SOUTH AFRICAN COAL ROADMAP

OUTLOOK FOR THE COAL VALUE CHAIN: SCENARIOS TO 2040






JULY 2013

DISCLAIMER

The statements and views of the South African Coal Roadmap are a consensus view of the participants in the development of the roadmap and do not necessarily represent the views of the participating members in their individual capacity. An extensive as reasonably possible range of information was used in compiling the roadmap; all judgments and views expressed in the roadmap are based upon the information available at the time and remain subject to further review. The South African Coal Roadmap does not guarantee the correctness, reliability or completeness of any information, judgments or views included in the roadmap. All forecasts made in this document have been referenced where possible and the use and interpretation of these forecasts and any information, judgments or views contained in the roadmap is entirely the risk of the user. The participants in the compiling of this roadmap will not accept any liability whatsoever in respect of any information contained in the roadmap or any statements, judgments or views expressed as part of the South African Coal Roadmap.

The Coal Roadmap was prepared by The Green House, acting as Technical Project Managers on behalf of the South African Coal Roadmap Steering Committee. The Roadmap and accompanying scenarios and technical reports are based on information, views and data provided to The Green House, supplemented by information obtained from the open literature. The views expressed in this document thus do not reflect those of The Green House.

Enquiries should be directed through the Fossil Fuel Foundation (www.fossilfuel.co.za) or the South African National Energy Development Institute – SANEDI (www.sanedi.org.za).

NOMENCLATURE

bbl	Barrel
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CO_2e	Carbon dioxide equivalent
CSP	Concentrated Solar Power
CTL	Coal-to-Liquid
FBC	Fluidised Bed Combustion
FGD	Flue-gas desulphurisation
FOB	Free-on-board
FTE	Full-time employee
GDP	Gross Domestic Profit
GHG	Greenhouse Gas
IEA	International Energy Agency
IRP	Integrated Resource Plan
IRR	Internal Rate of Return
kWh	Kilowatt hour
l/kWh	Litres per kilowatt hour
l/kWhSO	Litres per kilowatt hour sent out
MJ/kg	Megajoule per kilogram
MJ/MWh	Megajoule per Megawatt hour
Mm^3	Million cubic meters
Mt	Megatonne
Mtpa	Megatonne per annum
MW	Megawatt
MWhSO	Megawatt hour sent out
O&M	Operations and maintenance
PF	Pulverised Fuel
RBCT	Richards Bay Coal Terminal
RTS	Return-to-Service
SACRM	South African Coal Road Map
SC	Supercritical coal
UCG-CCGT	Underground Coal Gasification – Combined-Cycle Gas Turbine
USC	Ultra-Supercritical Coal

TABLE OF CONTENTS

NOMENCLATURE II

1 INTRODUCTION 1

2 SCENARIOS FOR THE COAL VALUE CHAIN 2

2.1 Coal use in South Africa 3

2.1.1 Electricity build plans 3

2.1.2 Coal demand for electricity generation 5

2.1.3 Coal-to-liquids 6

2.1.4 Other local uses of coal 7

2.2 Coal supply 7

2.3 South Africa's coal exports 8

3 IMPLICATIONS OF THE SCENARIOS 11

3.1 Resources and reserves 11

3.2 Timelines and skills requirements for electricity generation build plans 12

3.3 Economic implications 13

3.3.1 Investment requirements and electricity generation cost 13

3.3.2 Coal export prices and revenues 17

3.3.3 Coal local utility prices and local revenue 18

3.3.4 Competitiveness 19

3.3.5 Climate change adaptation costs 19

3.4 Energy Security 19

3.5 Employment and broader socio-economic implications 20

3.5.1 Employment in construction of power stations and CTL plants 20

3.5.2 Employment in operation of mines, power stations and CTL plants 21

3.5.3 Broader socio-economic considerations 23

3.6 Water demand 23

3.6.1 Water demand in the Central Basin 23

3.6.2 Water demand in the Waterberg 24

3.7 Infrastructure 25

3.7.1 Port capacity and rail capacity on the RBCT line 25

3.7.2 Coal transport on the Waterberg to Central Basin line 26

3.7.3 Water supply infrastructure 26

3.8 Contribution to greenhouse gas emissions 27

3.8.1 GHG emissions and GHG intensity of electricity generation 27

3.8.2 GHG emissions from CTL 28

3.9 Environmental implications 28

3.9.1 Water provision, land and biodiversity 28

3.9.2 Waste generation 29

3.9.3 Non-GHG emissions 30

INTRODUCTION

The South African Coal Roadmap aims to support the coal industry, policymakers and other stakeholders in navigating an uncertain future in which there are multiple objectives to be met and trade-offs to be made, in order for the country as a whole to flourish. A scenario approach has been used to develop the Roadmap. By identifying four different futures and conducting an in-depth quantitative and qualitative analysis of the implications of following each of these futures, an understanding is gained of the contribution of the coal value chain to the South Africa economy and the well-being of its people and natural environment under different scenarios.

This report presents a high-level summary of the outcomes of the quantitative and qualitative analysis of the scenarios, with full details of modelling assumptions and a complete set of results being contained in the associated Technical Report. Note that the baseline data and situational analysis for the scenarios were based on information from 2010, updated where possible to 2012.

The Roadmap was developed based on the understanding gained from the scenarios analysis, to provide insights into:

- **Common actions** that need to be undertaken regardless of how the future evolves;
- The **signals** that a particular future is evolving;
- Differing **objectives** that need to be considered in deciding between alternatives;
- **Activities** that need to be undertaken for the coal value chain to positively contribute to a flourishing South Africa; and
- **Key policy requirements.**

The Roadmap is presented in a separate document.

SCENARIOS FOR THE COAL VALUE CHAIN

The SACRM scenarios were established by considering a range of local and global drivers including:

- the global economy;
- the South African economy and local development priorities;
- the global climate change response;
- South Africa's climate mitigation response;
- the evolution of global coal markets;
- the necessity to balance exports and local demand in South Africa;
- the evolution of local infrastructure; and
- the evolution of technologies including carbon capture and storage.

Together, these often inter-dependant drivers will shape the future and the evolution of the coal value chain in South Africa. Of these, two drivers were selected that defined a set of four distinct scenarios with very different implications for the coal value chain. The framing drivers, along with the resulting scenarios named **More of the Same**, **Lags Behind**, **At the Forefront** and **Low Carbon World** are shown in Figure 1.

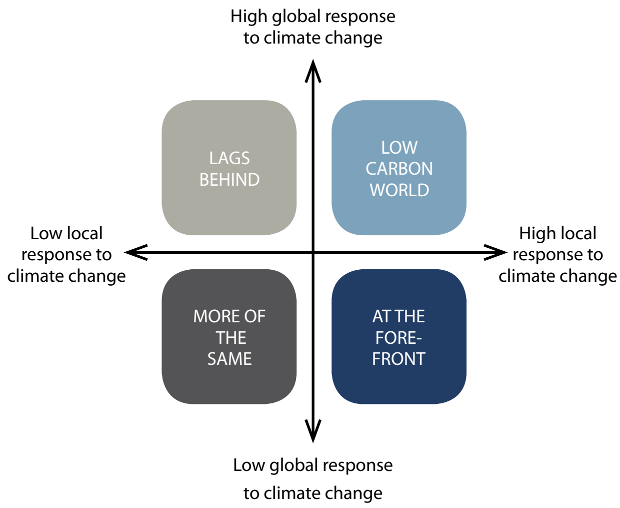

Figure 1: The four SACRM scenarios

The main determinants of the evolution of the coal value chain under the four scenarios between now and 2040 are summarised as follows.

MAIN DETERMINANTS

LAGS BEHIND

The world decarbonises, but coal remains a significant energy source in South Africa and other developing countries. Coal-based power generation still dominates local electricity supply, but with clean coal technologies such as ultra-supercritical power stations, carbon capture and storage and underground coal gasification as they become available.

A new coal-to-liquids plant is built in 2027 to meet local liquid fuels demand.

LOW CARBON WORLD

The world decarbonises and moves towards use of nuclear and renewables for electricity supply. Funding is available for South Africa to follow suit, with no new coal-fired power stations built beyond Medupi and Kusile.

Carbon capture and storage is pursued and no more coal-to-liquids plants are built in South Africa.

MORE OF THE SAME

Coal use continues globally and locally. Coal-based power generation using existing supercritical technologies dominates the electricity mix, and the life of existing power stations is extended.

Two new coal-to-liquids plants are built between 2027 and 2040 to meet local liquid fuels demand.

AT THE FOREFRONT

Coal use continues globally, but South Africa aims to diversify its energy mix to include renewables and more nuclear generation. New coal-fired power plants after Medupi and Kusile use ultra-supercritical technologies, with smaller power stations (including FBC stations) being built.

No more coal-to-liquids plants are built.

The implications for local coal demand, coal supply and exports of coal are presented in the sections that follow.

2.1 Coal use in South Africa

The scenario models are driven primarily from by local electricity demand. In other words, coal is mined to ensure local electricity security, but is supplied at a cost to the electricity generator that ensures adequate return on investment in mine projects and new mines. At the same time, various industry sources were used to identify coal projects that are likely to come on line between now and 2040. These projects are assumed to provide the thermal coal required for electricity generation, the thermal coal for non-Eskom domestic demand, the metallurgical coal for domestic demand, and coal for exports (both thermal and metallurgical). Coal demand for CTL plants is assumed to be met through existing and new mines.

2.1.1 Electricity build plans

The basis for the electricity build plans under the four SACRM scenarios are selected scenarios developed during the 2010 Integrated Resource Plan (IRP 2010) process. As in the IRP 2010, electricity demand for the country is assumed to be identical between scenarios and driven by a growth in GDP of 4.5%, corrected for a projected decline in energy intensity of the economy and adoption of demand side management opportunities. As the IRP currently only projects to 2030, assumptions were made about the build plan for the period 2030 to 2040. The build plan assumptions and resulting build plans are presented below.

COAL- FIRED ELECTRICITY BUILD ASSUMPTIONS

LAGS BEHIND

Follows IRP 2010 Base Case scenario to 2030, under which new power stations are mostly coal-fired.

From 2030-2040 new build is a mix of ultra-supercritical PF with FGD, FBC and UCG-CCGT and a smaller proportion of CCGT.

New PF is built in the Waterberg and FBC utilises discards in the Mpumalanga coalfields. UCG utilises coal resources in the Free State coalfields

CCS installed on new large coal build (USC PF) from 2034.

Mid-range decommissioning of coal-fired power stations.

LOW CARBON WORLD

Follows IRP 2010 Emissions 3 scenario to 2030, under which no new coal-fired power stations are built after Medupi and Kusile.

From 2020 new build is made up of nuclear and CCGT for base load and renewables/other supply (hydro imports, co-gen).

CCS is retrofitted to Medupi and Kusile from 2029.

Early decommissioning of coal-fired power stations.

MORE OF THE SAME

Follows IRP 2010 Base Case scenario to 2030, under which new power stations are mostly coal-fired.

