advantages and disadvantages associated with each technology option (Table 14 and Table 15) need to be compared against each other, and within the context of South Africa's ongoing electricity crisis, and the county's broader socio-economic and environmental context. The technology-level assessment, therefore, helps to improve understanding of the advantages and disadvantages of each individual technology. This, in turn, helps to identify potential trade-offs when planning for a particular energy mix. Safeguards can then be put in place to ensure any negative impacts from different trade-offs do not contribute to the triple challenge. Likewise, it can help identify co-benefits (in terms of energy equity, security, environmental and socio-economic sustainability) from the use of a combination of technologies. Some trade-offs to consider, might include, for example:

Nuclear energy is a stable and reliable source of electricity. It is also considered a clean electricity source because it emits no GHG emissions or other air pollutants and occupies a small amount of land in comparison to other generation technologies. It does, however, generate nuclear waste that must be disposed of in a safe and responsible manner. It uses relatively large amounts of water, which is critical in an arid country, and it is also expensive, requiring a large capital outlay and having one of the highest LCOE.

TABLE 14: SUMMARY RESULTS OF TECHNOLOGY ASSESSMENT (ENERGY GENERATION)

Technology Criteria	Coal	Gas	Nuclear	Wind	Solar PV	CSP	Large hydropower
Resource / feedstock availability in South Africa	High feedstock availability (53 bn tonnes in reserves)	Moderate feedstock availability - large potential resource but difficulty to exploit (200 tcf onshore, 60 tcf offshore)	Fuel imports required	High resource availability (average 559 W/m2)	High resource availability	High resource availability	Limited water resource availability
Build-time (years)	10 – 12	2 – 3	12 - 15	2 - 3	1.5 – 2	2 - 3	4 - 7
Cost / affordability (LCOE R/kWh)	~1 - R2.58	1.5 (combined cycle) and 3.4 (open cycle) 2.5 – 3.3 (Peaking support)	R2.23 - 3.47	0.44 – 0.85	0.48 – 0.7	2.1 – 2.65	0.31
CAPEX requirement (R/kW)	R105 285	R21 250	R212 500	R26 486	R16 575	R128 086	R20 192
Reliability and stability	Reliable and stable if existing fleet is maintained	Reliable and stable	Reliable and stable	Reliable and stable if coupled with storage and peaking support	Reliable and stable if coupled with storage and peaking support	Reliable and stable if coupled with storage and peaking support	Reliable and stable, but can be affected by drought
Direct GHG emissions (kgCO2e/kWh)	0.93 – 1.26	~0.45	0	0	0	0	0

Technology Criteria	Coal	Gas	Nuclear	Wind	Solar PV	CSP	Large hydropower
Lifecycle emissions ($KgCO_2e/kWh$)	🟥 1.023	🟨 0.45	🟩 0.015 – 0.05	🟩 0.012 – 0.015	🟨 0.124	🟩 0.009	🟩 0.021
Air pollution (gSO_2/kWh and gNO_x/kWh)	🟥 6.9 – 13 (SO_2) 2.3 – 6.1 (NO_x)	🟨 SO_2 NA 0.3-0.4 (NO_X)	🟩 No air pollutants from generation	🟩 0	🟩 0	🟩 0	🟩 0
Water use (l/kWh)	🟨 2 – 2.4 (wet cooling) 0.12 (dry cooling)	🟨 0.598	🟥 1.5 – 2.7	🟩 0	🟩 0	🟥 3.5	🟥 ~ 68
Land use (m^2/MWh)	🟥 15	🟨 1.3	🟩 0.3	🟩 0.4	🟩 19	🟩 22	🟩 14 for large plants 22 for small-to-medium plants
Waste	🟥 Significant quantities of fly ash produced. In South Africa 36 Mt of fly ash produced annually	🟨 No waste produced via the generation. Waste is associated with the decommissioning of facilities	🟥 Radioactive waste produced. Koeberg Nuclear Power Station produces 32t/yr. of spent fuel waste	🟨 No waste produced via the generation. Waste is associated with the decommissioning of facilities	🟨 No waste produced via the generation. Waste is associated with the decommissioning of facilities	🟨 No waste produced via the generation. Waste is associated with the decommissioning of facilities	🟨 No waste produced via the generation. Waste is associated with the decommissioning of facilities

Key	🟥 Significant disadvantage	🟨 Moderate disadvantage	🟩 Advantage	⬜ Neutral / NA

TABLE 15: SUMMARY RESULTS OF TECHNOLOGY ASSESSMENT (STORAGE TECHNOLOGIES)

Technology Criteria	Pumped Storage	Green H_2	CCUS	Battery Storage
Resource / feedstock availability in South Africa	Limited resource availability in South Africa	Medium resource availability (high solar and wind availability, but currently low clean electricity and water availability)	NA	Abundant metal reserves in Africa
Build-time (years)	4 – 10	Pipeline: 7-12	3-4	0.5 to 1
Cost / affordability (LCOE R/kWh)	1.8	0.76 – 1.57	Coal: 0.77 - 2.08 Gas: 0.37 – 0.74	R3 077 - R5 474 per kW-year for a 100MW/400 MWh[76]
CAPEX requirement (R/kW)	R40 490	R15 921 for water electrolysis	Coal: Increase in CAPEX of R19,610 with addition of CCUS Gas: Increase in CAPEX of R5,753 with addition of CCUS	R2431 – R3 366
Reliability and stability	May be impacted by droughts. Pumped storage is primarily used for satisfying peaking demand and does not provide long-term stable power	Still an immature technology	Still an immature technology	Allows for greater stability of supply for renewables during periods of low renewable energy generation. Largely a mature technology with significant innovation taking place.
Direct GHG emissions ($kgCO_2e/kWh$)	0	0	NA	0

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[76] Figures are levelized cost of storage.

Technology Criteria	Pumped Storage	Green H_2	CCUS	Battery Storage
Lifecycle emissions ($KgCO_2e/kWh$)	🟩 0.007	🟩 Green H2 from solar PV: 0.05-0.13 Green H2 from offshore wind: 0.01-0.02	⬜ NA	🟥 117
Air pollution (gSO_2/kWh and gNO_x/kWh)	🟩 0	🟩 NA	⬜ NA	🟩 0
Water use (l/kWh)	🟧 68	🟧 0.27	🟥 Coal: 1.18 – 1.94 Gas: 1.05	🟩 Water may be used in the cooling of certain battery systems, though water use is generally not associated with battery storage
Land use	🟧 14m²/mWh (large plants), 22m²/mWh (small-to-medium plants)	🟧	⬜ NA	🟥 0.092m²/kWh capacity
Waste	🟧 No waste produced from the generation of electricity through pumped storage. Waste may be generated through the commissioning and decommissioning of pumped storage facilities	🟧 No waste is produced during the production of green hydrogen	🟩 No waste produced	🟥 No waste is produced during the use-phase of utility scale battery storage. The decommissioning of spent batteries results in the generation of waste which contains toxic heavy metals such as lead, and cadmium

Key	🟥 Significant disadvantage	🟧 Moderate disadvantage	🟩 Advantage	⬜ Neutral / NA

7.2. Electricity pathways cluster assessment

Energy pathways and scenarios from the studies assessed in this report, were categorised into three clusters (Table 16). Each cluster was assessed against their ability to positively contribute to the four criteria for a Just Energy Transition: energy equity, energy security, environmental sustainability, and socio-economic sustainability. The main difference between the clusters was the pace of coal closure/reduced coal output. The reference scenario cluster follows coal closure based on the IRP 2019 and Eskom's planned retirement schedule beyond 2030. As such, coal is kept in the electricity mix longer. The moderate decarbonisation cluster follows endogenous coal decommissioning, and the ambitious decarbonisation cluster follows early coal closure. The results for each of these criteria are discussed in more detail below.

TABLE 16: GROUPING OF SCENARIOS/PATHWAYS WITH SIMILAR DECARBONISATION AMBITIONS INTO CLUSTERS

	Reference scenarios	Moderate decarbonisation cluster	Ambitious decarbonisation cluster
Description	Scenarios that are based on the IRP 2019 and which represent a business-as-usual or reference scenarios. These include any extensions, or models based on the IRP 2019, using updated assumptions[77].	These include pathways that follow a modest RE build and follow endogenous decommissioning of coal.	Scenarios that model high-climate ambition pathways. These pathways decommission coal plants much earlier than their original lifetime and includes significant renewable energy build.
Scenarios included under each cluster	• NBI: IRP pathway - both. • ESRG: Reference scenario. • CSIR: reference scenario. • CSIR: IRP2019 (DMRE).	• ESRG: Net Zero 45Mt sink with 8Gt-9Gt carbon budget. • CSIR: least-cost pathway. • CSIR: Modest RE pathway. • World Bank: Net Zero Reference	• NBI: Lowest emissions pathway – both. • ESRG: Net Zero 45 Mt sink with 7Gt-6Gt. • CSIR: Ambitious RE with coal off. • CSIR: Ambitions RE build. • CSIR: 2 Gt Carbon budget

7.2.1. Energy equity

All three clusters are closely related when it comes to energy equity, with marginal differences in the LCOE between the cluster and the ambitious decarbonisation cluster. Moderate and ambitious decarbonisation pathways could, however, have the advantage when it comes to electricity access. This is due to the modular design of technologies like solar PV and wind, which can be deployed at different scales, some needing significant grid expansion. They are safer and cleaner alternatives to fossil fuel-based generators and can support sustainable livelihoods under different community ownership models.

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[77] These are not directly comparable to the IRP 2019 due to, for example, differences in demand assumptions and technology costs.

7.2.1.1. Access to electricity

Access to electricity is more closely related to transmission and distribution infrastructure, rather than generation technologies. It is difficult to rank each of the clusters against an energy access metric, especially in the absence of some kind of “grid expansion” or “electricity accessibility” metrics within the individual scenarios that make up each cluster. Therefore, irrespective of preferred cluster, infrastructure investments to support electricity access across the country remains critical for a Just Energy Transition.

However, at a technology-level, renewable energy technologies like solar PV and wind probably have the advantage over fossil fuel technologies. This is because they can be deployed at various scales, and in some cases without necessarily needing to significant grid expansion, for example localised micro-grids.

7.2.1.2. Cost and affordability of electricity

The least-cost scenarios (included in the moderate decarbonisation cluster) favour renewable energy dominant systems with peaking support from a combination of battery storage, pumped hydro, and/or natural gas. Deviating from this pathway, such as forcing in new build coal or nuclear, is unlikely to be least-cost. More expensive electricity puts a drag on economic development and can lead to unjust outcomes.

The ambitious decarbonisation cluster was found to have marginally higher total systems costs associated with transitioning the electricity sector – between 1% and 6% higher relative to the reference scenario (depending on the specific study and scenario). The NBI, BUSA and BCG (2022) study estimated that the difference in total cost associated with an ambitious decarbonisation and a stated policies pathway is ~R200 billion between 2021 and 2050.

The same study suggests very little difference in the real relative cost of electricity by 2050, with both ambitious decarbonisation and stated policies pathways project to have a cost of R1.31/kWh. However, the ambitious decarbonisation pathway is projected to have higher electricity costs (between 2c/kWh and 9c/kWh higher) in the short to medium term (2025 to 2040) relative to the stated policies pathway. This is due to costs associated with early coal asset retirement and ambitious deployment of renewable energy technologies.

Pursuing an ambitious decarbonisation pathway, therefore, does not necessarily compromise the affordability of electricity. This is especially true if you also consider the value of avoided environmental externalities associated with more ambitious pathways. Affordability does, however, require an analysis of end consumer tariffs. In the case of South Africa, Eskom consumers have historically been benefiting from different types of fossil fuel subsidies. If these subsides are removed as part of the transition, electricity tariffs may end up increasing despite the efficiencies of the low carbon transition. Interventions may need to be required to support the affordability of power for low-income groups, through expanding and ensuring free basic electricity for these groups.

7.2.2. Energy security

7.2.2.1. Reliability and stability of supply

Reliability and stability of supply is a potential concern with scenarios in the ambitious and moderate decarbonisation clusters. This is largely due to renewable energy technologies (at a technology-level) not necessarily being able to provide electricity throughout a 24-hour period. Variable renewable resources (VRE) are weather-dependent, so their output can be variable and intermittent, posing challenges to grid stability. Sudden fluctuations in power output can destabilise the grid and cause power outages.

In addition, grid inertia needs to be managed in renewable energy-dominated energy systems. Synchronous generators, such as fossil fuel-powered turbines, provide the grid with voltage and reactive power support, as well as synchronous inertia to support frequency stability within the grid. This frequency inertia is provided by rotating mass within generators which move with the frequency of the grid, and act as a form of shock absorber against sudden spikes or dips of demand or supply that may occur. Renewable energy-dominated systems tend to lack rotating mass, which inhibits their ability to provide grid inertia. If not managed appropriately, it can lead to frequency nadir, voltage instability, and faster rate-of-change of frequency. This can potentially result in power disturbances and blackouts.

It is for this reason that many regard large-scale coal and nuclear power plants as critical to provide baseload to electricity systems because these technologies can provide supply 24-hours a day, overcome grid inertia challenges and compensate for the perceived variability of renewable energy facilities.[81]

However, international experience shows that renewable energy-dominated systems are stable. Countries around the world (Table 17) are increasingly able to absorb higher levels of VRE with greater predictability thanks to a combination of flexible domestic generation in the form of battery storage, pumped storage or gas-to-power plants operating as balancing, peaking and/or ramp rate control mode, employing measures to overcome grid inertia and well-functioning markets.

TABLE 17: TOP COUNTRIES AND REGIONS WITH LARGE A SHARE OF VARIABLE RENEWABLE ELECTRICITY GENERATION

Country/ region	Renewable energy generation
Germany	Germany has one of the most reliable grids in Europe, and renewables supply half of the electricity needs. Germany's System Average Interruption Duration Index (SAIDI), a measure of grid stability considering the average power outage duration experienced during a year, was only 0.25 hours, ahead of countries like France (0.35 hours) and Sweden (0.61 hours) that are largely reliant on nuclear power.[78]
Denmark	Denmark derived an average daily share of VRE of 54% in 2021, with a maximum daily penetration of 117% [79].
Ireland	Ireland has also made great strides in increasing their share of renewable generation, with over 300 onshore windfarms in operation. Ireland achieved an average daily share of VRE of 32%, and a maximum daily penetration of 78%.[80].
United Kingdom	The United Kingdom has made significant strides in increasing their share of RE supply. The United Kingdom achieved an average daily share of VRE of 24% in 2021, and a maximum daily penetration of 53%.[81].
Spain	Spain is another country which has recently rapidly rolled out RE projects. In 2021, Spain achieved an average daily share of VRE of 33%, and a maximum daily penetration of 69%[82]. This comes at a time where coal generation is at an all-time low for Spain. Coal-based generation currently stands at 1.9% of Spain's total generation mix[83].
Australia	In 2021, Australia achieved an average daily VRE share of 24%, and a maximum daily penetration of 40%. South Australia specifically achieved a 156-hour uninterrupted stretch of 100%-plus VRE in 2021[84].