From 2030-2040 new build is a mix of supercritical PF with FGD, FBC and UCG-CCGT with a smaller proportion of CCGT.

New PF is built in the Waterberg and FBC utilises discards in the Mpumalanga coalfields. UCG utilises coal resources in the Free State coalfields

Late decommissioning of existing coal-fired power stations.

AT THE FOREFRONT

Follows IRP 2010 Policy Adjusted scenario to 2030, which provides a diversified mix of new power stations including coal, renewables, CCGT and nuclear.

New PF coal build is ultra-supercritical with FGD.

New PF is built in the Waterberg and FBC utilises discards in the Mpumalanga coalfields.

Mid-range decommissioning of coal-fired power stations.

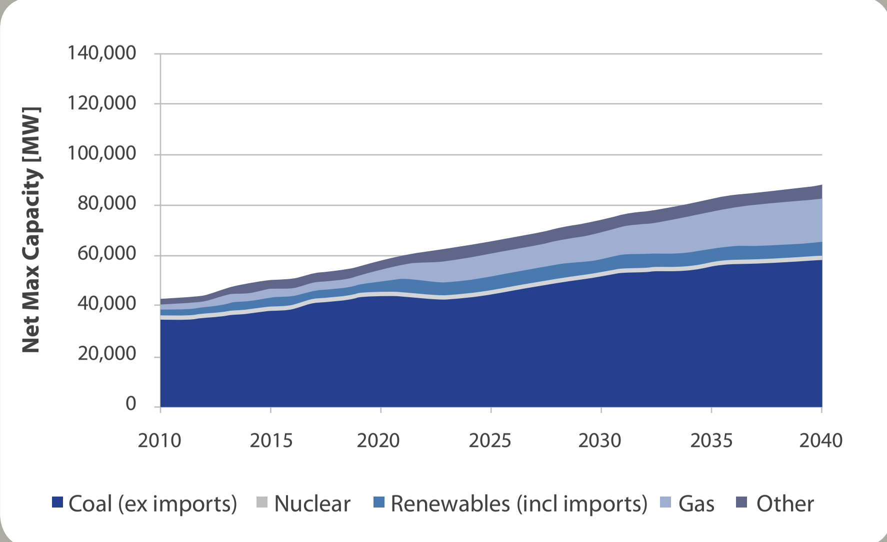

Figure 2: Electricity generation build plan (Lags Behind)

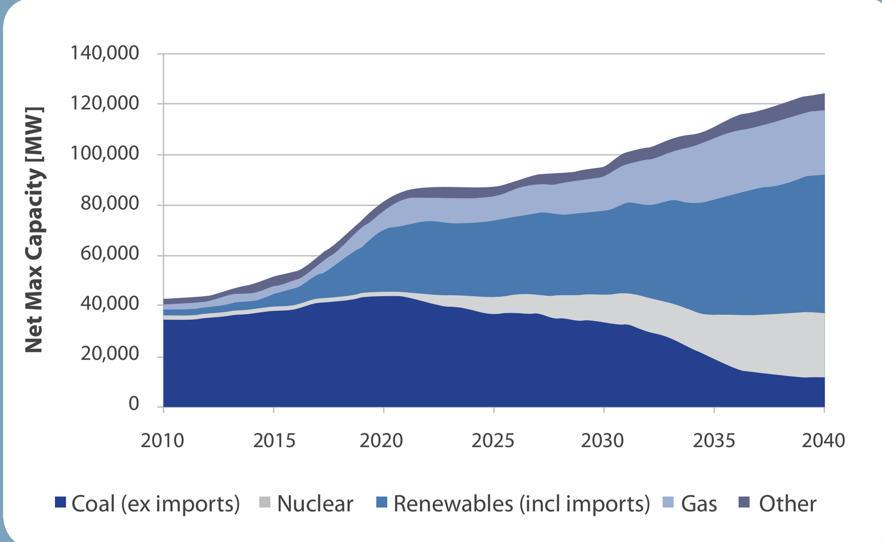

Figure 3: Electricity generation build plan (Low Carbon World)

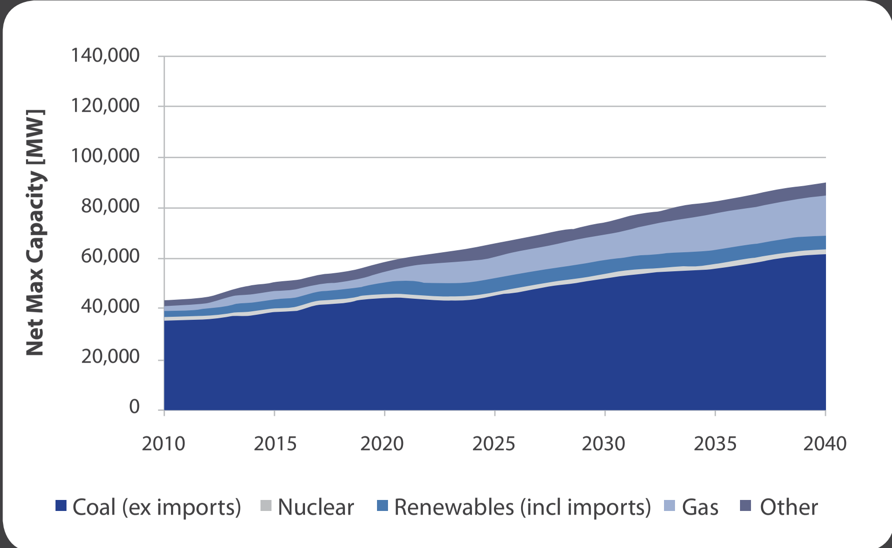

Figure 4: Electricity generation build plan (More of the Same)

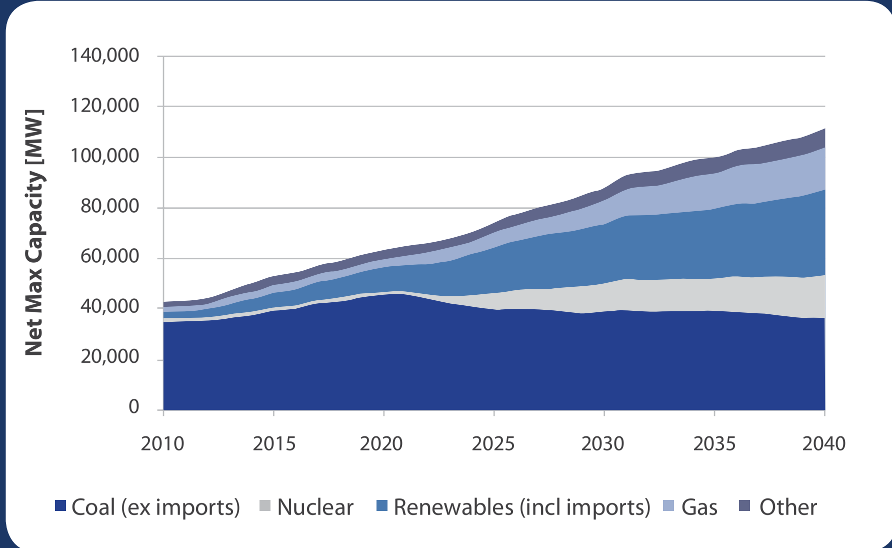

Figure 5: Electricity generation build plan (At the Forefront)

Observations

- The overall installed capacity by 2040 is significantly higher in **At the Forefront** and **Low Carbon World** (112,052 MW and 124,725 MW net max capacity respectively) than in **More of the Same** and **Lags Behind** (89,874 MW and 88,070 MW net max capacity respectively), to meet the same electricity demand projection. The difference is due to the lower capacity and availability factors associated with renewable energy technologies, which results in a higher net max capacity to be built to deliver the same electricity output.
- A further contributing factor to increased new build requirement in **Low Carbon World** is the impact of the early retirement of power stations post 2030.
- The power station build is still higher in **More of the Same** than in **Lags Behind**, even though existing power stations are decommissioned later under the former scenario. This is due to the lower efficiency of new supercritical coal-fired power stations as compared with the new ultra-supercritical coal stations in **Lags Behind**, resulting in more capacity required for the same power output.

2.1.2 Coal demand for electricity generation

The build plans presented above imply the coal demand of specific quality categories shown in the following graphs.

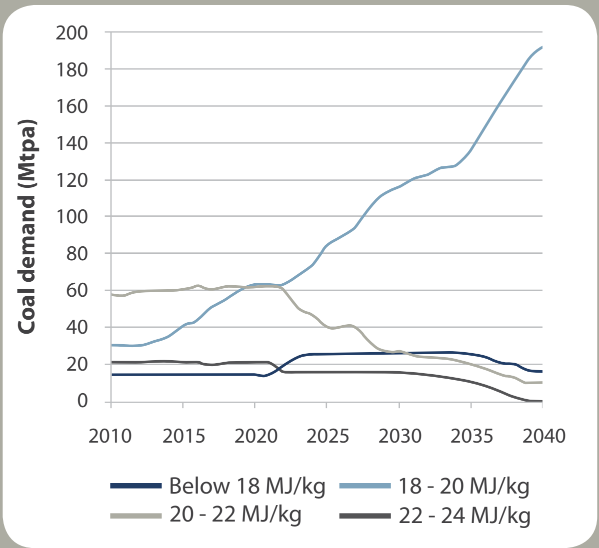

Figure 6: Coal demand for electricity generation (Lags Behind)

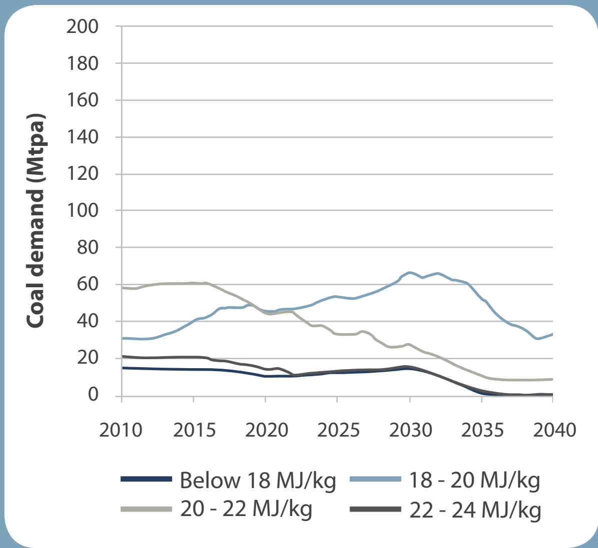

Figure 7: Coal demand for electricity generation (Low Carbon World)