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[78] Yale. 2021. Three myths about renewable energy and the grid debunked.
[79] Ren21. Renewables based energy systems
[80] Ibid.
[81] United States International Trade Administration.2022. United Kingdom – Country Commercial Guide
[82] Ren21. Renewables based energy systems
[83] United States International Trade Administration.2022. Spain – Country Commercial Guide
[84] Ren21. Renewables based energy systems

Greece	Greece achieved an average daily VRE share of 28% in 2021, and a maximum daily penetration of 67%[85]. Greece has reduced its reliance on coal, with the proportion of electricity produced from coal diminishing from 52.6% in 2011, to 10.9% in 2022.[86]
California	In 2020, California generated 34.5% of electricity from renewables such as wind and solar[87].

In South Africa, the contribution of renewable energy technologies (wind, solar PV and CSP) increased in 2022 to a total of 6.2 GW installed capacity and provided 7.3% of the total energy mix[88]. The maximum instantaneous contribution of wind, solar PV & CSP was 16.0% between 15h00-16h00 on 27 December 2020[89].

It is important to note that significant levels of coal capacity are still included in the medium term (pre-2035) for the moderate decarbonisation cluster. Here, coal is utilised as long as technically feasible, but no more than economically optimal, to support grid flexibility and stability.[90]

Nuclear power also requires back-up power, for example when reactors go down on unplanned outages, refuelling and maintenance, or as evidenced by Koeberg for more than 6 months at a time for life extension. While coal-based electricity is stable and reliable, as discussed in Section 5.1 the EAF of South Africa's coal fleet has declined significantly and, according to the MTSAO, is unlikely to recover to levels required to ensure stability. South Africa's coal fleet is aging and faces significant maintenance challenges. Following a stated polices pathway with limited amounts of renewable energy deployment may not significantly improve South Africa's energy security. The moderate and ambitious decarbonisation clusters show that greater deployment of renewable energy is required to ensure secure and reliable electricity supply in the short, medium, and long term.

7.2.3. Environmental sustainability

Clusters that follow more ambitious decarbonisation pathways were found to perform better against all environmental metrics, with limited energy equity or security trade-offs.

7.2.3.1. Climate change and GHG emissions

The reference scenario cluster was found to have the highest GHG emissions, with a cumulative 2050 carbon budget ranging between 4 $GtCO_2$ and 4.5 $GtCO_2$ for the electricity sector (~11 $GtCO_2$ for the economy as a whole). This cluster is expected to only reach Net Zero emissions after 2050 and is unlikely to be NDC compliant. The moderate decarbonisation cluster had a cumulative 2050 carbon budget ranging between 3.5 $GtCO_2$ and 4 $GtCO_2$ for the electricity sector (10 $GtCO_2$ for the economy) but still reaches Net Zero by 2050. This cluster is likely to comply with the upper half of the NDC range. The ambitious decarbonisation cluster has the lowest GHG emissions, with a cumulative 2050 carbon budget ranging between 2 $GtCO_2$ and 3.5 $GtCO_2$ for the electricity sector (~9 $GtCO_2$ for the economy) and reaches Net Zero by 2050. This cluster would likely comply with the lower half of the NDC range.

Therefore, the reference scenario cluster puts South Africa at the highest risk of international trade-related impacts. While there are potential opportunities to address GHG emissions using CCUS technologies, this will likely increase the cost of electricity under the reference scenario cluster. The ambitious decarbonisation cluster avoids the most climate change and international trade risks by decarbonising the economy the quickest.

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[85] Ren21. Renewables based energy systems.
[86] Igor Todorovic. 2022. Greece produces record 47.1% of electricity from renewables so far in 2022
[87] California Energy Commission. 2022. New Data Indicates California Remains Ahead of its Renewable Electricity Goals
[88] CSIR Energy Centre. 2023. Statistics of utility-scale power generation in South Africa in 2022.
[89] CSIR Energy Centre. 2021. Statistics of utility-scale power generation in South Africa in 2020.
[90] CSIR/Meridian Economics, 2020

7.2.3.2. Air quality and health impacts

Air quality trends are like GHG emissions trends, with the ambitious and moderate decarbonisation clusters outperforming the reference scenario cluster. However, only the ambitious decarbonisation cluster is likely to comply with MES. Figure 14 illustrates how air pollution decreases with greater climate ambition. For example, particular matter (PM) reduces from ~20 kt/year under a reference scenario, down to zero for the most ambitious scenario.

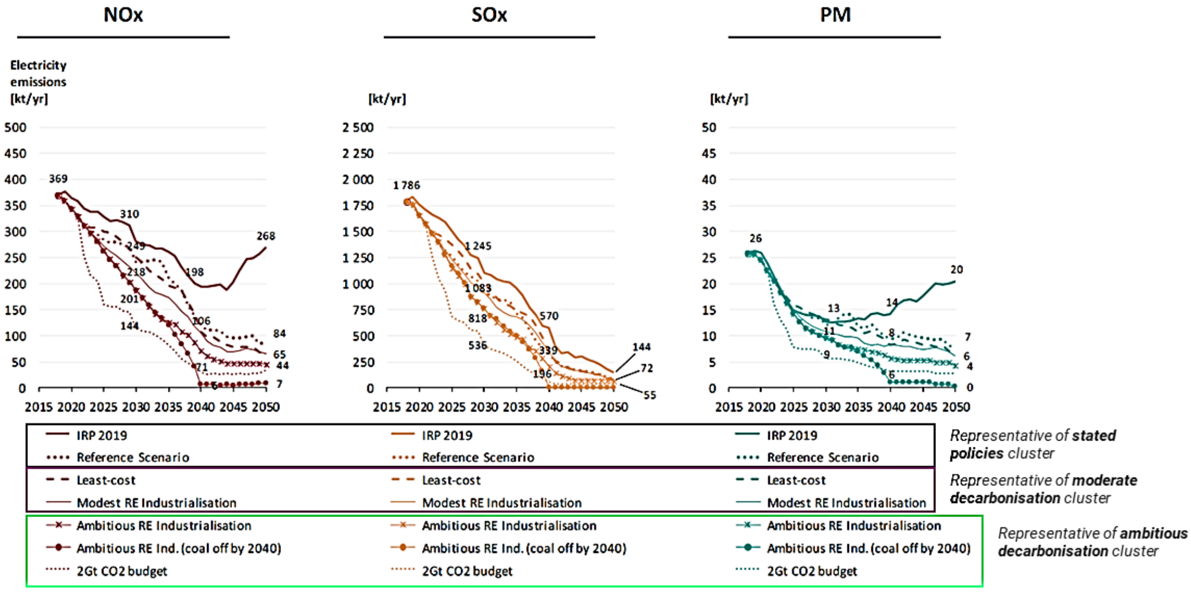

FIGURE 14: ELECTRICITY SECTOR AIR POLLUTION ASSOCIATED WITH DIFFERENT DECARBONISATION PATHWAYS[91]

Air quality is a critical consideration for a Just Energy Transition. Complying with MES at all coal-fired power stations operating beyond 2030 is expected to avoid 2 300 death per year form air pollution, with a savings of R42 billion per year in avoided healthcare expenses. Deploying the best available technologies to reduce air pollution beyond the MES requirements, or decommissioning coal early (~2040) could avoid as much as 57 000 death per year, with a savings of R1 trillion per year.[92]

In addition, nine of Eskom's coal power plants are at risk of being shut down due to non-compliance with MES requirements. The ambitious decarbonisation cluster will help avoid this and meet MES requirements without the need for additional expenditure and resources for cleaning up coal-fired power stations.

7.2.3.3. Water use

Water use in electricity generation also decreases with more ambitious decarbonisation, driven by an increased amount of RE technologies that don't use water to generate electricity. The ambitious decarbonisation cluster is, therefore, more water efficient that the reference scenario cluster. Figure 15 depicts this trend for water consumption across different scenarios with varying degrees of decarbonisation ambition. Again, while there are technologies available to reduce water consumption associated with coal (e.g., different cooling methods) they come at additional cost, further increasing the cost of coal-based electricity relative to renewable electricity.

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[91] CSIR and Meridian Economics. 2020

[92] Centre for Research on Energy and Clean Air. 2023. Health impacts of Eskom's non-compliance with minimum emissions standards.

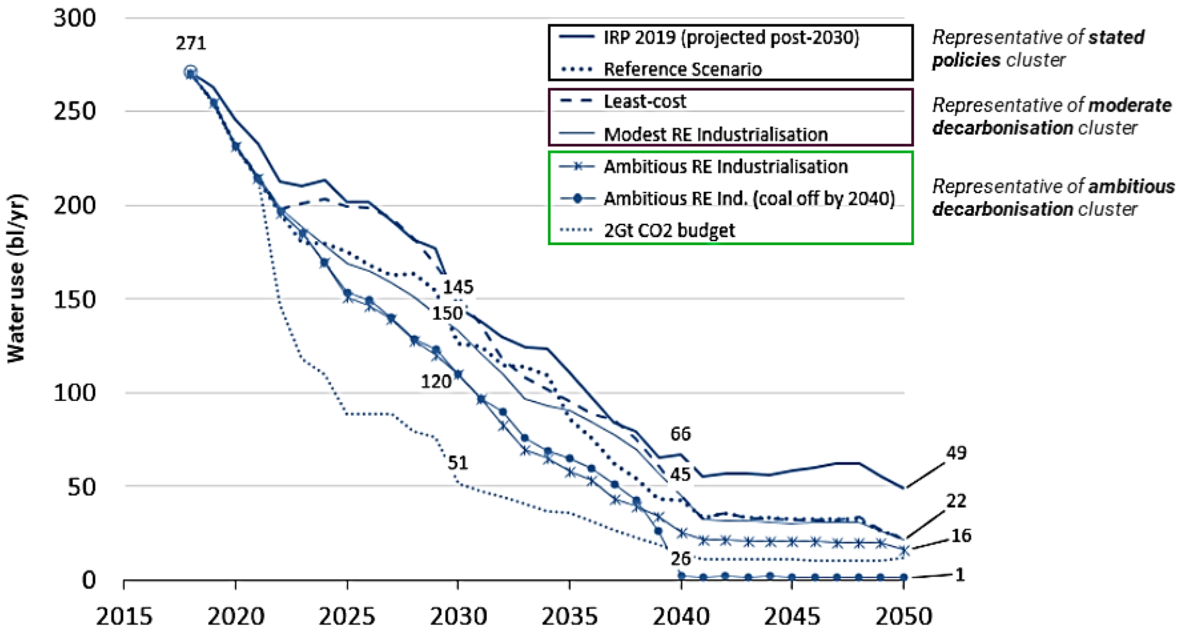

FIGURE 15: REDUCTION IN WATER USAGE ACROSS ELECTRICITY DECARBONISATION PATHWAYS (BL/YEAR)[93]

Water use, in respect of both quantity and quality, is a critical consideration for South Africa, given that it is a semi-arid country and vulnerable to droughts. Water is critical for power generation, economic development, livelihoods and human health and well-being. South Africa cannot afford to pursue a fossil fuel-based electricity pathway that contributes to both water scarcity and climate change, which in turn, reinforces water scarcity.

7.2.4. Socio-economic sustainability

7.2.4.1. Climate and transition risk exposure

Since the reference scenario cluster will result in more GHG emissions which will continue to contribute to global climate change, which in turn will also expose South Africa to greater climate change impacts (as part of one of the worse affected regions globally to such impacts). More frequent and intensive climate change impacts will, as discuss in Section 2, exacerbate the triple challenge. South Africa would also expose itself to increased transition risks (e.g., trade risks from CBAM and declining export markets). Which risks negative impacts to the balance of payments, trade balances, foreign exchange reserves, and employment across carbon-intensive sectors. Ensuring a Just Transition in this context would require the same interventions for supporting at-risk coal workers and communities under an ambitious decarbonisation pathway, except they would need to be deployed across several at-risk sectors.

However, the reference scenario cluster would reduce transition risks to the coal value chain, allowing more time for the value chain to structurally adapt in response to a slower transition. This could also allow more time to implement safeguards for at-risk workers and communities across the coal value chain (e.g., reskilling programmes, etc.) but at the expense of workers and communities in other carbon-intensive sectors that will be exposed to trade risks. It should be noted that a slower transition will not guarantee avoidance and mitigation of transition risks to the coal value chain by default. The

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[93] CSIR and Meridian Economics, 2020

only certain benefit in this regard, is more time for the process to unfold. A just and managed transition is needed to ensure that all possible transition risks to all sectors of the economy are mitigated.

Under the ambitious decarbonisation cluster, South Africa would be able to maintain, and even improve, its international trade-competitiveness in an ever increasingly carbon constrained global economy. South Africa could position itself as a leader in clean energy technology and low-carbon exports on the African continent. It would also help attract foreign direct investment from countries that are prioritising decarbonisation and sustainable development.

Furthermore, it would attract financial support and allow access to both local and international capital markets. Capital markets are increasingly concerned about climate change and will not lend to industries that do not meet the requirements of climate science. This is demonstrated by many South African lenders and banks that have policies prohibiting new coal investment and are seeking climate friendly and sustainable investments. This is also true for access to preferential and risk bearing donor and philanthropy support.

However, the ambitious decarbonisation cluster places greater pressure on the coal value chain. South Africa will need to accelerate measures and access to finance for supporting a Just Transition across the coal value chain (e.g., reskilling, education, social grant support), as the transition out of coal will happen over a shorter period. An important consideration is that South Africa has more control over policies and measures to mitigate transition risks across the coal value chain compared to mitigating transition risks from international trade, that would impact the broader economy.

7.2.4.2. Net job creation across the economy

Under the ambitious decarbonisation cluster, coal plants would close earlier, risking more job losses across the coal value chain sooner, relative to the reference scenario cluster. However, more ambitious decarbonisation will also catalyse growth and job creation in other sectors beyond the coal value chain. For example, the uptake of solar can create 30 000 to 50 000 full time jobs per year up to 2030 across the value-chain from O&M jobs to component manufacturing, to installation and maintenance jobs.[94]

In fact, the ambitious decarbonisation cluster is expected to generate more net-jobs relative to the reference scenario cluster (Figure 16). While the specific amount of net-job creation differs across studies, they all suggest that decarbonising the electricity sector, and capitalising on green industrialisation opportunities, will create net-positive jobs. For example, NBI, BUSA and BCG (2022), suggest that ambitious decarbonisation could create ~200 000 more net-job years by 2035, relative to their reference scenario, if South Africa can successfully localise elements of the renewable energy value chain and effectively re-skill the workforce.[95] The World Bank (2022) estimated that an ambitious decarbonisation pathway would generate 500 000 net-direct jobs between 2022 and 2050.