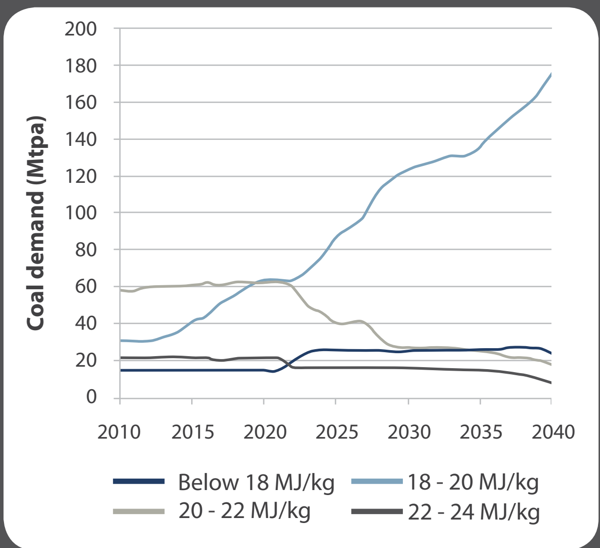

Figure 8: Coal demand for electricity generation (More of the Same)

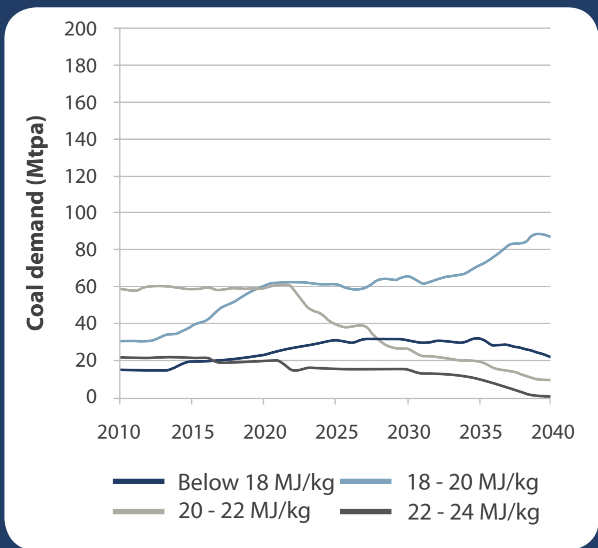

Figure 9: Coal demand for electricity generation (At the Forefront)

Observations

- Growth in demand from new PF stations in **More of the Same** and **Lags Behind** is in the 18 to 20 MJ/kg category, with demand approaching 200 Mtpa by 2040.
- Under all scenarios, there is an on-going demand for over 50 Mtpa of the 20 to 22 MJ/kg coal band to 2020 and shortly beyond, with the demand for this band of coal starting to drop as older power stations are decommissioned – this occurs earlier under **Low Carbon World** and **At the Forefront** than under **More of the Same** and **Lags Behind**.
- Coal in the 22 to 24 MJ/kg CV band is required up to 2038 in all scenarios, other than **More of the Same**, where it is required beyond 2040 due to the late decommissioning under this scenario. Ensuring security of this grade of utility coal is critical to meeting on-going electricity demand, without having to prematurely retire coal assets and build additional capacity to make up the shortfall.

2.1.3 Coal-to-liquids

CTL plants are built in **More of the Same** and **Lags Behind**, the scenarios in which coal continues to be the primary energy source. New CTL plants are located in the Waterberg.

CTL ASSUMPTIONS

LAGS BEHIND	LOW CARBON WORLD
One new CTL plant with a capacity of 80,000 bbl/day begins to be brought on line in 2027. CCS is fitted in 2034 to both Secunda and the new CTL plant to capture process CO_2 stream.	No new CTL plants are built. CCS is fitted to Secunda in 2029 to capture process CO_2 stream.
MORE OF THE SAME	**AT THE FOREFRONT**
A new CTL plant with a capacity of 80,000 bbl/year begins to be brought on line in 2027, with a further plant of the same capacity beginning to be brought on line by 2037. CCS is not fitted to these plants.	No new CTL plants are built.

The coal demand associated with existing capacity at Sasol's Secunda CTL operations and new CTL plants under the different scenarios is as follows:

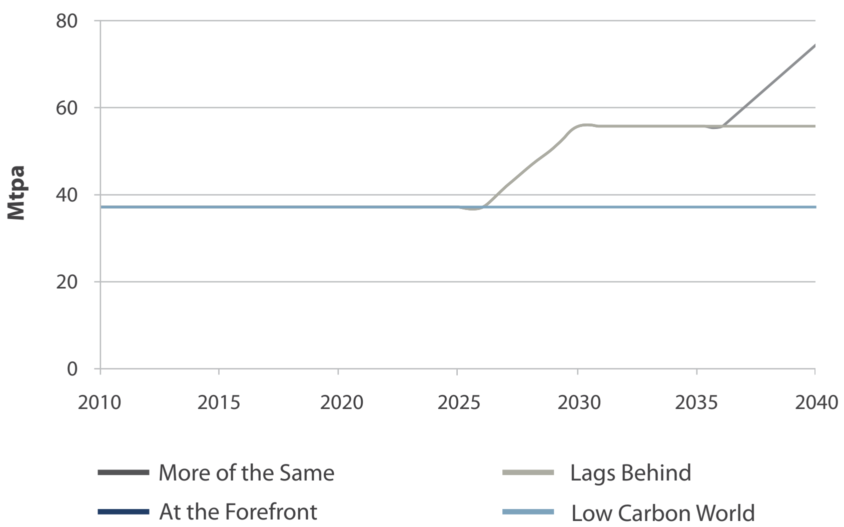

Figure 10: CTL coal demand per scenario

2.1.4 Other local uses of coal

Apart from power generation and CTL, coal is used locally in thermal applications (mostly boilers and heating) and in metallurgical applications including iron and steel production, ferroalloy production and cement. Demand for thermal coal remains unchanged over the analysis period under all four scenarios, as the use of alternative fuels, including gas, is assumed to offset growth in this energy demand. The demand for metallurgical coal differs across the scenarios, where **At the Forefront** provides the baseline projection, in which ferrochrome and ferromanganese production and associated coal demand grow at 2% per annum throughout the analysis period to 2030, **More of the Same** and **Lags Behind** fall above this with a high output projection, and **Low Carbon World** below with a low output projection.

2.2 Coal supply

The scenario models are primarily demand driven, in other words it is assumed that sufficient coal is mined to meet the local demand for utility coal and other domestic coal. The models also look at projections of coal supply from existing mines and projects, which were collated from annual reports, the Wood Mackenzie coal supply service data and industry experts. For thermal coal projects, the coal from a particular project was allocated either to Eskom, other domestic supply or to export. If there was no information on the project, the coal was allocated according to wherever there was shortfall in supply to meet the demand, which in most cases meant that coal was first allocated to Eskom. A number of projects were identified as not for Eskom, in which case the coal was designated for export, unless it was needed to meet other domestic demand. Projects supplying coal for domestic use are assumed to come on line when required by the demand, i.e. whenever there is a shortfall in that grade of coal. This demand-driven timing was applied also to dual-producing mines, where the timing, quantity and quality of the export fraction is assumed to depend on first meeting the domestic requirement. The timing of export-only projects is according to industry expert opinion and the Wood Mackenzie database. These are critical assumptions. If they are relaxed, exports from the Central Basin could be increased; however this will be at the cost of larger and/or earlier shortfalls for electricity generation.

Coal supply from new mines in the Central Basin and the Waterberg are shown below for the scenarios:

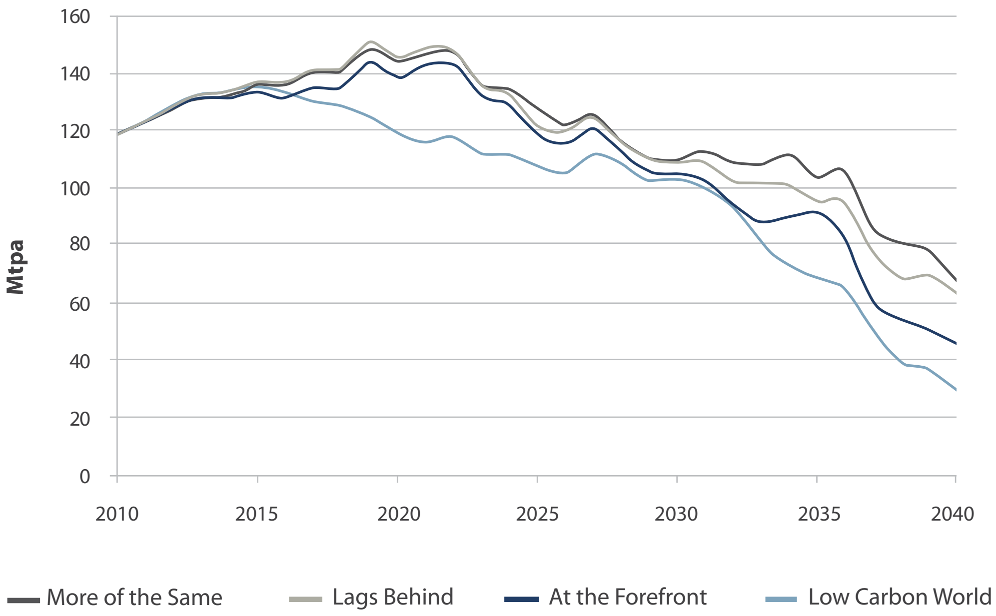

Figure 11: Utility coal supply from existing mines and projects in Central Basin

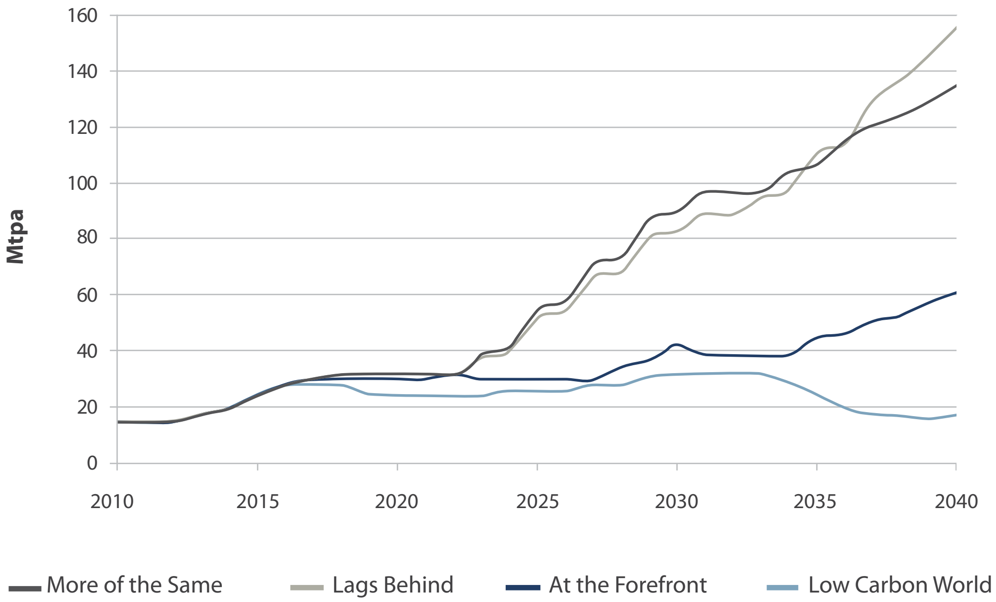

Figure 12: Utility coal supply from existing mines and projects in Waterberg

Observations

- Sufficient projects were identified in the Central Basin coalfields to secure coal supply to the existing power stations and to other non-Eskom domestic users throughout the 2010 to 2040 period, in all scenarios other than in **More of the Same**. Nonetheless, sensitivity analyses show it would be prudent to augment coal supply options (e.g. a with rail line from the Waterberg) from the early-2020s as supply of high-grade utility coal is very constrained from the mid-2020s in all scenarios other than in **Low Carbon World.**
- In **More of the Same,** where the decommissioning of power stations is delayed and 22-24 MJ/kg coal is required beyond 2040, there is shortfall in this grade of coal from the Central Basin and an alternative source of coal will be required from the mid 2030s (and most likely earlier, given the tightness in supply from the mid-2020s).
- Coal supply from the Central Basin increases slightly to 2020 and then declines to 2040, with some variations across the scenarios due to generating load and the timing of decommissioning of power stations.
- Most of the growth in coal supply occurs in the Waterberg, where it is assumed all future coal-fired power stations are located. **At the Forefront** shows limited growth in the Waterberg, under which less coal is mined than in **More of the Same** and **Lags Behind.**
- Even in **Low Carbon World**, coal mining continues beyond 2040 to supply power stations.