However, this is not to say that the transition will automatically create more jobs. Creating and realising these net-positive employment opportunities requires responsible and timely deployment of Just Transition interventions within the coal value chain (to “transition out of coal”) and in new emerging sectors (to “transition into green industrial sectors”). This means deploying a range of Just Transition interventions, from reskilling and education programmes for existing and future workers, through to

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[94] World Bank. 2022. Sola Group. 2021. New Report Shows that job creation in the PV sector is inevitable.

[95] NBI, BUSA and BCG. 2021.

industrial policies that enable foreign direct investment into new green industrial sectors (e.g., energy transition metal value chains – from mining through to technology development).

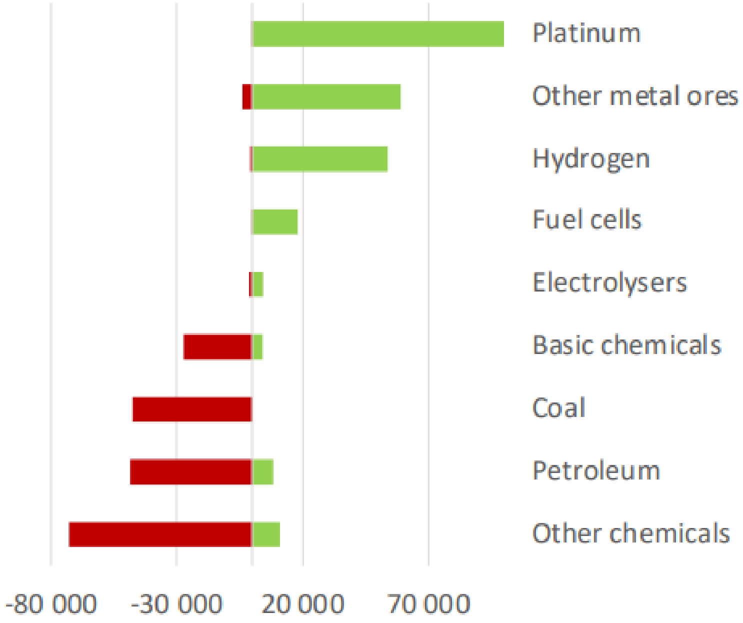

FIGURE 16: EMPLOYMENT SHIFT ACROSS SECTORS ASSOCIATED WITH AMBITIOUS DECARBONISATION (9GT CARBON BUDGET)[96]

7.2.4.3. Economic development opportunities

The ambitious decarbonisation cluster carries greater economic development potential, relative to the reference scenario cluster, despite the contraction of the coal value chain. For example, the World Bank (2022), suggests that an ambitious decarbonisation pathway could almost double GDP between 2022 and 2050, with an average annual growth rate of about 2.3% (double the average growth rate achieved between 2009 and 2019).

Ambitious decarbonisation could also catalyse innovation, new market development and a green industrial revolution, not just in South Africa, but in the rest of Africa via the Africa Continental Free Trade Area and as part of the Continental Master Plan for Energy, where South Africa can play a leading role in supporting clean energy development in Africa. For example, the energy transition will significantly increase the demand for energy transition metals like copper (~200%) and nickel (~150%).[97] A sizable portion of untapped reserves are in Africa, meaning the continent has an opportunity to develop local value chains (from mining to technology development) for low-carbon technologies such as solar PV, wind, batteries, and electric vehicles. Table 18 presents a summary of these various considerations for each of the electrify scenario clusters reviewed in this report. Conclusions and recommendations are provided in the following section.

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[96] PCC. Jobs and Just Transition Energy Dialogue. 2022

[97] IFC. 2023. Net Zero Roadmap for Copper and Nickel Mining Value chains.

Table 18: Summary assessment pathway clusters with various decarbonisation ambitions against the Just Energy Transition criteria

Assessment metrics		Reference scenario cluster	Moderate decarbonisation cluster	Ambitious decarbonisation cluster
Energy equity	Access to electricity	Dependent on grid infrastructure (transmission and distribution) for ensuring access to electricity.	Dependent on grid infrastructure (transmission and distribution) for ensuring access to electricity. Renewable technologies could have an advantage here since they can be deployed at various scale without necessarily needing grid connection.	Dependent on grid infrastructure (transmission and distribution) for ensuring access to electricity. Renewable technologies could have an advantage here since they can be deployed at various scale without necessarily needing grid connection.
	Cost and affordability of electricity	The real relative cost of electricity is expected to be ~R1.31/kWh in 2050, with little difference across clusters. Should policy changes not be imposed, these pathways have marginally less systems cost as compared to the moderate decarbonisation pathways.	The real relative cost of electricity is expected to be ~R1.31/kWh in 2050, with little difference across clusters. A 1% - 2% higher total system / investment costs relative to reference scenario cluster.	The real relative cost of electricity is expected to be ~R1.31/kWh in 2050, with little difference across clusters. 2c – 9c/kWh higher real relative cost of electricity between 2025 and 2040. A 3% - 6% higher total system / investment cost relative to the reference scenario.
Energy security	Reliability and stability	Although this cluster maintains the current coal-fleet, it is aging and faces significant maintenance challenges resulting in extended loadshedding. Relying on an aging coal fleet while deploying small amounts of RE may not be enough to ensure reliability and stability of supply.	The combination of new, reliable and quick-to-deploy RE technologies, combined existing coal for flexibility and stability, will increase overall energy security under this cluster.	Early closure of coal and accelerated deployment of RE will need to be supported by energy storage technologies, gas and/or green hydrogen for supporting peak load and demand variability.
Environmental sustainability	Climate change / GHG emissions	Cumulative carbon budget between 2021 and 2050: 4 – 4.5 GtCO$_2$ for the electricity sector (~11 GtCO$_2$ for the economy as a whole) Would only reach Net Zero emissions post-2050	Cumulative carbon budget between 2021 and 2050: 3.5 – 4 GtCO$_2$ for the electricity sector (~10 GtCO$_2$ for the economy as a whole) Would reach Net Zero emissions by 2050.	Cumulative carbon budget between 2021 and 2050: 2 – 3GtCO$_2$ for the electricity sector (~9 GtCO$_2$ for the economy as a whole). Would reach Net Zero emissions by 2050.
	Air quality	High levels of air pollution (~20 kt/year of PM) and not expected to meet MES requirements. Technologies to reduce air pollution will increase cost of electricity	Relatively lower levels of air pollution (~7 - 6 kt/year of PM) but still not expected to meet MES requirements. Technologies to reduce air pollution will increase cost of electricity.	Low levels of air pollution (~4 – 0 kt/year of PM) and expected to meet MES requirements.
	Water use	Highest water use at ~49 bl/y and significant exposure to climate-related water risks. Technologies to reduce water use will increase cost of electricity	Moderate water use at ~16 – 22 bl/y and moderate exposure to climate-related water risks.	Lowest water use at ~1 bl/y, reducing climate-related water risks.

Assessment metrics		Reference scenario cluster	Moderate decarbonisation cluster	Ambitious decarbonisation cluster
Socio-economic sustainability	Climate and transition risk exposure	🟥 High climate risk exposure to the economy High trade risk exposure to broader economy Low transition risk exposure in coal value chain.	🟨 Moderate climate risk exposure to the economy Moderate trade risk exposure to broader economy. Moderate transition risk exposure in coal value chain.	🟩 Low climate risk exposure to the economy. Low trade risk exposure to broader economy, with potential trade opportunities. High transition risk exposure in coal value chain.
	Net job creation across the economy	🟨 Expected to create fewer net jobs, relative to the ambitious decarbonisation cluster (e.g., 0.8 million net-job years by 2035).	🟨 Expected to create fewer net jobs, relative to the ambitious decarbonisation cluster, but more than the reference scenario cluster if Just Transition interventions are implemented appropriately.	🟩 Expected to create more net jobs, relative to both the moderate decarbonisation and reference scenario clusters (e.g., 1 million net-job years by 2035) if Just Transition interventions are implemented appropriately
	Economic development opportunities	🟥 Limited economic development opportunities without catalysing demand for metals and other inputs used in RE technologies. Further, international trade risks could contract existing, carbon-intensive export sectors.	🟩 Good economic development opportunities associated with the local and international transition (e.g., localising RE technology value chains; increased manufacturing of low-carbon technologies and green industrialisation). Mitigates some of the potential international trade risks.	🟩 Good economic development opportunities associated with the local and international transition (e.g., localising RE technology value chains; increased manufacturing of low-carbon technologies and green industrialisation). Mitigates some of the potential international trade risks.

Key	🟥 Significant disadvantage	🟨 Moderate disadvantage	🟩 Advantage

8. Discussion

Electricity planning should be based on sound technical and least-cost principles. However, policymakers must also consider, and balance, the advantages and disadvantages of different options with respect to the “electricity planning framework for enabling a Just Transition” criteria (i.e., energy equity, security, environmental sustainability, and socio-economic contribution).

Electricity planning should ensure that a chosen electricity pathway is equitable, meaning that all South Africans have access to and can afford electricity. It should also provide secure, reliable and stable electricity supply. Most electricity mix options (i.e., fossil fuel vs renewable energy dominated systems) can achieve these two requirements with the right governance structures in place to prevent sabotage and corruption interfering with electricity cost and supply. However, different electricity mix options perform very differently when it comes to environmental sustainability and socio-economic contributions.

Electricity planning should favour those with lower environmental impact, to both mitigate negative environmental impacts and build resilience to biophysical climate change risks. Technology and pathway choices should also consider socio-economic risks and opportunities they present for international trade, health, employment, new value chains and reindustrialisation in South Africa.

8.1. The preferable electricity planning cluster

Results from the “electricity scenario cluster assessment” (Table 18), gives the ambitious decarbonisation cluster the advantage across the board, except for affordability (albeit with only a marginal 3% to 6% increase in the cost of electricity relative to the reference cluster).

Following the ambitious decarbonisation cluster would mean planning for an electricity mix that is made up mostly of variable renewable energy (VRE). Figure 18 provides an overview of the anticipated installed capacity for VRE and shows a broad range across different electricity pathway clusters. Following the ambitious decarbonisation cluster would mean installing between 55 GW and 75 GW of VRE by 2030 as well as upgrading and expanding transmission and distribution systems to support the added VRE capacity.

System flexibility becomes increasingly important as more renewables form part of the generation mix. The role of storage technologies (e.g., battery and pumped hydro storage) and natural gas or green hydrogen will become key to ensure grid reliability and stability and to overcome potential challenges. These systems have been demonstrated to be reliable and stable when the appropriate amounts of storage and supporting technologies are provided, and the proper measures are used to manage the grid. Renewable energy is also the technology that can provide additional generation capacity onto the grid the fastest and the cheapest and would therefore help to alleviate the current electricity supply crisis in a cost-efficient way.

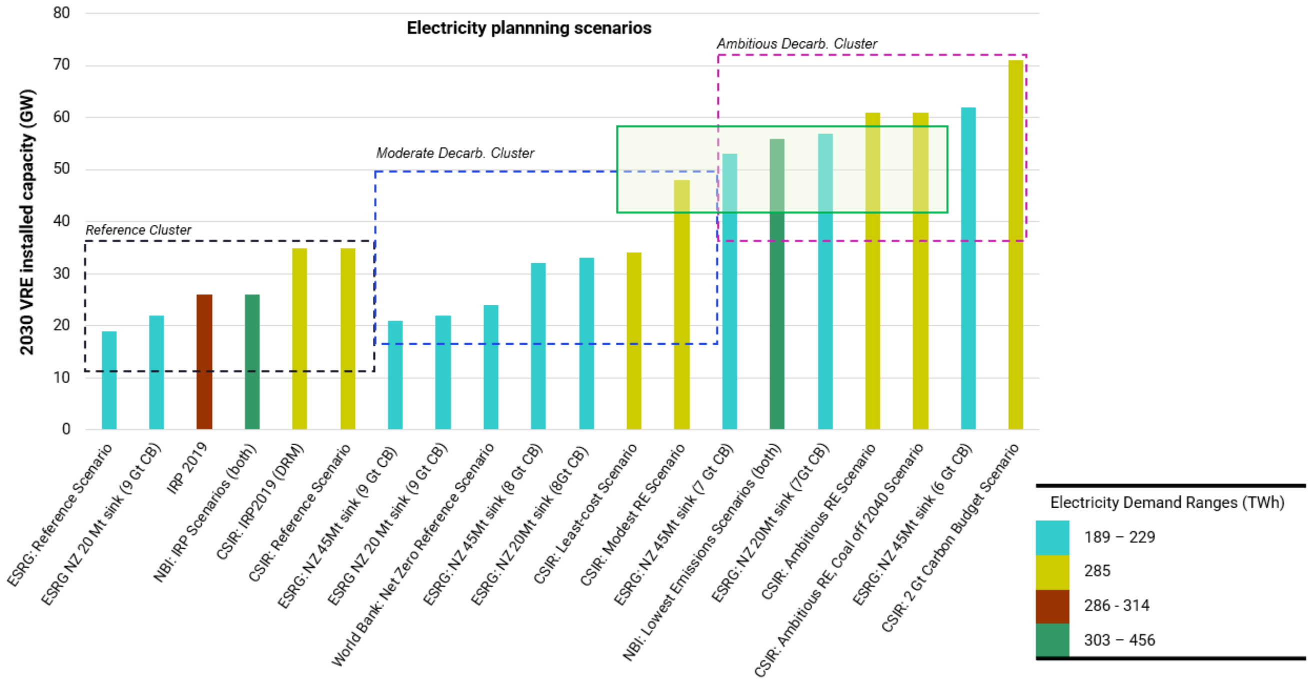

FIGURE 17: INSTALLED CAPACITY FOR VARIABLE RENEWABLE ENERGY (2030) ACROSS DIFFERENT SCENARIOS

Noting that the ambitious decarbonisation cluster is expected to cause a marginal increase in the cost of electricity (between ~2c and 9c per kWh in 2050 relative to the reference cluster), aiming for the lower end of installed VRE capacity (e.g., 50 – 60 GW by 2030 or 6 – 8 GW per year) would be preferable. The increase in cost associated with the ambitious decarbonisation cluster is mostly attributed to early coal closure rather than additional VRE capacity.[98] Aiming for the lower end of the ambitious decarbonisation cluster, therefore, doesn't deviate significantly from least-cost principles. Especially when considering the gains from avoiding international trade risks and negative external costs from climate change and other environmental impacts associated with the reference cluster.

Decommissioning coal earlier may have negative socio-economic impacts across the coal value chain and impede energy security if it is not done in a just and responsible manner. The feasibility of early coal closure should, therefore, be studied very carefully, such as through ongoing studies by the Coal Asset Transition Accelerator (CATA) project[99].

Following more ambitious decarbonisation pathways has the added benefit of lower GHG emissions, which will help the country meet its climate change commitments, as outlined in South Africa's NDC. An extensive analysis was undertaken to inform the JET-IP and offers similar insights regarding installed VRE capacity and climate change mitigation. Figure 18 illustrates how a 2030 installed VRE capacity of between 50 and 60 GW meets different parts of South Africa's NDC range (without energy efficiency measures). Scenarios with installed VRE capacity closer to 60 GW meet the lower end of the NDC range, while those with installed VRE capacity closer to 50 GW meet the upper end of the NDC range. However, with additional energy efficiency measures, South Africa could meet the lower end of the NDC range with 40 to 45 GW of installed VRE in 2030. Therefore, while the JET-IP scenarios in Figure 18 were not included in this technical assessment, they provide similar results: South Africa

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[98] While ambitious decarbonisation cluster pathways do not build new coal or nuclear, some keep current plants as part of the generation mix for many years to come (decommissioned according to the end of their technical life), and others include early coal closure.

[99] CATA-SA aims to explore the potential for accelerated phase-out of the coal-fired power plant (CFPP) fleet in South Africa, in the context of the country's NDC commitment to 2030 and long-term intention of moving towards a net zero carbon economy. The study further considers the implications of air quality (AQ) compliance requirements on the energy mix, and the overarching imperative of ensuring that the transition of the country's energy sector is just and fair to all, especially across the coal value chain.

should aim for a 2030 installed VRE capacity of between 50 and 60 GW (assuming no energy efficiency improvements) to meet its climate change commitments.

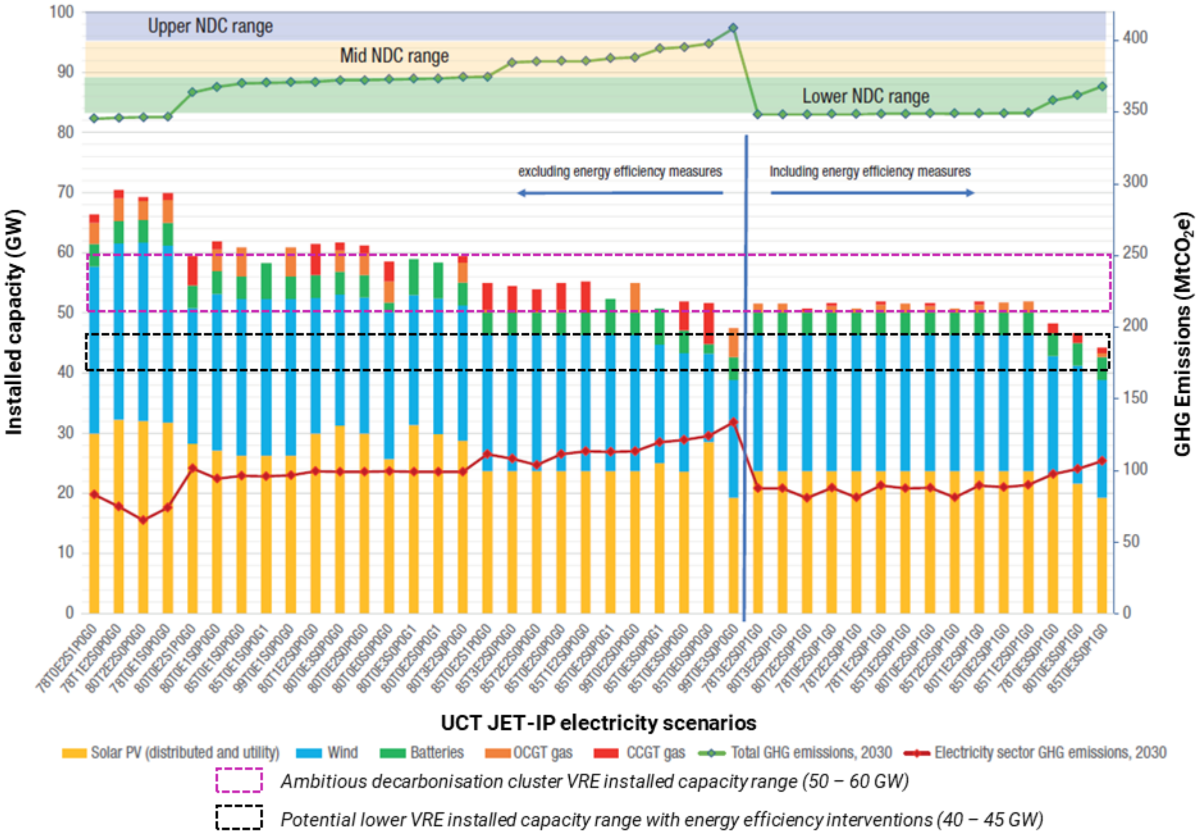

FIGURE 18: 2030 INSTALLED CAPACITY FOR SELECTED TECHNOLOGIES (EXCLUDING RESIDUAL CAPACITY), CORRELATED WITH GHG EMISSIONS[100]

In addition, meeting our climate change commitments will have various environmental and socio-economic co-benefits, including reduced biophysical climate change and mitigating international trade risks, new green industrialisation opportunities and jobs, and improved access to international climate finance.

Aligning with the ambitious decarbonisation cluster will also help reduce water consumption and air pollution associated with the current electricity mix. Given that South Africa is a water-stressed country prone to prolonged droughts, it is critical that electricity generation is as water-efficient as possible (in terms of both quantity and quality) to avoid additional water resource pressures.

Similarly, transitioning away from coal-based electricity will significantly improve air quality, which will improve the health and life expectancy of the surrounding communities, and reduce external cost born to the healthcare system. Renewable energy has the lowest cost of generation expansion; therefore, by encouraging its expansion, the government will have enough capacity in the system to adhere to environmental regulations without exacerbating the energy crisis.

However, aligning with the ambitious decarbonisation cluster is not without its risks and costs. Reducing demand for coal-based electricity will have negative impacts across the coal value chain that need to be managed in a just and inclusive manner to ensure a Just Energy Transition. Taking advantage of economic opportunities presented by the transition is also critical (e.g., green

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[100] JET-IP Secretariate 2022, in: The Presidency, Republic of South Africa. 2022. South Africa’s Just Energy Transition Investment Plan (JET-IP).

industrialisation). This requires swift and ambitious action to develop and implement policies and measures aligned with the PCC Just Transition Framework.[101]

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[101] The Presidency, Republic of South Africa. 2022. South Africa's Just Energy Transition Investment Plan (JET-IP).

9. Conclusions and recommendations

9.1. Recommendations on planned and ongoing responses to the electricity crisis

Every effort is needed to solve the current supply crisis and set the path for a reliable, stable, affordable, and environmentally sustainable electricity supply for all South Africans. The Commission supports the planned and ongoing responses to the electricity crisis outlined in Section 5.2. These interventions present several ‘no-regret’ opportunities which could resolve the short-term challenge while safeguarding the 2030 decarbonisation commitments and long-term Net Zero aspirations. The no-regret solutions must be implemented to ensure growth and development in line with a Just Energy Transition. Considering these planned and ongoing responses, and the comments and inputs of stakeholders from recent engagements, the Commission makes further recommendations for several priority interventions, with the deepest systemic impact, that are aligned with climate positive outcomes and meet the criteria for a Just Energy Transition:

1. 2030 electricity mix:
    - Given the importance of electricity for development, electricity planning should be anchored on least-cost pathways. All models reviewed showed that a least-cost energy model would be made up of investment in VRE (wind and solar), storage (batteries and pumped hydro) and peaking support. None of the models build new coal or nuclear or have gas at high utilisations. Any deviation from this least cost pathway would add system cost and must be justified by a strong developmental argument.
    - The PCC expects a policy adjusted IRP to promote approximately 50 to 60 GW of variable renewable energy by 2030, supported by co-located storage, and between 3 and 5 GW of peaking support (which could be gas running at low utilisations, pumped hydro, or other liquid fuels). There should be no new coal, and gas should be kept to the role of peaking support.
    - This recommendation is based on the need for inclusive economic development, low-end NDC ambition and the possibility of a slow implementation of energy efficiency and EAF improvement. Depending on assumptions used (notably energy efficiency implementation) South Africa could still get into the bottom range of the NDC with about 45 GW of VRE in 2030. A minimum of around 35 GW should be built to be within the top range of the NDC. It should be clear that lower ambition now will have significant cost later. Furthermore, it is unlikely that scenarios building less renewables will be compliant with air quality legislation – these scenarios would have to factor in both the direct cost of technology retrofits and the externality of the loss of human life and health.
    - The recommendations above:
        - Align with the ambitious end of the NDC and the PCC believes this introduces very little additional cost compared to pathways aligned with the middle or upper end of the NDC.
        - Consider electricity demand to be aligned with economic growth, while the 50 – 60 GW VRE capacity assumes little energy efficiency intervention.
        - Better align with air quality regulations and mitigate water scarcity risks.
        - Are an input into policymaking, given the differences in modelled scenarios and the dynamism of this space. The recommendations represent the climate and Just Transition leadership position.

  - And the assumptions they embody, need to be an input into the debates around the IRP. They provide an indication for 2030, though the actual numbers are incredibly complex (e.g., the recommendation could be 45 to 55 GW or 50 to 60 GW depending on assumptions around energy efficiency and economic growth). The key issue is that South Africa must build out approximately 6 to 8 GW of VRE per year from 2020, which will alleviate higher levels of deployment closer to 2030.

  - Are risk adjusted, in that, if South Africa does not achieve planned EAFs, VRE presents options. Renewable energy is modular and therefore build rates can be slowed if demand assumptions fail to materialise (as opposed to large dispatchable generation sources where build and cost are locked in).

TEXT BOX 5: CORE CONSIDERATIONS BEHIND THE ENERGY MIX RECOMMENDATIONS

- The model scenarios assessed in this Technical Report are purely a guide - they can become out of date.
- Technically, all scenarios are least-cost for the constraints put on them.
- Each scenario makes a series of assumptions that means scenarios are not strictly comparable with one another. Although, in aggregate, they offer key lessons – all least-cost scenarios build some combination of renewables, storage and peaking support over new coal and nuclear.
- Key assumptions that drive GHG emissions are EAF/Load Factors and demand/economic growth forecasts.
- The market and consumer preferences are changing rapidly. This is likely to drive RE for generation.

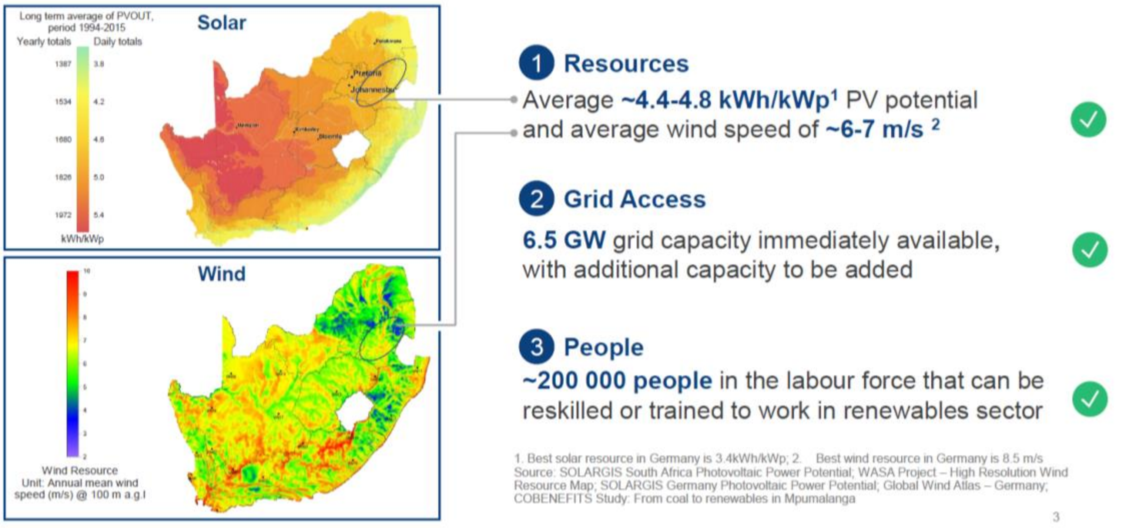
2. Short-term spatial planning:

   - Through a transparent and consultative process, develop a short-term spatial plan that maximises grid usage (see also ITSMO and grid recommendations below); this could be addressed as part of an updated IRP.

   - The focus on best price at point of generation means that new generation capacity is not being built where the grid is readily available, or where the total cost of supply (generation and transmission) is the lowest. However, there is opportunity for connection in areas with available grid capacity, albeit lower PV and wind potential (Figure 19).

   - Connecting new generation in readily available areas, such as Mpumalanga, will help resolve the short-term supply constraints. In parallel, planning and implementation of the required grid strengthening and expansion can be undertaken.

   - A review and revision of the current grid queuing process can ensure that policymakers, investors, OEMs, and manufacturers have clear sight of the pipeline of generation and transmission projects (including the capital requirements).



1 Resources

Average **~4.4-4.8 kWh/kWp**[1] PV potential and average wind speed of **~6-7 m/s** [2] ✓

2 Grid Access

6.5 GW grid capacity immediately available, with additional capacity to be added ✓

3 People

~200 000 people in the labour force that can be reskilled or trained to work in renewables sector ✓

1. Best solar resource in Germany is 3.4kWh/kWp; 2. Best wind resource in Germany is 8.5 m/s
Source: SOLARGIS South Africa Photovoltaic Power Potential; WASA Project – High Resolution Wind Resource Map; SOLARGIS Germany Photovoltaic Power Potential; Global Wind Atlas – Germany; COBENEFITS Study: From coal to renewables in Mpumalanga

3

FIGURE 19: GRID CAPACITY IN MPUMALANGA IMMEDIATELY AVAILABLE[102]

2. Governance of the electricity sector

   - As outlined in Section 4.1, there are currently several organs of state that have a role in the governance of the electricity sector, to a greater or lesser extent. This presents several challenges for policymakers across these entities. Critically, the current structure lends itself to a siloed approach making it difficult for all considerations to be contemplated holistically. Many of these challenges are being addressed for the current crisis through the intergovernmental structures under the Presidency, like NECOM and Operation Vulindlela. It is recommended that this more holistic approach is codified for future energy planning within a central structure such as the Independent Transmission System and Market Operator (ITSMO).
   - Many municipalities have become dysfunctional and lack requisite skills and capacity to properly manage, for example, the distribution of electricity, infrastructure maintenance and expansion, distribution of the free basic electricity grant to indigent households, tariff structuring and revenue collection. Capacity building for municipalities to address skills or resource challenges is urgent to enable local government to implement the required changes and ensure revenue security. This should include training and capacity building for municipal financial managers and teams on electricity tariff structuring and revenue management, particularly for cost-of-supply studies and the design of feed-in tariffs to support the expansion of embedded generation. This should also include support for the development and implementation of Municipal Distribution Plans. Here, public-private partnerships (PPP) and infrastructure concession models could be considered to upgrade, strengthen, and protect systems and local grids.
   - Municipalities are at the frontline of electricity supply and will play a key role in energy efficiency and other demand-side management initiatives, as well as regulating and incentivising the expansion of embedded generation and storage. Support is required to capacitate municipalities to fulfil this role. Support is also required for local governments to ensure that measures are implemented to support those most impacted by load shedding and who cannot afford electricity. This would include a review of the process to determine who

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[102] Eskom. 2022.

qualifies for free basic electricity, and stricter governance to ensure it is appropriately disbursed.