2.3 South Africa's coal exports

Global demand for coal differs between the scenarios as follows:

GLOBAL COAL DEMAND

LAGS BEHIND

Although there is some lock-in to existing infrastructure growth for the higher grade export products slows and ultimately declines. All new demand in export coal from 2020 onwards is assumed to be for low-grade coal for Asian markets.

LOW CARBON WORLD

Global demand for coal declines as the world moves away from fossil fuels, retiring existing coal-fired power stations early. Whilst demand for the higher grades of export coal declines, demand in low-grade coal for Asian markets remain strong throughout the period.

MORE OF THE SAME

Global demand for coal grows, with high demand from Asia for coal including lower grade products for power stations.

AT THE FOREFRONT

Global demand for coal grows, with high demand from Asia for coal including lower grade products for power stations.

While acknowledging these global changes, South Africa makes up a relatively small proportion of global trade in coal, and hence under the SACRM it is assumed that a market will still exist for exports. Coal exports are thus driven in the scenario models primarily by production to meet local demand, as many new mines, particularly those in the Waterberg, produce coal for both domestic use and export markets.

Exports from existing mines and projects were projected from a collation of data from annual reports, the Wood Mackenzie coal supply service data and expert input. For many mines and projects, the mine was configured to meet Eskom's requirements in line with the demand driven nature of the scenario models, with the remainder allocated to exports. In the few cases, where specific information could not be found or was not supplied regarding a particular project, especially with regards to potential product grades and markets, these were estimated by assuming indicative yields and product splits according to the grade of the coal resource. Further, if the deposit was sufficiently high-grade, a dual-producing mine was selected as the default option, with the mine configuration selected based on the option giving the lowest cost of the particular grade of utility coal required while still providing an IRR to the mine of a 10% (real). Thus, in all cases, the export yield is dependent on the utility demand (grade and volume). In **More of the Same** and **Lags Behind**, projects are assumed to be brought online to meet demand (i.e. shortfalls are avoided). This is a significant assumption and in reality there are many obstacles to maintaining coal supply (discussed in the Roadmap). In the less coal reliant scenarios, project start dates are pushed out until the utility coal is required (as happens in **At the Forefront**), whilst if there is no utility demand, as happens in **Low Carbon World,** the mine is assumed to produce for export only. Projects utilising lower-grade deposits and which were identified by the experts as not for Eskom in the scenario models, were assumed to produce low-grade exports and were timed to come on line in such a way as to keep export volumes and utilisation of associated transport infrastructure as constant as possible.

An important assumption for the predicted growth in exports is the dependency of exports from the Waterberg on securing a market for a utility coal stream, i.e. that all future Waterberg mines will be dual-producing (along the lines of the only currently operating Waterberg mine). Export potential could be far higher should future exploration of the Waterberg suggest alternative product splits from its mines, such as the production of a low-grade export stream.

Metallurgical exports are estimated from total metallurgical coal production less the predicted domestic demand in metallurgical coal. Metallurgical coal production from existing coal mines and projects was taken from the Mackenzie coal supply service data.

Overall exports predicted under the scenarios (combined thermal and metallurgical exports), shown as five-year rolling averages, are as follows:

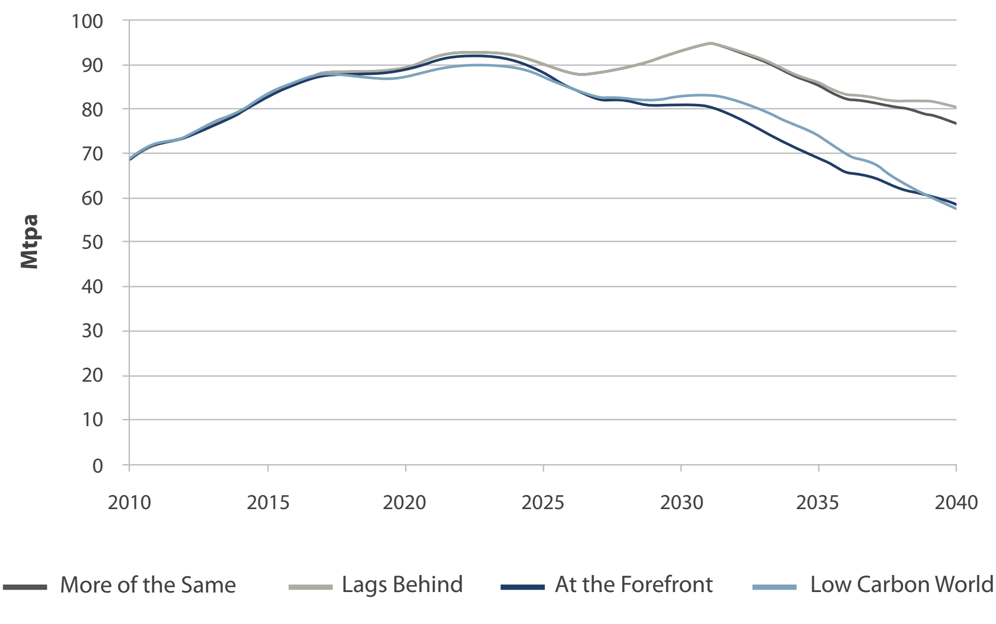

Figure 13: South African coal exports

Export trends can be seen more clearly in Figure 14 and Figure 15, which show the exports from the Central Basin and Waterberg, respectively. Exports are reported as a five-year rolling average.

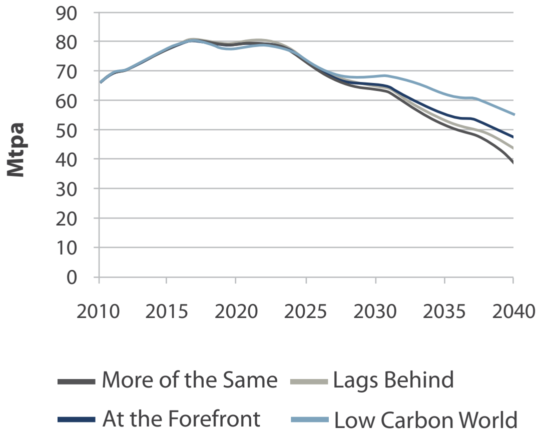

Figure 14: Exports from Central Basin

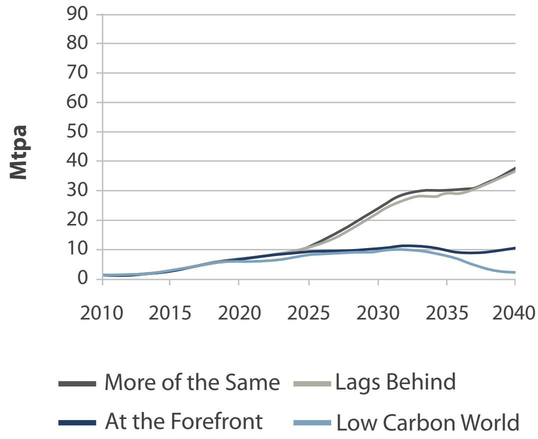

Figure 15: Exports from the Waterberg

Observations

- Under all four scenarios total exports grow to around 90 Mtpa by 2018 and then remain fairly constant at these levels until 2025. Exports under **More of the Same** and **Lags Behind** then increase further (to 95 Mtpa) as new power stations are opened in the Waterberg, and then from 2031 decline to around current levels (80 Mtpa) as mines in the Central Basin close. In contrast, exports from **At the Forefront** and **Low Carbon World** start to decline gradually from 2025 to below current export levels after 2030, as mines close in the Central Basin, and are not replaced by as much coal being mined in the Waterberg.
- Considering the period 2020 to 2040 on average, indications are that it would be possible to maintain exports at around 90 Mtpa under **More of the Same** and **Lags Behind.** In **At the Forefront** and **Low Carbon World**, total exports could be maintained at 85 Mtpa for the period 2018 – 2030.
- **Low Carbon World** shows higher exports from the Central Basin than the other scenarios because early decommissioning of power stations under this scenario means that certain projects supplying utility coal in the other scenarios are assumed to go ahead as export only mines.
- Export volumes from the Central Basin could be 15-20% higher if demand for non-Eskom domestic coal declines, rather than staying constant at current levels as assumed here.
- If exports are to grow beyond current levels further exploration and development is required in the Waterberg to demonstrate the feasibility of export only mines and/or the possibility of a higher-yielding export fraction in dual producing mines (either without decreasing the yield or quality of the domestic fraction, or by moving to new power stations able to burn lower quality coal, e.g. Fluidized bed combustion).

IMPLICATIONS OF THE SCENARIOS

The implications of following the different scenarios for the coal value chain and the country more broadly are now considered.

3.1 Resources and reserves

The remaining run-of-mine coal resources in the Witbank, Highveld and Ermelo coalfields are estimated to be around 12,000 Mt (combined reserves and resources across all three coalfields). Various internal industry reports and expert opinion were used to obtain this value and categorise these remaining resources into four possible grades:

- High (> 24 MJ/kg), making up 4% of remaining resources
- Medium (22 to 24 MJ/kg), making up 26% of resources
- Low (20 to 22 MJ/kg), making up 40% of resources
- Very low (<20 MJ/kg), making up 30% of resources

Run-of-mine coal from the existing mines and projects in these coalfields was assigned to one of these resource grades. The analysis is necessarily approximate because estimates of resources are uncertain and can differ substantially between studies, largely because of what can be considered a mineable resource. For example, whether resources are adjusted for environmental considerations (e.g. wetlands), whether pillars from old underground workings are included and whether the possibility of reworking fines and discard dumps is included. Note that these factors are excluded from the resource estimate used in the SACRM scenario models.

The depletion of resources according to these resource grades up to 2040 is shown in the following figures (where low and very low are combined):

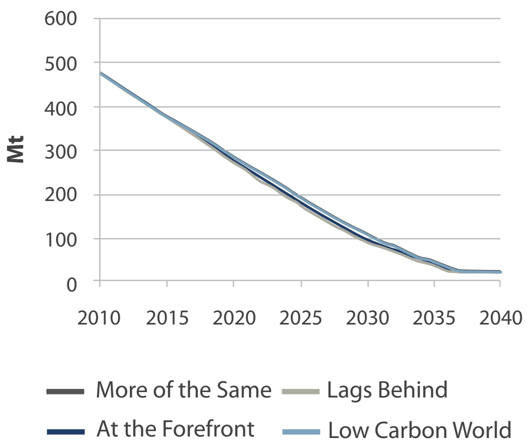

Figure 16: Decline in high grade (> 24 MJ/kg) run-of-mine coal resources in Central Basin

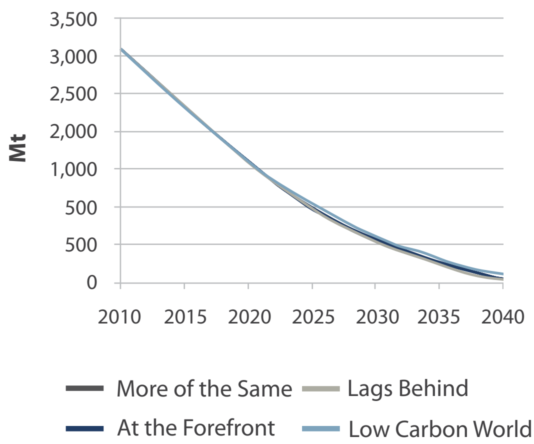

Figure 17: Decline in medium grade (22-24 MJ/kg) run-of-mine coal resources in Central Basin

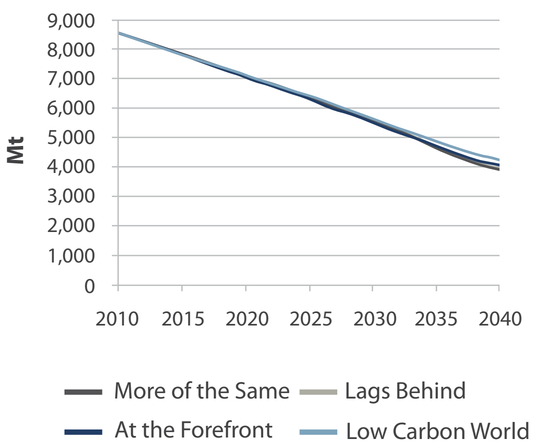

Figure 18: Decline in lower grade (<22 MJ/kg) run-of-mine coal resources in Central Basin

Observations: Resources according to grade

- Under all scenarios, the high and medium grades of resources (those with a run-of-mine calorific value above 22 MJ/kg) are close to being depleted by 2040.
- There are still large volumes of lower grade resources remaining in the Central Basin, even though these resources are more than halved over the period 2010 to 2040.

Resources in the Waterberg coalfield are extensive, and an indicative value of 45,000 Mt run-of-mine resources in 2010 is used in the analysis. Total resource depletion in the Central Basin and Waterberg coalfields are shown below as the total run-of-mine coal extracted from these coalfields over the period 2010 to 2040:

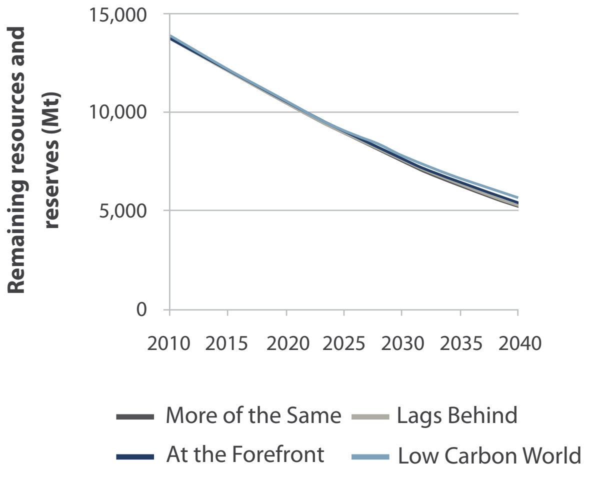

Figure 19: Decline in run-of-mine coal resources in Central Basin

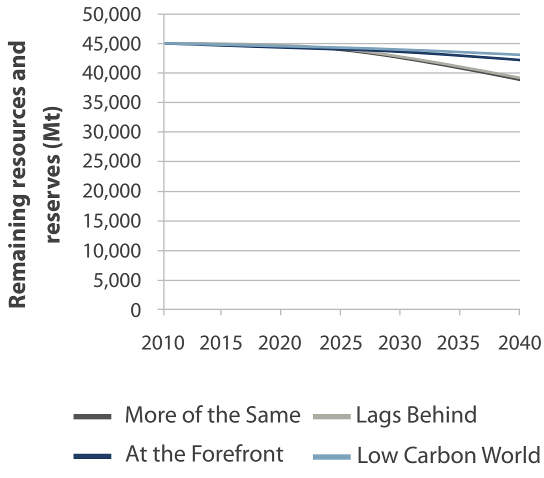

Figure 20: Decline in run-of-mine coal resources in the Waterberg

Observations: Overall resources

- All four scenarios show very similar profiles in terms of decline of resources in the Central Basin, as the same set of existing mines and projects is applicable to all scenarios.
- The resource base of the Waterberg coalfield is so large that even with the considerable coal consumption of **More of the Same** and **Lags Behind**, the resource base is depleted by less than 15%.

3.2 Timelines and skills requirements for electricity generation build plans

BUILD PLAN REQUIREMENTS: TIMELINES AND SKILLS

LAGS BEHIND

New coal has a lead time of 8 years, requiring decisions to be made by 2015.

High capital costs, power plant efficiency penalties, increased water demand, technical challenges and regulatory and liability matters related to CCS will need to be addressed before 2034.

Skills required in mining and coal-fired power generation as well as clean coal technologies including CCS.

LOW CARBON WORLD

New nuclear required by 2022. The 10-year lead time may mean that it may be too late to follow this plan as defined by the scenario.

Ambitious nuclear and renewables build requires major investment in local manufacturing capacity and skills development in the very short term.

High capital costs, power plant efficiency penalties, increased water demand, technical challenges and regulatory and liability matters related to CCS will need to be addressed before 2029.

MORE OF THE SAME

New coal has a lead time of 8 years, requiring decisions to be made by 2015.

Skills required in mining and coal-fired power generation.

AT THE FOREFRONT

New nuclear required by 2023. The 10-year lead time may mean that it may be too late to follow this plan as defined by the scenario.

Ambitious nuclear and renewables build requires major investment in local manufacturing capacity and skills development in the very short term.

3.3 Economic implications

Economic implications of the scenarios are considered in terms of:

- Electricity generation infrastructure investment and generation cost
- Revenues associated with local sales and export sales of coal
- Competitiveness

3.3.1 Investment requirements and electricity generation cost

Annual and total investment in electricity generation infrastructure is shown the first set of four figures below, with the following four figures showing the indicative generation cost. All figures are in 2010 real Rand values, and include technology learning for certain technologies. The generation costs take into account increased prices which will be paid for coal in the future, but exclude inflation in other input costs, which are acknowledged to be increasing rapidly – suggesting that the generation costs could well be under-estimated for coal technologies, and to a lesser degree gas, which have high material inputs during operation. Furthermore, the numbers are based primarily on the costs of building new power plants given in IRP2010, as that was the most up-to-date data at the time of building the models. More recent experience suggests that these numbers could be quite different to those used in IRP 2010, with the costs of renewables being lower and the cost of building nuclear being substantially higher. Finally neither investment nor generation costs take into account capital required for new power stations or nuclear decommissioning post 2040, and thus any figures after about 2035 will be understated.

It is important to recognise that generation cost is not the same as electricity price. Generation cost as calculated in the SACRM models is indicative as it includes an allowance for capital cost of new build only (and excludes depreciation of existing capital which is consistent across scenarios), O&M (including water and sorbent costs), fuel costs as well as environmental levies on electricity generated from non-renewable resources. It thus excludes transmission and distribution, cost of imports, transport and injection costs associated with CCS and other costs typically taken into account in determining electricity price.

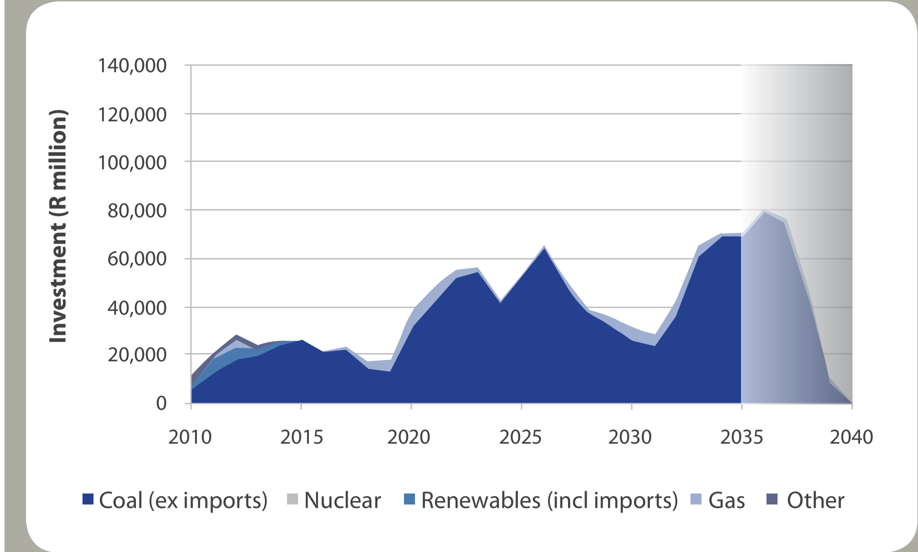

Figure 21: Annual investment in electricity generation capacity (Lags Behind) R 1,240 billion total investment

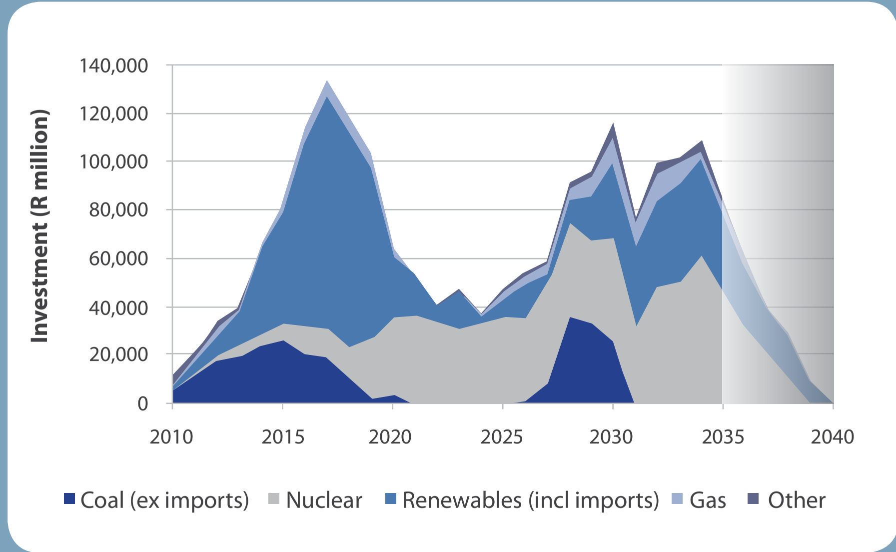

Figure 22: Annual investment in electricity generation capacity (Low Carbon World) R 2,060 billion total investment