3. Demand-side measures and energy efficiency (EE)

   - Part of the solutions proposed by NECOM are to work with public and private stakeholders to drive EE imperatives. This is a critical lever for demand side interventions to address the current crisis and an essential decarbonisation tool. All the studies assessed assume that EE targets, such as those set out in the draft post-2015 National Energy Efficiency Strategy (NEES), will be met. The role of EE in addressing the energy crisis and decarbonisation efforts is therefore critical and should be prioritised.
   - Despite the recent strengthening of EE drivers, such as positive policy changes and above inflation increases to energy prices, there remains little uptake of EE in South Africa, limited to easily implementable technologies (i.e., low hanging fruit). Limited EE uptake is due to limited awareness of EE, limited technical expertise, lack of access to finance, and limited regulatory drive. As a result, SA remains among the most energy intensive economies in the world. Energy efficiency is a critical tool, particularly in the short term, to address energy security, national decarbonisation, and economic productivity. EE has not yet reached the scale needed to significantly reduce GHG emissions, improve energy security, and transition the country from its present energy intensive economic pathway to a truly decoupled economy. It is estimated that South Africa could save as much as 412 PJ combined from its industrial, agricultural, and public sectors – savings of 14% of total energy consumption (against 2017 energy consumption figures).[103]
   - Demand-side energy efficiency, load shifting or demand response measures properly incentivised are low-hanging fruit and should be pursued aggressively to flatten demand. Solutions that remove energy demand from the system will help alleviate supply-side energy shortages and reduce the economy's overall energy and carbon intensity. To drive investments in energy efficiency, government should build an enabling ecosystem that actively creates demand for energy efficiency as well as improves access to finance. Investment in energy efficiency could be facilitated through:
     - Progressing key draft regulations to final, such as: the draft post-2015 National Energy Efficiency Strategy, the draft Regulations Regarding Registration, Reporting on Energy Management and Submission of Energy Management Plans, 2015, the Climate Change Bill, as well as avoiding further postponement of the deadline for when buildings must display Energy Performance Certificates;
     - Advancing public sector energy efficiency programmes to full implementation;
     - Scaling up the ESCO market; and
     - Supporting awareness through replicating and/or scaling up energy efficiency programmes which offer subsidies/free energy audits, coupled with project preparation support.

4. Tariff pricing reform

There is a need for pricing reform throughout the electricity value chain. Currently, Eskom is not able to recover its full costs, which leads to borrowing to cover operational expenses, often diesel supplies. This is unsustainable and leads to spiralling energy availability factors as Eskom pushes assets harder

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[103] Energy Partners and Carbon Trust. Development of Sustainable Financing Mechanisms for Demand-Side EE Market Transformation in South Africa. 2021.

to earn revenue and is unable to adequately fund maintenance. Furthermore, as the electricity system transitions to VRE and the grid becomes more central to planning, the restructuring of tariffs is critical to ensure that the fixed costs of supply (transmission and distribution) can be fully and transparently recovered through the tariffs.

In addition, as households and businesses start generating their own renewable electricity, they will want to feed this back into the grid and offset their installation costs. This will impact local government power utility business models and municipal revenue models. There are varying perspectives on pricing in South Africa with policy messages and determinations from NERSA misaligned.

However, while tariffs need to reflect the efficient cost of electricity, any increase in electricity prices would negatively impact low-income households and small businesses, reducing their access to electricity and increasing energy poverty. Therefore, to avoid these risks, low-income households and small businesses need to be supported through the expansion of free basic electricity allocation and progressive tariff structures/subsidies.

A Presidential sponsored and independent study on electricity pricing reform in South Africa and how it can support a Just Energy Transition, including energy access and energy poverty, is recommended.

Other considerations worth noting include:

- Supporting public, private, and household distributed RE generation and storage through incentives and tariff restructuring, including feed-in tariffs and net metering.
- Implementing progressive pricing to minimise pass through to vulnerable communities.
- Ensuring that subsidies are fair and transparent.

9.2. Planning for a Just Energy Transition

Energy equity, security and environmental sustainability are largely influenced by technology and decarbonisation pathway choices (since some technologies are lower carbon than other, for example). Socio-economic sustainability is largely dependent on good governance and macro-economic policy. Ensuring a Just Transition, therefore, is largely influenced by policies and measures deployed to mitigate any risks and maximise any opportunities arising from technology and decarbonisation pathway choices.

For example, the moderate and ambitious decarbonisation clusters anticipate net-positive job creation from the expansion of local renewable energy and low carbon technology value chains. However, this will only materialise if the right decisions, policies and Just Transition interventions are implemented effectively, to incentivise economic shifts and protect at-risk workers and communities.

The following recommendations[104] are put forward to ensure the pursuit of any given pathway is just and contributes positively to South Africa's developmental requirements.

1. Support those most impacted by load shedding, including SMMEs and indigent households. SMMEs and low-income households are disproportionately impacted by loadshedding because they, generally, cannot afford alternatives (e.g., generators, solar PV). Small businesses often fall outside of the incentives promoted in the recent budget speech as they do not have access to capital for investment into rooftop solar, generators or inverters. They need specific support that enables them to access alternative electricity sources, at an affordable rate, to see out load

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[104] The recommendations put forward in this report are based on those from the PCC Just Energy Transition Framework.

shedding. They also need to be supported via increased access to insurance, to protect their alternative energy sources, given their disproportionate exposure to crime, for example.

2. Electricity Distribution Reform. 70% of indigent households do not receive their free basic electricity (FBE) allocation due to misappropriation of funds. This is also partially due to administrative and skills challenges faced within local government. It is important that FBE reaches households that deserve it. Furthermore, a review of the amount of FBE allocated to each household (50 kWh a month) is required. Some stakeholder feedback suggested that a just allocation of FBE could be as much as 350 to 400 kWh a month. Other stakeholder feedback suggests that FBE should not be increased without deep and sustainable reforms to the sector as simply increasing the FBE will only increase the amount of funds that are misappropriated. A complete reform of the existing subsidy mechanism is therefore critical. Increasing access to electricity to those who do not have physical access through either grid extension, mini-grids or solar home systems, is equally important. Mini-grids and solar home systems would require conducive policy and regulatory environments, as well as innovative business models. Community ownership models should also be piloted as a means for enabling energy access and a Just Energy Transition.

3. Identify and measure the extent of transition risks associated with the chosen electricity pathway. This includes developing baselines for monitoring progress on key metrics/KPIs (e.g., jobs, skills etc.), like the Employment Vulnerability Assessments and Sector Jobs Resilience Plans developed by TIPS in 2020.[105]

4. Ensure procedural justice in electricity planning and decision making, and in identifying, designing, and implementing Just Transition interventions.[106] This includes engaging with stakeholders to better understand their vulnerabilities, values, needs, and recommendations, to ensure that any Just Transition interventions are human-centred and fit for purpose.

5. Invest in human resource and skills development, including: (i) the reskilling and upskilling of existing workers so that they are better equipped to navigate the transition; (ii) future proofing the education system by accounting for future skills and labour force requirements, particularly those required for the transition and new green industries; and (iii) prioritise foundational skills across the education system to improve the adaptive capacity of the broader workforce. Prioritising skills development for at-risk populations (e.g., coal value chain dependant, woman, and youth) will be important for building their resilience and addressing existing inequalities.

6. Provide technical and financial support to municipalities for preparing for the electricity transition and improving access to electricity for small business and low-income households. Several municipalities still struggle to deliver basic services, including electricity. It is, therefore, critical for a Just Energy Transition that municipalities are supported, both technically and financially, to deliver an affordable, secure, and sustainable electricity supply. This includes understanding tariff and business model reform, skills development, improving administration systems to handle feed-in tariffs, EE interventions, and support in local electricity planning (e.g., distribution network development plans, including wheeling of power and expanding and maintaining distribution infrastructure). SALGA is an important partner in this regard. An allocation of grant funded support in the JET-IP for this purpose is recommended.

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[105] TIPS 2020. Sector Jobs Resilience Plans.

[106] Just transition interventions are differentiated from principles. Principles refer to procedural, distributive, and restorative justices. Interventions refer to programmes that aim to deliver on the principles, and include, for example, reskilling programmes for workers or building new industrial development zones to produce low carbon technologies.

7. Support green industrial development, economic diversification, and localisation of key transition value chains, particularly in at-risk regions (e.g., Mpumalanga). Develop competitive industries to locally extract, produce and manufacture inputs (green copper, nickel, steel, cement, etc.) and support services (design, engineering, and maintenance) for green technologies, including renewable energy technologies, battery cells, electric vehicles, green hydrogen, etc. This is vital for creating new, decent work for at-risk workers and new workers. Support for SMMEs to better capitalise on the opportunities the low carbon transition presents is equally important. In the short term, investment should prioritise at-risk regions, such as Mpumalanga, Limpopo and KZN. There are several entities working to support the Just Transition in Mpumalanga, including Impact Catalyst, Green Cape, TIPS, various local and international development finance institutions, donor programmes, and the Mpumalanga Green Cluster, as well as the PCC itself. The PCC will play a role in coordinating these programmes as well as building the capacity of workers and communities to participate in decision-making processes that impact their lives. Furthermore, Eskom's Just Energy Transition Plan and Office is leading the repurposing and, where feasible, the repowering of coal plants and surrounding land to create alternate employment and economic options.
8. Avoid and clean up environmental damage. Ensuring a clean and healthy environment is critical for supporting livelihoods, human health, and well-being. Therefore, any actions taken during the transition – transition out of certain sectors and into new sectors – needs to be done in an environmentally sustainable way to avoid negative environmental externalities, particularly on low-income households and at-risk groups (e.g., women and youth). Any historical environmental damage must also be cleaned up in pursuit of restorative justice.
9. Provide and enhance social protection measures. This includes "traditional" social protection measures (e.g., grants, unemployment insurance, etc.) for workers who, for whatever reason, cannot transition to alternative low carbon livelihoods. It also includes the provision of universal access to basic services (e.g., clean energy, water, sanitation, transport, education, healthcare, etc.), so that workers and communities can leverage these services in building their resilience to external shocks (either from climate change or the energy transition).

10. Appendix A: Details and illustrative representations of modelled pathways and scenarios

10.1. Detailed assumption of modelled pathways and scenarios

TABLE 19: DETAILED ASSUMPTIONS OF SCENARIOS

Study/report name	Organisation	Pathway/ Scenario name	Demand assumptions (TWh)	VRE new build constraints	Electricity price	Total investment required
Decarbonising South Africa's Power System.	NBI, BCG and BUSA	Lowest emissions with gas and DACCS	370 (2050) with 10% - 15% reserve	Not specified	R1.31/kWh (2050)	R75.5 trillion
		Lowest emissions with Green H2	370 (2050) with 10% - 15% reserve	Not specified	R1.30/kWh (2050)	R75.5 trillion
		IRP pathway with gas and DACCS	370 (2050) with 10% - 15% reserve	Not specified	R1.31/kWh (2050)	R75.3 trillion
		IRP pathway with green H2	370 (2050) with 10% - 15% reserve	Not specified	R1.30/kWh (2050)	R75.4 trillion
Systems analysis to support increasingly ambitious CO2 emissions scenarios in the South African electricity system.	CSIR and Meridian Economics	Reference (Currently Policy)	285 (2030) 355 (2050)	None	R1.09/kWh (2050)	R3 565 billion[107]
		Least-cost	285 (2030) 355 (2050)	None	R1.08/kWh (2050)	R3 500 billion
		Modest RE pathway	285 (2030) 355 (2050)	Minimum limits varying per year	R1.09/kWh (2050)	R3 526 billion
		Ambitious RE	285 (2030) 355 (2050)	Minimum limits varying per year	R1.12/kWh (2050)	R3 596 billion
		Ambitious RE pathway & coal off by 2040	285 (2030) 355 (2050)	None	R1.17/kWh (2050)	R3 624 billion
South Africa Country and Climate Development Report (CCDR).	The World Bank	Net zero reference scenario	Not specific	Not specified	Not specified	R933 billion (net present value)
Exploring Net Zero pathways for South Africa.	University of Cape Town's Energy Systems Research Group	Reference	~350 (2050)	None	Not specified	~R1 800 billion
		Net Zero 20 MT sink	~490 (2050)	None	Not specified	Not specified
		Net Zero 45 MT	~475 (2050)	None	Not specified	~R3 000 billion - R3 600 billion depending on carbon budget

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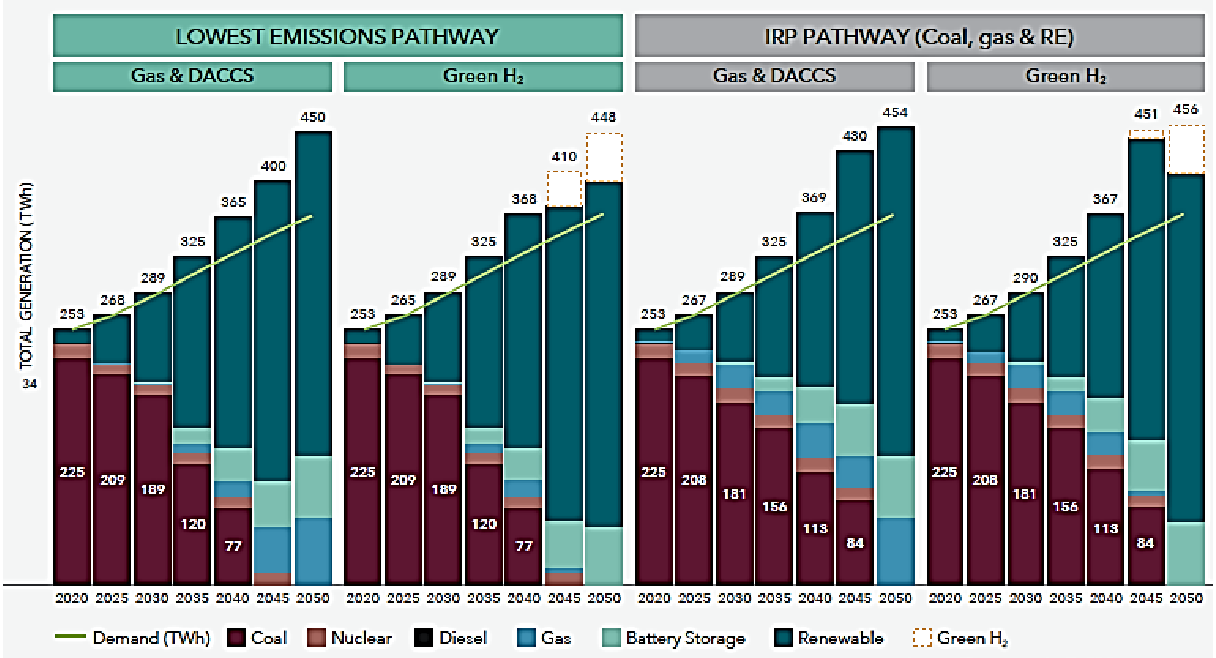
[107] Total system cost, discounted (2020-2050)

10.2. Illustrative representation of electricity generation in TWh by source across scenarios

- Decarbonising South Africa's Power System – NBI, BCG and BUSA, 2021



Source: Plexos model, NBI-BCG project team.