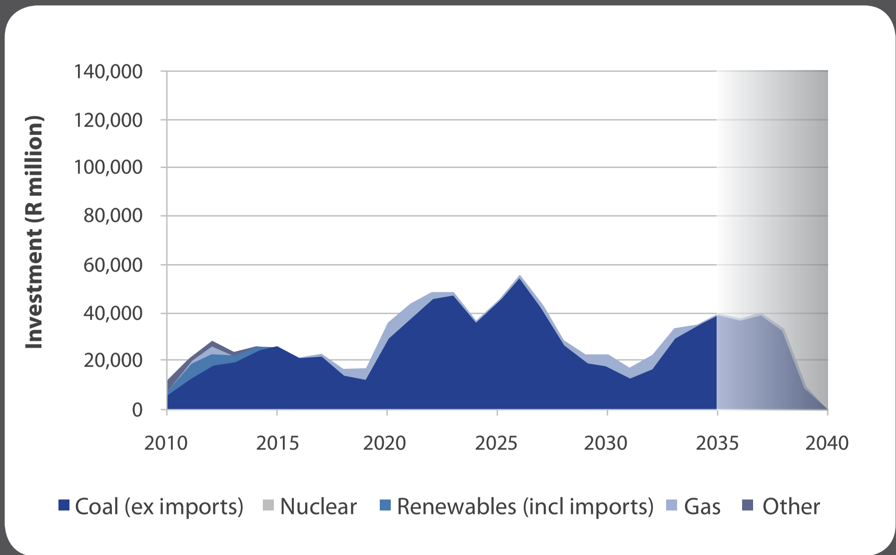

Figure 23: Annual investment in electricity generation capacity (More of the Same) R 930 billion total investment

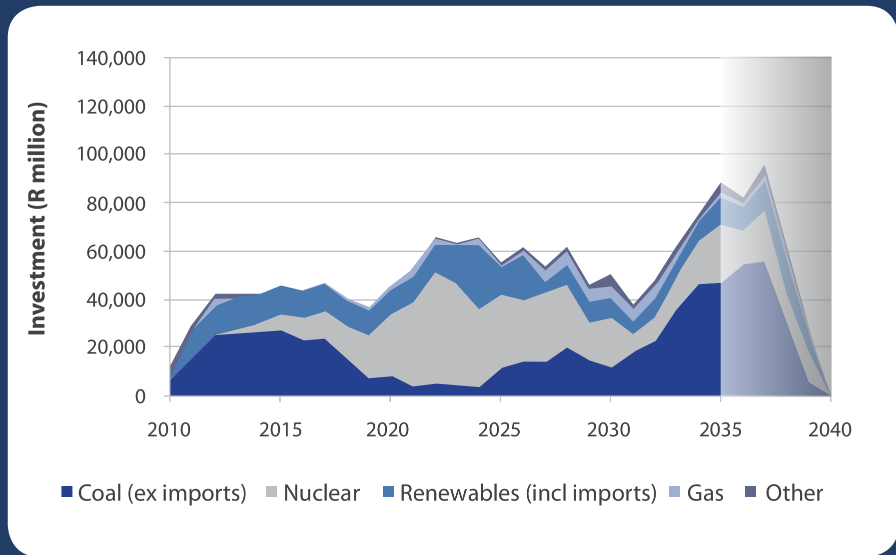

Figure 24: Annual investment in electricity generation capacity (At the Forefront) R 1,590 billion total investment

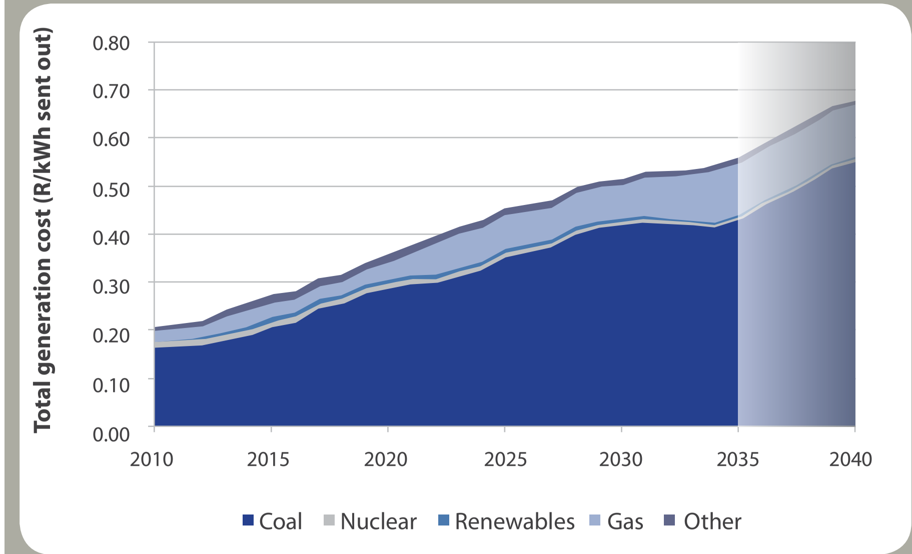

Figure 25: Indicative electricity generation cost (Lags Behind)

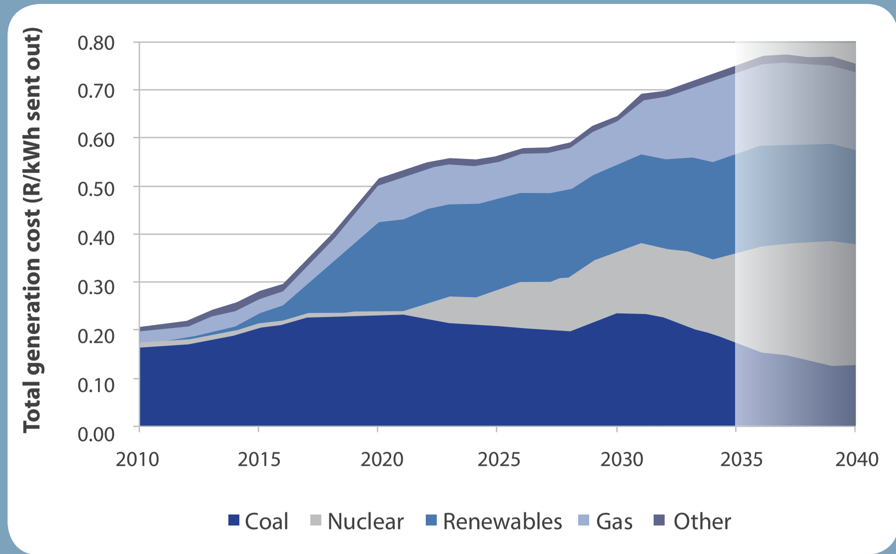

Figure 26: Indicative electricity generation cost (Low Carbon World)

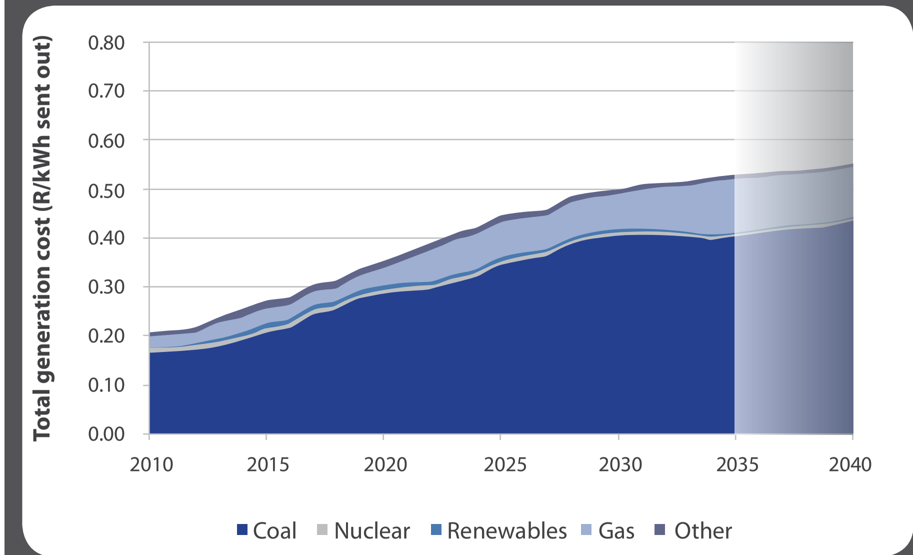

Figure 27: Indicative electricity generation cost (More of the Same)

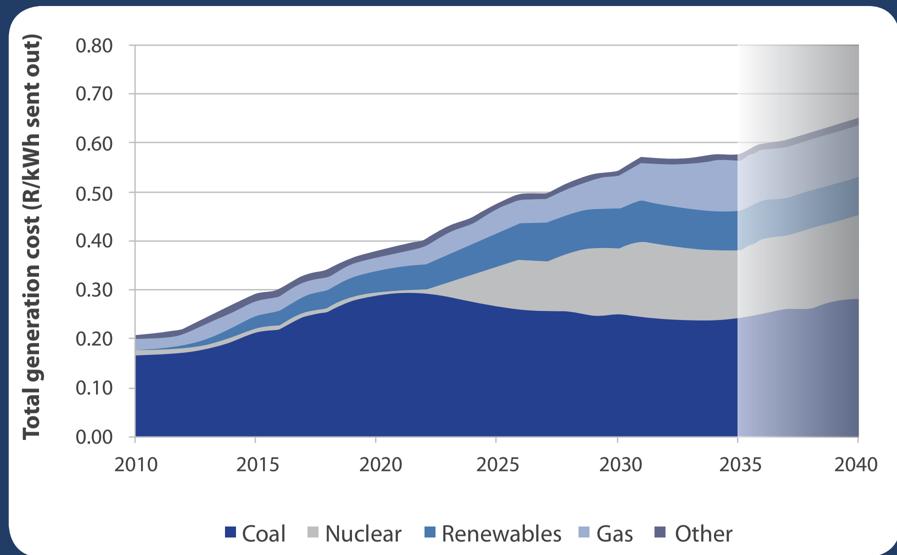

Figure 28: Indicative electricity generation cost (At the Forefront)

Observations: Investment cost

- **More of the Same** offers the lowest requirement for upfront capital, primarily attributed to the continued building of supercritical power stations.
- The substantial capital cost implications of fitting CCS to new power stations built from 2034 onwards in **Lags Behind** is apparent.
- Rapid technology and local manufacturing capacity development is required particularly for the roll-out of wind and CSP technologies under **Low Carbon World** from 2017 onwards.
- The upfront capital expenditure associated with pursuing an electricity build plan which relies primarily on renewables and nuclear under **Low Carbon World** is substantial, although technology learning is expected to bring down the cost of renewable technologies in future.
- Solar technologies will likely be located in the Northern Cape where the solar resource is highest, but where there is limited existing grid infrastructure. Similarly, nuclear power stations will likely be at the coast, so as to allow the use of seawater for cooling, thus requiring grid infrastructure to wheel power to the inland centres of economic activity. A further consideration in **Low Carbon World** is that a high renewables contribution to the grid requires infrastructure to manage grid stability. The costs of new grid infrastructure were not included in the analysis.
- The biggest uncertainties in costs lie in those for CCS, and ultra-supercritical and nuclear power stations.

ACCESS TO GLOBAL FUNDING

LAGS BEHIND

Until 2034 South Africa receives little global support for coal-fired electricity supply infrastructure, as the remainder of the world moves away from coal. Support is provided for introduction of CCS on new power stations built from 2034 onwards.

LOW CARBON WORLD

High funding requirements under this scenario will be met by global support for the transition away from coal. However there could be competition for support from other developing countries.

MORE OF THE SAME

Lowest funding requirement of the four scenarios. Likelihood of funding being available from international funders due to the global continuation of coal being used as a primary energy source globally.

AT THE FOREFRONT

Funding may be a significant challenge as South Africa diversifies its electricity mix while the remainder of the world continues to use coal as the primary energy source.

Observations: Generation cost

- In terms of indicative electricity generation cost, **More of the Same** demonstrates the lowest overall costs, starting from about 21 cents per kWh in 2010 and rising to around 52 cents per kWh in 2035 (after which the generation cost is uncertain). The increase in cost of generation is attributed primarily to the cost of new power generation infrastructure.
- **At the Forefront** and **Lags Behind** track closely in generation costs, with both scenarios having generation costs of between 60 and 70 cents per kWh in 2040, and **At the Forefront** coming in slightly below **Lags Behind**. The additional cost of diversification into renewables and nuclear in **At the Forefront** is offset by the costs associated with installing flue gas desulphurisation onto new plants in the Waterberg, as well as CCS onto those built from 2034 onwards, under **Lags Behind**. Notwithstanding the high uncertainties in costs in both scenarios, this points to the fact that a diversified electricity generation mix can be competitive with a clean coal generation mix, especially where the latter includes CCS.
- The impact of cleaner coal technologies can be seen by comparing **More of the Same** and **Lags Behind**. These two scenarios are similar in terms of generation cost to just after 2030. The additional costs associated with ultra-supercritical PF technologies up to this year are offset by the higher efficiency of the ultra-supercritical as compared to the supercritical technologies used in **More of the Same**. Post 2034, however, when all new power stations are fitted with CCS under **Lags Behind**, the cost of electricity generation increases significantly, ending higher by 2040 at about 68 cents per kWh in **Lags Behind** as compared to 55 cents in **More of the Same**.
- The indicative electricity generation cost is 15% higher in 2040 in **Low Carbon World** than At the Forefront, due to the high costs of renewables and nuclear capacity.
- The highest uncertainty once again surrounds the costs of construction and O&M of CCS, and those of new ultra-supercritical and nuclear power stations.

3.3.2 Coal export prices and revenues

Revenue from export sales is used as a proxy indicator of contribution of the coal value chain to the economy. This indicator was calculated by multiplying tonnages of coal by the associated selling price (in 2010 Rands).

Coal export prices are assumed to differ per scenario as follows:

COAL EXPORT PRICES

LAGS BEHIND

Coal prices are as projected under the IEA Energy Technology Perspectives' New Policies scenario, representing a world which makes some progress in moving away from coal, and takes account of global policy commitments already made in the form of national pledges to reduce greenhouse gas emissions under the Copenhagen Accord. The IEA projections are to 2035, prices are assumed in SACRM to remain flat thereafter.

LOW CARBON WORLD

Export prices follow the IEA 450 Scenario, which assumes that the world achieves ambitious policy implementation to achieve the upper estimate of greenhouse gas reductions, with the aim of limiting atmospheric concentrations of CO_2e to 450 ppm and global temperature rise to 2 °C.

MORE OF THE SAME

In a world in which demand for export coal remains high, coal prices continue to increase. Here export prices are assumed to follow the trajectory proposed in the IEA "current policies" scenario to 2020, the Woodmac FOB Atlantic price projection to 2030, and remain flat thereafter.

AT THE FOREFRONT

In a world in which demand for export coal remains high, coal prices continue to increase. Here export prices follow the IEA 450 Scenario, which assumes that the world achieves extensive policy implementation to achieve the upper estimate of greenhouse gas reductions, limiting atmospheric concentrations of CO_2e to 450 ppm and global temperature rise to 2 °C. The IEA projections are to 2035, prices remain flat thereafter.

Observations

- Under all of the scenarios, the contribution of thermal and metallurgical coal exports to bringing in foreign revenue grows until 2030, bringing in almost R 120 billion per annum by 2030 in **More of the Same** and R 80 billion in **Low Carbon World** (in 2010 Rands). Thereafter, however, the export revenue declines as mines are closed in the Central Basin. These results do, however, need to be understood in the context of the SACRM assumption that Waterberg mines require a revenue stream from local utility sales to be economically feasible. This stresses the need to explore the possibility of higher-yielding export fractions in dual producing mines and/or export only mines in the Waterberg, should South Africa wish to continue to ensure that coal contributes to earning foreign revenue.
- Assuming the latter is possible, maintaining (or growing) export revenue by unlocking exports from the Waterberg will require sufficient additional water and rail infrastructure being in place by 2030.

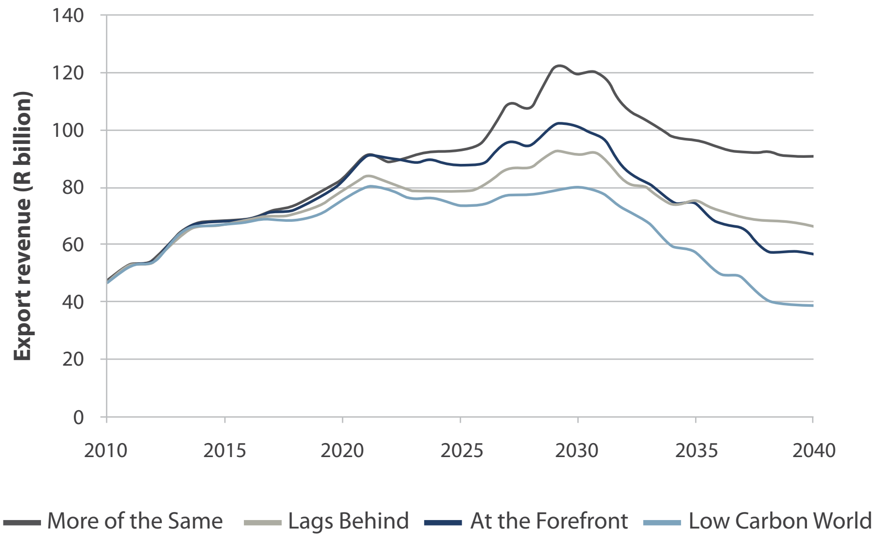

Figure 29: Export sales revenue (metallurgical and thermal coal)

3.3.3 Coal local utility prices and local revenue

Revenue from local sales is seen as a further proxy indicator of contribution of the coal value chain to the economy. This indicator was calculated by multiplying tonnages of coal by a calculated average selling price (in 2010 Rands).

Utility coal from existing mines was assumed to fetch an average price of R 205 per ton in 2010. For projects and new mine developments, a simple mine economic model was used to predict a local utility coal price (per mine) that achieved a 10% IRR (real), given assumed mine establishment costs, costs of production, cost of transport, and projected export revenues.

Based on these assumptions, the local prices that need to be paid by Eskom and other coal-based electricity generators will grow under all scenarios. The higher price of coal in **Low Carbon World** as compared to the other scenarios is attributed to the fact that the under the model assumptions comparatively little coal from the Waterberg is used for power generation in **Low Carbon World**. Under the model assumptions, Waterberg coal is also substantially cheaper than Central Basin coal, bringing down the average under the other three scenarios.

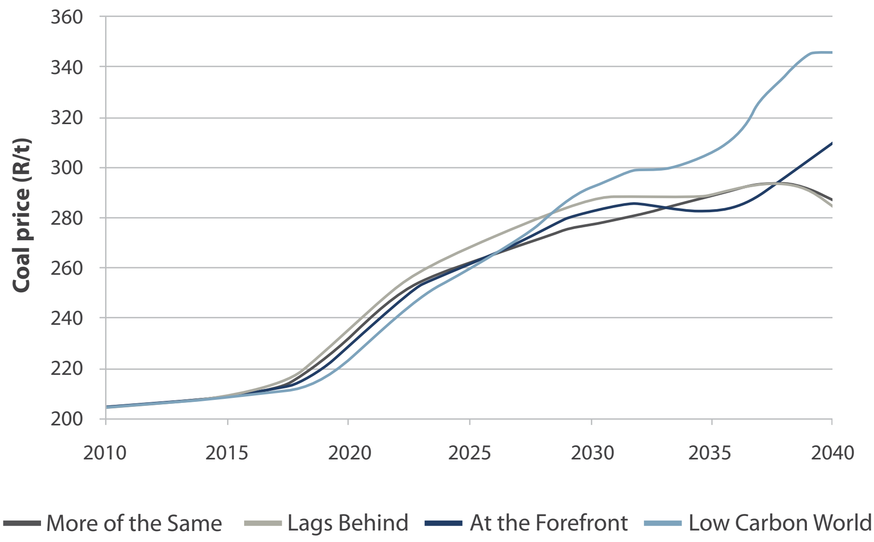

Figure 30: Five year rolling average price of coal sold to Eskom

Local sales revenue (for thermal coal for electricity generation and other uses) reflects trends in coal demand and the price of coal.