Figure 20: Electricity generation by source, lowest emission pathways and IRP pathways[108]

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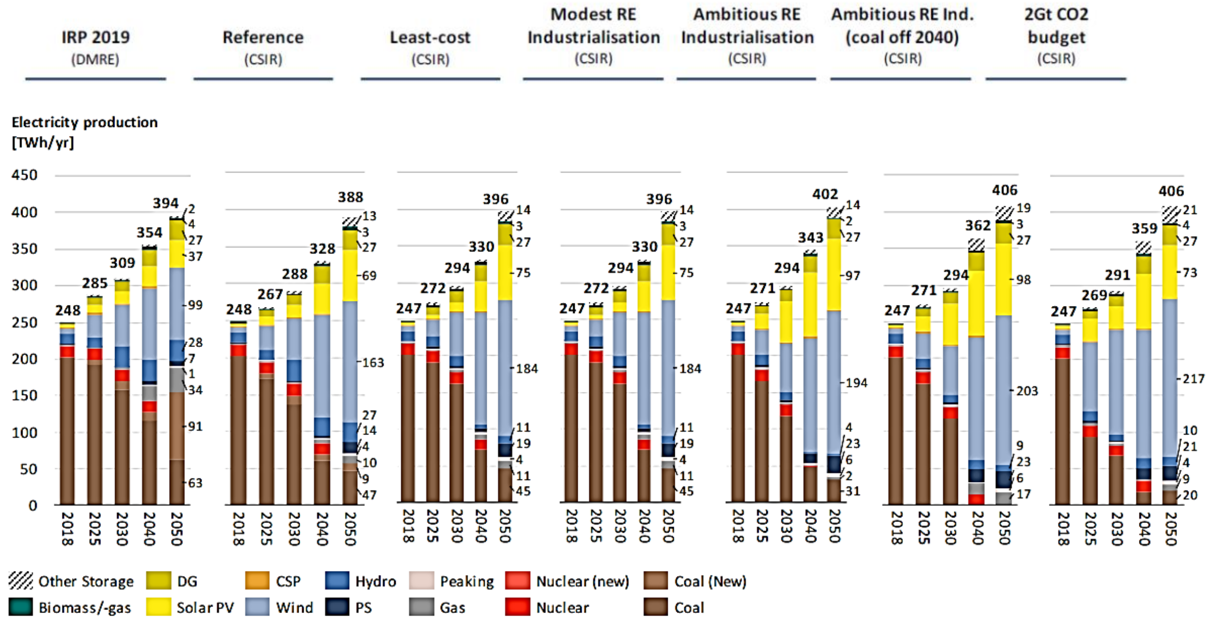
[108] The lowest emission pathway consists of ~130 GW of RE (52 GW wind and 78 GW solar), 29 GW gas (Open Cycle Gas Turbine [OCGT] and Combined Cycle Gas Turbine [CCGT]), and 15 GW of battery storage. A breakdown of installed capacity per technology for the 'IRP Pathway' is not provided.

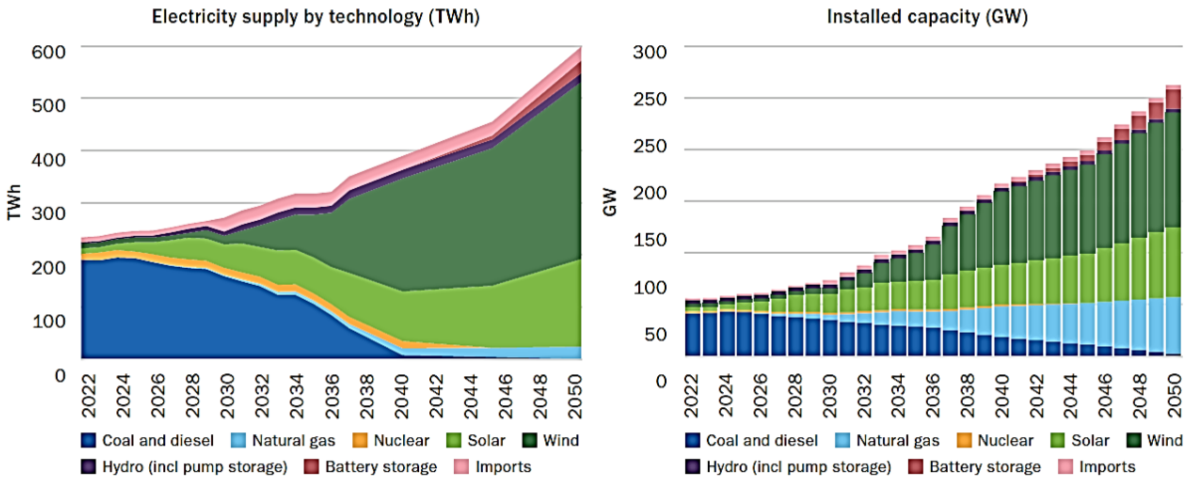
- Systems analysis to support increasingly ambitious CO_2 emissions scenarios in the South African electricity system – CSIR and Meridian Economics, 2020



DG = Distributed Generation; PS = Pumped Storage
Sources: CSIR Energy Centre analysis

FIGURE 21: ELECTRICITY PRODUCTION BY SOURCE (TWH/YEAR)

- South Africa Country Climate and Development Report (CCDR) – World Bank, 2022



Source: SATIM

FIGURE 22: ELECTRICITY GENERATION BY SOURCE – NET ZERO SCENARIO WITH 10 MT LAND SINK[109]

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[109] The net-zero reference scenario indicates that by 2050, wind and solar could account for 85 percent of electricity generated and 67% of capacity installed.

- Exploring Net Zero pathways for South Africa – ESRG 2023

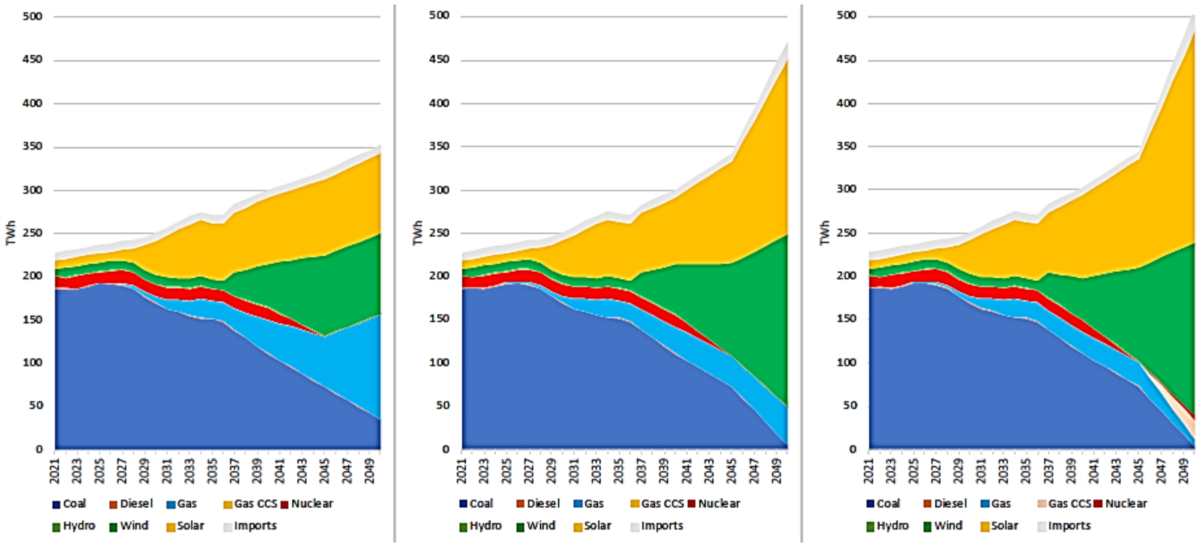

FIGURE 23: ELECTRICITY (TWH) BY SOURCE WITH NO CARBON BUDGET IMPOSED – REFERENCE SCENARIO (LEFT), NET ZERO 45 MT CASE (CENTRE), AND NET ZERO 20 MT SINK (RIGHT)

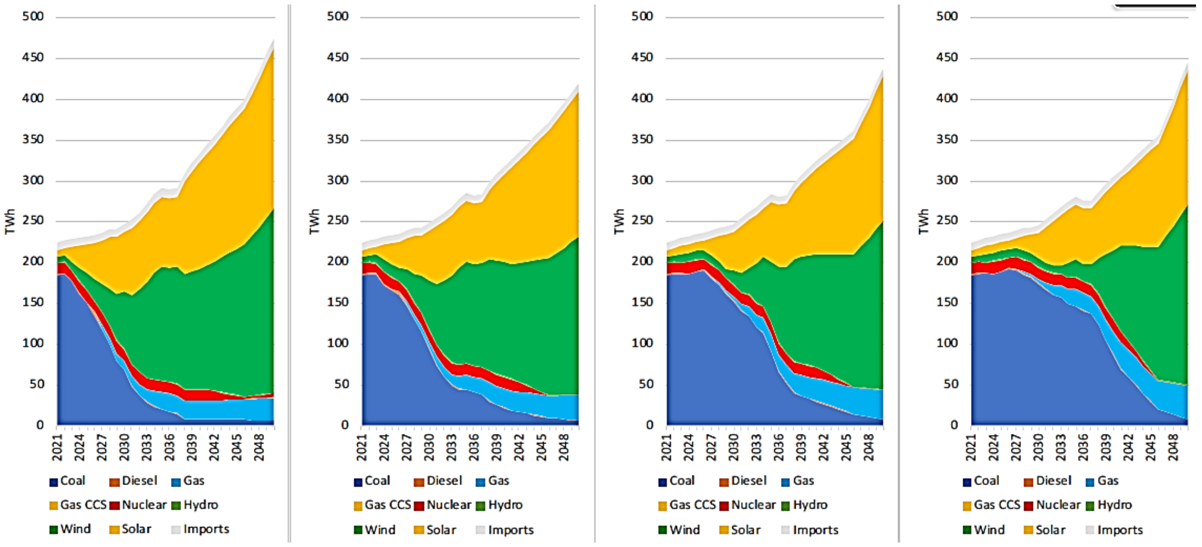

FIGURE 24: ELECTRICITY PRODUCTION BY SOURCE IN THE NET ZERO 45 MT SINK CASES WITH GHG BUDGETS OF 6 – 9 GT (LEFT TO RIGHT)

TABLE 20: PERCENTAGE ELECTRICITY GENERATED BY FUEL SOURCE OVER THE PERIOD 2021-2050 (EXCLUDING IMPORTS)

Fuel source	Reference	Net zero CO_2, 45Mt sink, 6 Gt	Net zero CO_2, 45Mt sink, 7 Gt	Net zero CO_2, 45Mt sink, 8 Gt	Net zero CO_2, 45Mt sink, 9 Gt
Coal	48.74%	18.27%	24.20%	32.41%	41.71%
Diesel	0.23%	0.27%	0.26%	0.24%	0.23%
Gas	12.11%	5.31%	5.53%	6.13%	6.62%
Nuclear	3.72%	3.81%	3.68%	3.68%	3.72%
Hydro	0.26%	0.23%	0.24%	0.24%	0.25%
Wind	14.33%	38.43%	35.74%	30.16%	23.65%
Solar	20.62%	33.67%	30.35%	27.14%	23.83%

11. Appendix B: Technology Assessment

11.1. Coal-fired power stations

Advantages:

- Coal is a widely available fossil fuel feedstock for coal-fired power stations. There are an estimated 53 billion tonnes of coal reserves in South Africa, equating to approximately 200 years of supply, at current use levels[110].
- Coal-fired power stations are not dependent on weather and are therefore generally considered reliable and stable sources of electricity should coal fleets be operated, managed, and maintained correctly to reduce occurrences or breakdowns and interruptions to electricity supply.[111].

Disadvantages:

- New coal-fired power stations can take between 10 and 12 years to build[112]. However, construction delays can increase build times, as has been the case with Medupi and Kusile, whose construction was commenced in 2007 with an expected completion dates of 2012 and 2014 respectively. These projects have experienced significant delays, with Medupi predicted to be fully completed by 2023 (including repairs), while Kusile is predicted to be completed by 2026[113]. These delays have led to significant cost increases, with costs for Medupi increasing from an initial projection of R80 billion in 2008 to R234 billion in 2019[114]. The cost of completing Kusile has increased from an initial projection of R80 billion to an estimated R226 billion[115]
- Compared to other technologies, the capital cost for a new-build coal power station is high compared to other technologies, at approximately R105 825/kW (US$6 225/kW).[116] Furthermore, new coal builds have a Levelized Cost of Electricity (LCOE) range of between of ~R1.00/kWh to R2.58/kWh (US$ 0.065c/kWh to US$1.52/kWh) – the upper estimate includes 90% emission reduction from CCUS).[117]
- Costs are compounded where retrofitting technologies (e.g., Carbon Capture Utilisation and Storage (CCUS)) must be added. Eskom estimates a price tag of R300 billion for retrofitting investments to meet air quality standards set out by DFFE (equivalent to decommissioning 15 GW of coal-fired power).[118]
- Burning coal for electricity releases between 0.93 $kgCO_2e/kWh$ and 1.26 $kgCO_2e/kWh$ of GHG emissions in South Africa[119]. In terms of life cycle emissions, a global average for coal-fired power stations has been estimated at 1.023 $kgCO_2e/kWh$[120] Using Carbon Capture and Storage (CCUS) technology at coal-fired power stations can mitigate some of these emissions. However, CCUS

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[110] Eskom.2021. Fact Sheet: Coal in South Africa

[111] Taylor. 2018. Coal-Powered Electric Generating Unit Efficiency and Reliability Dialogue

[112] Eskom Stats in PCC Dialogues Presentation

[113] BusinessTech. 2022. Fresh delays at Medupi and Kusile amid eye-watering costs

[114] News24.2021. After billions in cost overruns, design flaws, delays and loadshedding, Medupi is finally complete

[115] Illidge.2022. Medupi and Kusile – 8 years late and R300 billion over budget

[116] Eskom Stats in PCC Dialogues Presentation

[117] Lazard. 2021. Levelized Cost of Energy, Levelized Cost of Storage, and Levelized Cost of Hydrogen.; Upper end estimate (R2.58/kWh) includes 90% carbon, capture and storage embedded in the LCOE reported.
The LCOE of R1/kWh is a lower estimate from Lazard. 2020.

[118] Eskom. 2021. Eskom receives DFFE's decisions on minimum emissions standard; will engage DFFE and key stakeholders on way forward.; World Bank. 2022.

[119] Centre for Environmental Rights. 2017. Assessment of Eskom Coal Fired Power Stations for compliance with their 1 April 2015 AELs over the period 1 April 2015 to 31 March 2016; and ranking of their pollutant and CO_2 emission intensities

[120] UNECE.2021.Lifecycle Assessment of Electricity Generation Options

technologies are currently still immature and expensive[121], with other risks that need to be considered.

- Burning coal can also release dangerous air pollutants. In South Africa sulphur dioxide (SO_2) emissions range between 6.92 gSO_2/kWh and 13 gSO_2/kWh, while nitrogen oxide (NO_X) emissions range between 2.3 gNOx/kWh and 6.1 gNOx/kWh[122]. Furthermore, particulate matter and heavy metals may be emitted to the atmosphere, both of which have negative implications for human health.[123] While coal-fired power stations can be retrofitted with technologies to reduce air pollution, they are costly.
- Coal-based electricity can also be water-intensive,[124] an important consideration in the context of South Africa's climate. Depending on the cooling method, coal-based electricity uses between 2 *l*/kWh and 2.38 *l*/kWh (for wet cooling) and approximately 0.12 *l*/kWh (for dry cooling). While dry cooling reduces water consumption significantly, it is more expensive and can increase the cost of electricity.[125]
- Another disadvantage of coal for consideration includes direct land-use. Coal-based generation requires approximately 15 m^2 of land per MWh produced[126]. While this is lower than other sources of electricity production, such as ground based solar PV (19 m^2/MWh) and CSP (22 m^2/MWh), it is higher than alternatives such as nuclear (0.3 m^2/MWh) and gas (1 m^2/MWh).[127]
- Coal mines are also a key source of methane leakage, with significant climate change impacts[128].

11.2. Gas-to-power

Advantages

- Gas can provide a reliable, stable, and flexible supply of electricity to balance and provide back-up power to the grid to meet peaks in demand. Gas-to-power can be produced through various methods. This includes open cycle gas turbines (OCGT), combined cycle gas turbines (CCGT) and combined heat and power (CHP).
- Gas-based electricity infrastructure can take around 2.5 years to build.[129] However, gas exploration and extraction can take longer – between 10 – 25 years – particularly for offshore gas.[130]
- South Africa has significant gas reserves. Offshore gas reserves have been estimated in the region of eleven billion barrels oil equivalent (bbls), which equates to roughly 375 years' worth of supply[131]. The Petroleum Agency SA (PASA) estimates South Africa to hold 60 trillion cubic feet (tcf) of gas resources offshore. For onshore, the estimate exceeds 200 tcf for prospective shale gas resources, biogenic gas, and coal bed methane[132]. Most of South Africa's natural gas originates from the maturing offshore F-A field and the South Coast Complex fields[133].

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[121] McKinsey. 2022. Scaling the CCUS industry to achieve net zero emissions
[122] Centre for Environmental Rights. 2017. Assessment of Eskom Coal Fired Power Stations for compliance with their 1 April 2015 AELs over the period 1 April 2015 to 31 March 2016; and ranking of their pollutant and CO_2 emission intensities
[123] U.S. Energy Information Administration.2022. Coal explained: Coal and the Environment
[124] Life After Coal.2018. Water Impacts and Externalities of Coal Power
[125] Water Resource Commission.2020.Water Use and Generation
[126] Ritchie. 2022. How does the land use of different electricity sources compare?
[127] Ritchie. 2022. How does the land use of different electricity sources compare?
[128] IEA. 2023. Driving down coal mine methane emissions.
[129] Eskom Stats in PCC Dialogues Presentation
[130] Oceans Not Oil, Phases of Offshore Oil and Gas.; Coastal Review. 2015. An Offshore Timeline.
[131] Operation Phakisa.2023. Offshore oil and gas exploration
[132] The Petroleum Agency South Africa. 2023., from Rob Hersov. South Africa's potential oil and gas prospectivity
[133] US Energy Information Administration. 2022. Country Analysis Executive Summary: South Africa

TotalEnergies have announced two natural gas and condensate discoveries (Brulpadda and Luiperd) approximately 110 miles south of Mossel Bay, with potential to boost supplies.

- Gas has relatively low water consumption over its life cycle compared to coal and nuclear, with a median blue water consumption of 0.598 *l*/kWh.[134]

Disadvantages

- Compared to other technologies, the capital cost for gas is high at approximately R21 250/kW (US$1 250/kW).[135] Similarly, the LCOE for CCGT is estimated at R1.50/kWh and R3.40/kWh for OCGT, which is high compared to other technologies. [136] For peaking gas, the LCOE increases to between R2.57/kWh and R3.33/kWh (US$1.51/kWh and US$1.96/kWh).[137] Although OCGT is less efficient than CCGT, there are some applications that it is used for. OCGT is more commonly used for peaking power as it has a shorter start-up time than CCGT. OCGT systems are also smaller so may be beneficial where space is limited. CCGT has higher capital costs but lower operating costs than OCGT.
- Exploration and extraction can take up to 25 years, particularly for offshore gas. It is likely that the significant South African reserves will take many years to develop. Offshore oil and gas exploration also faces strong public opposition, which can significantly delay or cause projects to be abandoned, as demonstrated by Shell's intention to exploit South Africa's offshore reserves.
- Currently South Africa imports most of its natural gas from neighbouring countries such as Mozambique (in 2019 South Africa produced about 43 billion cubic feet (Bcf) of dry natural gas – predominantly from the offshore F-A field and the South Coast Complex fields – and consumed 169 Bcf in that same year)[138]. Although South Africa reportedly has large shale gas resources in the Karoo Basin, there are significant challenges with commercially exploiting this (such as lack of infrastructure to transport/process and the basin's complex geological characteristics).
- Gas is relatively carbon-intensive with average lifecycle GHG emissions of approximately 450 gCO_2e/kWh.[139] However, methane leakage from gas infrastructure is a risk and can increase the GHG emissions associated with gas-based electricity.
- Activities related to the production of gas can lead to the emission of nitrogen oxides (NO_X) and volatile organic compounds (VOCs) – both of which are precursors to the formation of ground-level ozone which are harmful to human health and the environment[140]. NO_X emissions across the gas lifecycle are estimated to range from 0.2754 g/kWh for a CCGT and 0.4411 g/kWh for OCGT[141].

11.3. Nuclear

Advantages:

- Nuclear power is generally considered to be a reliable and stable source of electricity generation and can run continuously throughout the day and night[142]. However, one drawback of nuclear power is that refuelling can take several months to complete, such as has been the case at

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[134] Jin *et al.* 2019. Water use of electricity technologies: A global meta-analysis

[135] Eskom Stats in PCC Dialogues Presentation

[136] IISD. 2022. Gas Pressure: Exploring the case for gas-fired power in South Africa

[137] Lazard. 2021.

[138] U.S. Energy Information Administration. 2022. South Africa Executive Summary

[139] LSE. 2022. What is the role of nuclear energy in the energy mix and in reducing greenhouse gas emissions?

[140] Alvarez & Paranhos.2012. Air Pollution Issues Associated

[141] Babaee et al. 2020. Incorporating upstream emissions into electric sector nitrogen oxide reduction targets

[142] International Energy Forum.2022. Nuclear Energy: Low-carbon, reliable and innovative

Koeberg, where Unit 2 was taken offline for five months in 2022 for refuelling[143]. Refuelling is required every 15 to 18 months[144].

- Nuclear power has a small carbon footprint, with lifecycle emissions ranging between 15 gCO_2e/kWh and 50g CO_2e/kWh[145], However, no direct emissions result from the generation of nuclear power[146] and does not release any air pollutants.[147]
- Nuclear power requires limited land-use for operations, with an average of 0.3 m^2/MWh.
- However, disposing of nuclear waste responsibly can increase land-use requirements and presents a significant environmental and human health risks.[148]

Disadvantages:

- South Africa does not produce its own nuclear fuel and imports nuclear fuel for both reactors at Koeberg from the United States and France.[149]
- Nuclear power plants on average take between 12 and 15 years to construct and commission, with an average construction time for a generation unit of between 7 years.[150]
- Nuclear is expensive to build, with an estimated capital cost of R212 500/kW (US$12 500/kW).[151]
- The LCOE for nuclear ranges between R2.23/kWh and R3.47/kWh (US$ 13c/kWh and US$ 20c/kWh).[152]
- Nuclear power is water-intensive, using between 1.5 *l*/kWh and 2.7 *l*/kWh.[153] South Africa's Koeberg nuclear plant uses approximately 1 370 kilolitres/day of potable water and an additional 7 million kilolitres/day of sea water for cooling purposes.[154]

11.4. Wind

Advantages:

- South Africa has significant wind resource potential. In terms of onshore wind potential, South Africa's mean power density for the top 10% windiest areas is 559 W/m^2, on par with Germany, one of the countries with most installed onshore wind generation, with a mean power density of 595 W/m^2.[155]
- Wind energy does not release any GHG emissions during its use-phase/generation. Even across its lifecycle, it has a low carbon footprint, with mean lifecycle GHG emissions ranging between 12 gCO_2e/kWh and 15g CO_2e/kWh[156].
    - Wind farms are quick to build, with an average construction period of between approximately 24 – 36 months.[157]

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[143] Eskom.2022. Koeberg long term outage
[144] News24.2022. Unit 1 of the Koeberg Nuclear Power Station switched off
[145] LSE. 2022.
[146] U.S. Energy Information Administration. 2023. Nuclear Explained: Nuclear and the Environment
[147] NEI. 2023. Does nuclear cause air pollution?
[148] U.S. Energy Information Administration. 2023. Nuclear Explained
[149] World Nuclear News.2023. 'No crisis' for Koeberg fuel supply as South Africa continues loadshedding
[150] Shykinov et al. 2016. Importance of Advanced Planning of Manufacturing for Nuclear Industry
[151] Eskom Stats in PCC Dialogues Presentation
[152] Lazard. 2021.
[153] Monarch Partnership. 2019. Nuclear power and its water consumption secrets
[154] News24. 2018. Eskom responds to water crisis with Koeberg desalination plant
[155] Energydata.info.2023.Global Wind Atlas
[156] University of Edinburgh.2015.Life cycle costs and carbon emissions of wind power: Executive Summary
[157] Eskom stats in PCC Dialogs presentation

- The LCOE for wind in South Africa is estimated to range between R0.44/kWh to R0.85/kWh (US$ 2.6c/kWh - US$ 5.4c/kWh)[158]. However, the 20-year replacement cycle of wind farms allows for continuous uptake of innovations and cost improvements.
- Capital costs are estimated to be approximately R26 486/kW (US$ 1 450/kW).[159] Cost projections for wind anticipate a drop in the initial capital costs of more than 20% between 2020 and 2050.
- Wind power does not require water to generate electricity.
- Land use requirements for wind farms vary according to technologies used, turbine spacings, and site context. Wind farms may require between 8.4 m^2/MWh and 99 m^2/MWh produced. However, the direct land use requirements for a wind turbine equates to 0.4 m^2/MWh produced. It is important to note that wind farms can be constructed on marginal land, improving the economic productively of marginal or unproductive land.[160]
- Further, for South Africa to satisfy the entirety of its energy demand by utilising 0.3% of the country's landmass for wind farms[161]. This is far less than the amount of land utilised by commercial plantation forests (1.2% of South Africa's landmass)[162].

Disadvantages:

- Wind power can be variable as it is dependent on the weather and time of year, and like solar, will need to be supported by storage and peaking technologies.
- If incorrectly located, wind farms have the potential to adversely impact migratory birds and bats, through collision, disturbance, and habitat loss.
- While the physical components of wind turbines are largely recyclable, there have been issues with recycling of wind turbine blades – many of which have ended up in landfills.[163]

11.5. Solar PV

Advantages:

- Solar resources in South Africa are amongst the best in the world, with an average of 220 W/m^2[164]. This compares favourably with other parts of the world, with parts of the United States experiencing 150 W/m^2, while Continental Europe and the United Kingdom
- Solar PV projects are quick to build, with an average build time of 18 – 24 months.[165]
- The LCOE of utility-scale solar PV is between R0.48/kWh and R0.70/kWh (US$ 2.8c/kWh and US$3.8c/kWh).[166]
- Capital costs for new build solar projects estimated at approximately R16 575/kWh (US$ 975/kWh).[167] On average, a 1MW solar PV plant costs within the region of R8 million to R10

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[158] Lazard. 2021.
[159] Eskom Stats in PCC Dialog presentation.
[160] Nitsch et al. 2019. Observation-based estimates of land availability for wind power: A case study for Czechia
[161] Bischof-Niemz.2020. Is land a constraint to a renewables-led energy system in South Africa?
[162] South African Government.2023. Forestry
[163] Bloomberg.2020. Wind turbines can't be recycled, so they're piling up in landfills
[164] DMRE.2023. Solar Power
[165] Eskom Stats in PCC Dialogues Presentation
[166] Lazard. 2021.
[167] Eskom Stats in PCC dialogs presentation

million.[168] Cost projections for solar anticipate a drop in the initial capital costs of more than 40% for solar energy between 2020 and 2050.

- There are no direct GHG emissions from the use of solar-based technologies. Their total lifecycle GHG emissions are estimated at 124 gCO_2e/kWh (solar PV),[169] lower than direct combustion emissions from both coal and gas.
- Solar PV technologies are water efficient, using approximately 95% less water than coal and nuclear.[170]

Disadvantages:

- Solar power potential is limited to daytime and output can vary depending on the weather. While a disadvantage, it is not a significantly limiting factor. However, large scale solar needs to be supported with energy storage and peaking solutions such as batteries, pumped-hydro power and/or gas.
- Solar PV requires a large amount of land-use, of approximately 19 m^2/MWh and 22 m^2/MWh.[171] However, these technologies can be built on marginal land, agricultural land, and water transport/storage systems (e.g., canals and dams), with climate adaptation co-benefits (e.g., reducing evaporation form canals and evapotranspiration from crops).
- Solar panels contain harmful substances and are metals intensive. Increased demand for solar technologies will lead to an increase in metals mining around the world, but especially in Africa.[172] This presents a significant risk and opportunity for the continent.

11.6. Concentrated Solar Power (CSP)

Advantages

- Solar resources in South Africa are amongst the best in the world, with an average of 220 W/m^2.[173]
- Concentrated Solar Power (CSP) have an average build time of between 24 and 30 months.[174]
- There are no direct GHG emissions from the use of solar-based technologies. Lifecycle GHG emissions for CSP are estimated to be 9.8 gCO_2e/kWh (CSP),[175] lower than direct combustion emissions from both coal and gas.

Disadvantages

- Solar power potential is limited to daytime and output can vary depending on the weather. While a disadvantage, it is not a significantly limiting factor. However, large scale solar needs to be supported with energy storage and peaking solutions such as batteries, pumped-hydro power and/or gas.
- The LCOE for CSP ranges between R2.10/kWh and R2.65/kWh (US$ 12.6c/kWh and US$ 15.6c/kWh).

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[168] Business Media Magazine.2022. Investing in Renewable Energy

[169] Mehedi et al. 2022. Life cycle greenhouse gas emissions and energy footprints of utility-scale solar energy systems

[170] Pv-Magazine.2019. 100% renewables mean 95% less water consumption for conventional power generation

[171] Ritchie. 2022. How does the land use of different electricity sources compare?

[172] IFC. 2023. Net Zero Roadmap for copper and nickel mining value chains.

[173] Department of Mineral Resources and Energy.2023. Solar Power

[174] BusinessTech.2022. Massive new solar power plant to be built in South Africa by 2023

[175] Casa et al.2021. Life Cycle Assessment (LCA) of a Concentrating Solar Power (CSP) Plant in Tower Configuration with and without Thermal Energy Storage (TES)

- CSP is water-intensive, with some CSP projects consuming up to 3.5 *l*/kWh.[176]
- CSP requires a similarly large amount of land-use to solar PV, of approximately 19 m^2/MWh and 22 m^2/MWh.[177]
- CSP carries relatively high capital costs of approximately R128 086/kW[178]

11.7. Large Hydropower

Advantages:

- Large hydropower has low LCOE, estimated at R0.31/kWh for new hydropower.
- The capital costs of installing new hydropower have been estimated at R20 192/kW produced[179],
- There are no GHG emissions associated with the direct generation of hydro-based electricity. However, hydropower can generate 21 gCO_2e/kWh across its lifecycle due to construction emissions and decaying vegetation in flooded areas.

Disadvantages

- Hydropower may be susceptible to droughts which can impede generation and storage potential. Owing to this, the general aridity and dearth of significant river systems in South Africa, the potential for hydropower is limited in the country.[180]
- Hydropower projects may take between four and seven years to complete.[181]
- Large hydropower may have detrimental impacts on biodiversity, such as disrupting migration routes for fish species.[182]
- Hydropower is water-intensive, consuming 68 *l*/kWh on average. This is largely due to evaporation from hydropower dams.[183]

11.8. Pumped Storage

Advantages

- Pumped storage has a relatively low LCOE R1.80/kWh for new pumped hydro storage.
- Though the capital costs for pumped storage are higher than for large hydropower projects at R40 490/kW[184], these costs compare favourably against the capital costs of nuclear and coal.
- The generation of electricity from pumped storage does not result in direct emissions of greenhouse gasses, and lifecycle emissions are low at approximately 7.4 gCO_2e/kWh.[185]

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[176] World Bank. 2013. Cutting Water Consumption in Concentrated Solar Power Plants
[177] Ritchie. 2022. How does the land use of different electricity sources compare?
[178] Potts & Walwyn.2020. An exploratory study of the South African concentrated solar power sector using the technological innovation systems framework
[179] Mark David Skar-Chik.2017. System Cost of Energy Generation Scenarios for South Africa: Understanding the real cost of integrating energy generation technologies
[180] Schroeder et al. 2021. The potential for exploitation of South Africa's latent hydropower
[181] AQPER.2023. How long does it take to build a hydroelectric power station?
[182] Okafor. 2022. What are the environmental impacts of hydropower?
[183] Lee et al. 2017. Regional water consumption for hydro and thermal electricity generation in the United States
[184] Mark David Skar-Chik.2017. System Cost of Energy Generation Scenarios for South Africa: Understanding the real cost of integrating energy generation technologies
[185] NREL. 2021. Life Cycle Greenhouse Gas Emissions from Electricity Generation: Update

Disadvantages

- As with large hydropower, the ability of pumped storage to produce electricity may be affected by droughts, and, as South Africa is generally arid and lacks significant river systems, large-scale adoption of pumped storage may be limited.
- Pumped storage systems may experience long build times. The Ingula Pumped Storage Scheme was commenced in 2007 and took 10 years to build, being completed in 2017[186].

11.9. Green Hydrogen

Advantages:

- The combustion of green hydrogen[187] results in no emissions of CO_2.
- Lazard's analysis provides a range for the levelized cost of hydrogen (LCOH) for green hydrogen. LCOH builds on their levelized cost of energy (LCOE) and levelized cost of storage (LCOS) studies. The LCOH ranges from R25.40/kg – R52.60/kg ($1.40/kg – $2.90/kg) H_2 depending on the electrolyser technology (Alkaline or PEM) and the electrolyser capacity (1 000, 20 000 or 100 000 kW) used in the study[188]. Given the energy density of hydrogen is 33.6 kWh/kg[189], we can divide by this to estimate a LCOE for hydrogen of R0.76 – R1.57/kWh.

Disadvantages

- Capital costs for hydrogen produced by electrolysis are estimated at R15 921/kW (US$ 900/kW)[190].
- Green hydrogen is currently more expensive than the conventional fuels or grey hydrogen it would displace. Electricity represents ~30% –60% of the cost to produce hydrogen from electrolysers with a capacity of 20+ MW, therefore the LCOE for hydrogen is highly dependent on the cost of the available sources of electricity.
- Although burning green hydrogen does not produce CO_2 emissions, the lifecycle emissions are heavily dependent on the source of electricity used. For green hydrogen produced with solar PV, the overall GHG footprint is in the range 1.7 – 4.4 kg CO_2e/kg H_2.[191] For offshore wind-based hydrogen, GHG footprint ranges from 0.4 – 0.8 kg CO_2e/kg H_2. Given the energy intensity of green hydrogen is 33.6 kWh/kg, we get a lifecycle GHG footprint of 0.05 – 0.13 kgCO_2e/kWh H_2 from solar PV, and 0.01 – 0.02 CO_2e/kWh H_2 from offshore wind. Hydrogen may result in increasing amounts of methane, ozone, and water vapour in the atmosphere, leading to indirect global warming.[192]
- Producing green hydrogen is water intensive. Green hydrogen may be produced through the splitting of water via electrolysis, thus requiring water resources during its production[193]. For every 1 kg of green hydrogen produced, 9 litres of water need to be consumed[194]. As with the cost

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[186] Mail & Guardian.2017. Eskom's Ingula, Africa's largest water-pumped power scheme, reaches completion

[187] Green hydrogen refers to hydrogen produced by splitting water into hydrogen and oxygen using renewable electricity. In contrast, grey hydrogen is traditionally produced by methane, split with steam into CO2 and H2. Blue hydrogen follows the came process as grey but includes carbon capture.

[188] Lazard. 2021. Lazard's Levelized Cost of Hydrogen Analysis

[189] RMI. 2019. Run on Less with Hydrogen Fuel Cells

[190] IEA. 2019. IEA G20 Hydrogen report: Assumptions

[191] Kleijne et al. 2022. The many greenhouse gas footprints of green hydrogen

[192] Warwick et al. 2022. Atmospheric implications of increased hydrogen use.

[193] ACS Energy Letters.2021. Does the Green Hydrogen Economy have a Water Problem?

[194] Beswick et al. 2021. Does the Green Hydrogen Economy Have a Water Problem?

calculation, we can use the energy density of hydrogen so estimate the water use of green hydrogen to be 0.27 *l*/kWh.

- Building the infrastructure for large scale hydrogen use (pipelines, export/import terminals) will take many years. For example, it takes around 7 – 12 years to plan and build a pipeline[195].
- In terms of resource availability, production of green hydrogen requires clean electricity and water as a feedstock. South Africa has a high availability for solar and wind resources, although clean electricity availability is currently low. Water availability is also currently limited in South Africa.
- Producing hydrogen is not energy efficient – describe the energy loss from converting solar radiation into electricity and then into green hydrogen.
- Burning of hydrogen may lead to the formation of nitrogen oxides (NOx). Hydrogen leaks may result in the formation of ozone, which can lead to respiratory health impacts.

11.10. Carbon Capture Utilisation and Storage[196]

Advantages:

- The main advantage that CCUS technologies have is their potential to capture GHG emissions from fossil fuel-based power stations before they go into the atmosphere.
- CCUS projects have a relatively short build-time, with construction of projects in operation over the last decade taking 3 – 4 years for construction[197]. Although there is less visibility of the time taken for earlier stages of development, previous examples (Boundary Dam, Petra Nova) have taken 3 – 4 years to progress from being identified to construction, so a reasonable assumption is that it takes 6 – 8 years for new CCUS projects to progress through the full development cycle[198].

Disadvantages:

- CCUS technology is still an immature and expensive technology. For power sector applications, CCUS are mostly at a "demonstration" technology readiness level.[199]
- The costs for CCUS in power sector applications ranges between R915/tCO_2e and R1830/tCO_2e (US$ 50/tCO_2e and US$ 100/tCO_2e).[200] This indicates that utilising CCUS technologies for high-emission power sources becomes more expensive, therefore increasing the LCOE. Considering the carbon intensity of coal is between 0.93 kgCO_2e/kWh and 1.26 kgCO_2e/kWh, and if we assume that 90% of emissions can be captured, the additional cost of CCUS on a coal-fired power plant could be between R0.77 – R2.08/kWh. Lazard estimates the LCOE for coal in the range of ~R1.00 – R2.58/kWh, where the upper value includes 90% carbon capture and storage, suggesting that the addition of CCUS may increase the LCOE by up to R1.58/kWh. This additional cost sits within the calculated range of R0.77 – R2.08/kWh. Similarly for gas (which has an emissions intensity of 0.45 kgCO_2e/kWh), we can perform the same calculation to get a cost range of R0.37 – R0.74/kWh.
- When considering the CAPEX for CCUS, we consider the CAPEX for a coal or gas power plant with and without CCUS. For a coal plant, the CAPEX is estimated to be R29 600/kW, which increases to R49 210/kW with the addition of CCUS.[201] For a natural gas plant the CAPEX increased from

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[195] PWC. The green hydrogen economy

[196] The CCUS section only reviews "end-of-pipe" applications and does not include other technologies such as Direct Air Capture, or Bioenergy with Carbon Capture and Storage (BECCS).

[197] Global CCS Institute. 2020. Scaling up the CCS market to deliver net-zero emissions

[198] Global CCS Institute. 2020

[199] IEA. 2020. "Special Report on Carbon Capture Utilisation and Storage"

[200] IEA. 2021. Is carbon capture too expensive?

[201] Zero Emissions Platform. 2011. The costs of CO2 Capture, Transport and Storage

R14 597/kW without CCUS to R20 350/kW with CCUS. Taking the differences between the without CCUS and with CCUS figures, this suggests CAPEX for the integration of CCUS of R19 610 for coal and R5 753 for gas.

- Adding CCUS technology on to fossil fuel production will make those electricity technologies more expensive and more energy-intensive, therefore, making them less competitive compared to renewable energy technologies. Estimates suggest that the development of CCUS plants attached to plants which emit greenhouse gasses such as coal-fired power plants may have costs equivalent to 50% – 100% of the total costs of developing the main plant itself[202]
- Water use for CCUS varies depending on the application/ technology type – in this case we are focusing on post-combustion CCUS for power production. It is estimated that a coal-fired powerplant retrofitted with CCUS has a median water footprint of 1.71 *l*/kg CO_2.[203] Using the emissions intensity for coal as above and assuming 90% CO_2 captured, we get a range of water use for coal of 1.18 – 1.94 *l*/kWh. For a natural gas combined cycle power plant retrofitted with post-combustion CCUS has a median water footprint of 2.59 *l*/kg CO_2. Using the same calculation, we get an estimated water footprint of 1.05 *l*/kWh for natural gas with CCUS.

11.11. Battery Storage

Advantages:

- Battery storage, when paired to renewable energy generation systems, slows for a more continuous supply of renewable energy at times when renewable energy generation is low. Battery storage thus allows for greater uptake of renewable energy technologies within national grids and can thus improve potentials for grids to be based primarily on renewable energy generation.
- The use of battery storage within a generation grid can help lower the emissions associated with a grid, as this technology can lower the reliance of grids on traditional energy generation methods such as fossil fuels.
- Development of utility scale battery storage facilities are quick to build, with general build times of less than a year[204].

Disadvantages:

- Battery storage has relatively high capital costs. On average total capital costs range from between R2 431 (US$ 143)/kWh and R3 366 (US$ 198)/kWh[205]. This would be an additional cost attached to the capital costs associated with the development of renewable energy plants.
- Levelised costs of storage (LCOS) figures vary depending on battery types but can range between R3 077(US$ 181) and R5 474 (US$ 332) per kW-year for a 100 MW / 400 MWh[206] battery storage system.
- Battery production carries significant environmental impacts. Lithium is required to produce lithium-ion batteries, and the mining of lithium is both water intensive and can lead to contamination of water sources[207].

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[202] News24 (2021) Can previously written-off carbon capture and storage still be the answer for SA?

[203] Rosa *et al*. 2021. The water footprint of carbon capture and storage technologies

[204] Eskom.2022. Construction of Eskom's first battery energy storage project begins

[205] National Renewable Energy Laboratory. 2021. Cost projections for utility scale battery storage

[206] Lazard. 2021. Levelized Cost of Energy, Levelized Cost of Storage, and Levelized Cost of Hydrogen

[207] The Guardian. 2021. Millions of electric car batteries will retire in the next decade: What happens to them?

- Life cycle emissions are high for battery storage. Life cycle emissions, which include the manufacturing and disposal of batteries, have been estimated at between 39 –196 kgCO_2e/kWh, with a midpoint of 117 kgCO_2e/kWh[208].

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[208] Circular Energy Storage.2019. Analysis of the climate impact of lithium-ion batteries and how to measure it