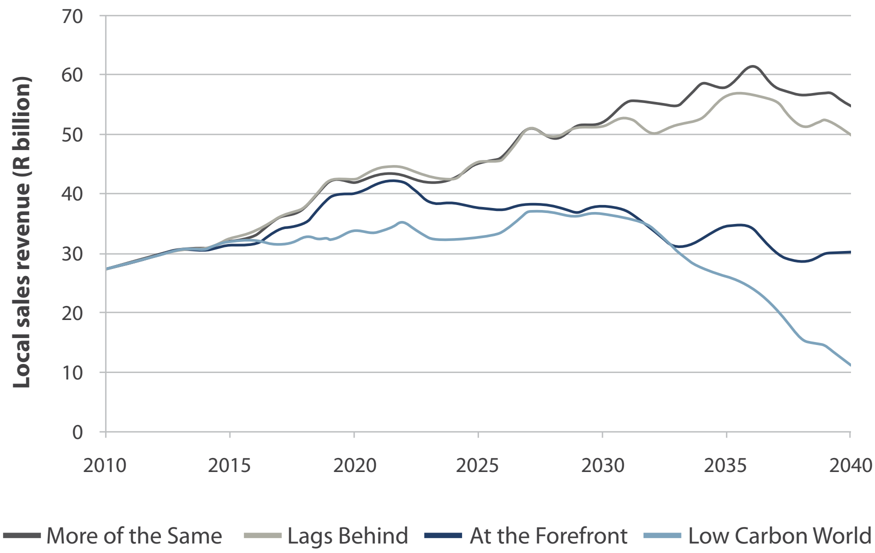

Figure 31: Local sales revenue (utility coal only)

3.3.4 Competitiveness

COMPETITIVENESS

LAGS BEHIND South Africa's export markets could be heavily penalised due to the continued coal intensity of the economy, given the global drive away from coal towards lower carbon energy sources. This penalty could be in the form of border tax adjustments on export products.	**LOW CARBON WORLD** South Africa's efforts to reduce greenhouse gas emissions should ensure a place in the global export markets, as the world decarbonises.
MORE OF THE SAME South Africa remains competitive globally. There is no pressure to reduce dependence on coal, and markets and prices for coal exports remain strong.	**AT THE FOREFRONT** South Africa does not gain any global competitiveness benefits from diversification of its energy supply, except in the case of trade with a select few countries that continue to pursue a low carbon trajectory.

3.3.5 Climate change adaptation costs

In all scenarios there are likely to be significant costs associated with adapting to climate change and its associated impacts in the form of extreme weather events (floods, droughts and heat waves) as well as impacts on water resources, agriculture (and hence food security), forestry, human health etc.

The extent of climate change and consequent impacts and the associated costs, including those for the coal value chain depend primarily on global efforts at mitigation of greenhouse gas emissions (as South Africa is a relatively small emitter as compared to the world's major emitters). On this basis, impacts and the consequent adaptation costs are expected to be lower in **Low Carbon World** and **Lags Behind**, where global action is taken on climate mitigation, than they are in **More of the Same** and **At the Forefront**, where greenhouse gas emissions globally continue unabated. The timing of action is critical to determining the scale of impacts and adaptation costs: early action may imply a greater upfront cost, but will reduce adaptation requirements down the line. Delayed action will in turn result in a need for greater investment in adaptation and in dealing with the costs of impacts.

The actual cost of adaptation is uncertain and will be highly localised. Globally indicative adaptation costs are estimated to be in the order of ten to hundreds of billions of dollars per year.

3.4 Energy Security

Energy security refers to the ability to maintain uninterrupted availability of a country's main energy sources at an affordable price. Two key factors are suggested to be important in this regard, being reliance on local resources as opposed to energy imports, and technology related considerations.

ENERGY SECURITY

LAGS BEHIND	LOW CARBON WORLD
Primarily reliant on local coal, with small reliance on imports (gas, hydro and coal). Reduced reliance on foreign crude oil with one new CTL plant.	Primarily reliant on local coal in the near term with increasing reliance on nuclear and renewables. Strong reliance on processing nuclear fuel overseas, increased local fuel processing would increase security. High reliance on foreign companies to service nuclear plants, and increasing competition for nuclear skills in a low carbon world. Fair reliance on gas, which if imported, offers less security. Increased global competition for skills and foreign companies servicing renewable plant, with reduced security unless SA develops the necessary capacity early.
MORE OF THE SAME	**AT THE FOREFRONT**
Primarily reliant on local coal, with small reliance on imports (gas, hydro and coal). Reduced reliance on foreign crude oil with two new CTL plants.	Primarily reliant on local coal, with fair reliance on imports (hydro and coal). Some reliance on processing nuclear fuel overseas, increased local fuel processing would increase security. Some reliance on foreign companies to service nuclear plants. Increased global competition for skills and foreign companies servicing renewable plants, with reduced security unless SA develops the necessary capacity early.

3.5 Employment and broader socio-economic implications

3.5.1 Employment in construction of power stations and CTL plants

The jobs created in construction of power stations and CTL plants across scenarios is presented in the Figure below.

Notable here is the jobs associated with the intensive build of solar CSP and wind under **Low Carbon World** between 2014 and 2021. Supplying this level of skilled employees within the relatively short term in South Africa could well present a substantial challenge.

A further concern here is availability of skilled personnel for building of nuclear power stations under **At the Forefront** and **Low Carbon World**. An estimated 96,100 FTE-years of employment is created between 2010 and 2030 under **At the Forefront** and 122,000 FTE-years of employment under **Low Carbon World** in construction of nuclear power stations alone. There is reportedly a global shortage of skilled people to build nuclear power stations, so sourcing skills could be challenging.

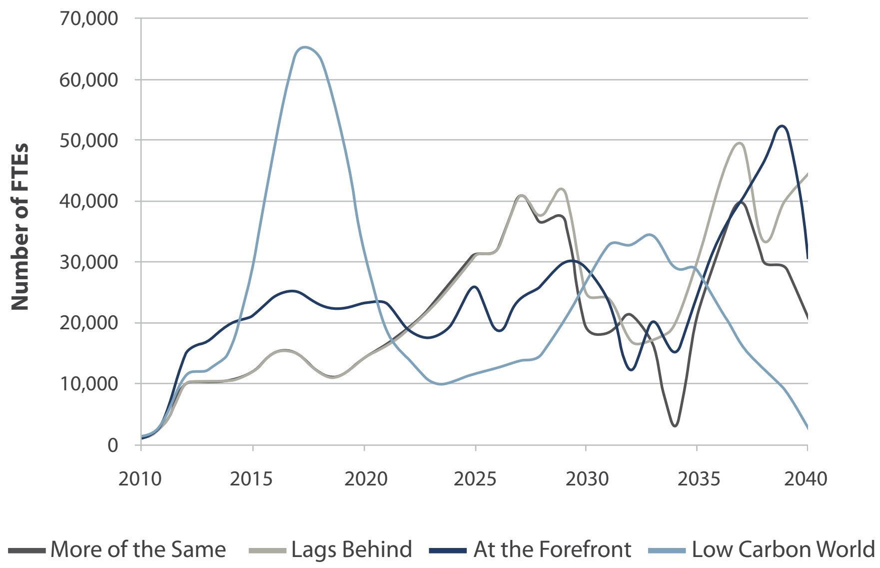

Figure 32: Construction jobs across the scenarios for power stations and CTL

3.5.2 Employment in operation of mines, power stations and CTL plants

Total employment for the operational phase of mines, power stations and CTL plants are shown below. These figures show the overwhelming dominance of mining jobs in determining the overall employment profile for the coal value chain, and that almost 35,000 more jobs are created by 2040 in the coal dominant **Lags Behind**, as compared to **Low Carbon World**. Once again, these employment figures exclude indirect employment. Furthermore, they do not make allowance for any decreases in employment intensity of mining due to increased mechanisation, which may well reduce the contribution of mining to employment.

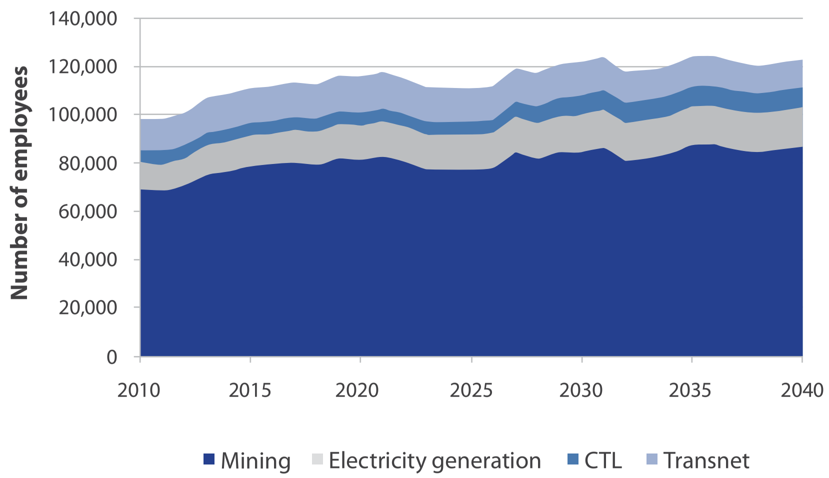

Figure 33: Total employment (Lags Behind)

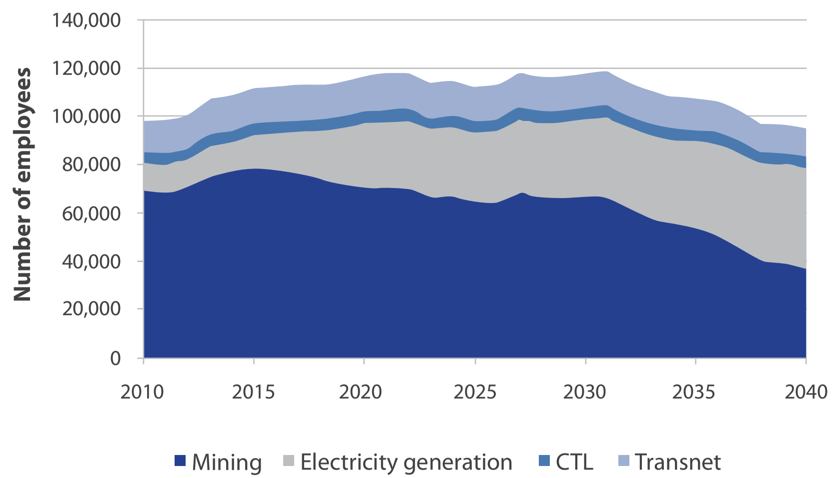

Figure 34: Total employment (Low Carbon World)

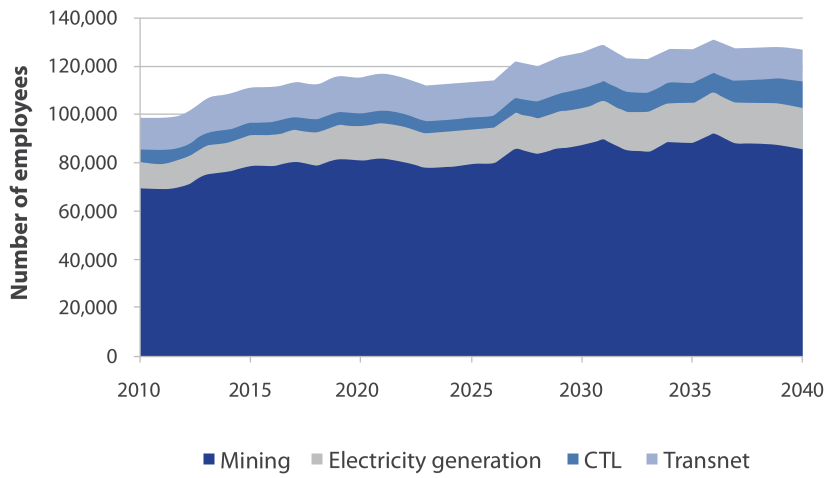

Figure 35: Total employment (More of the Same)

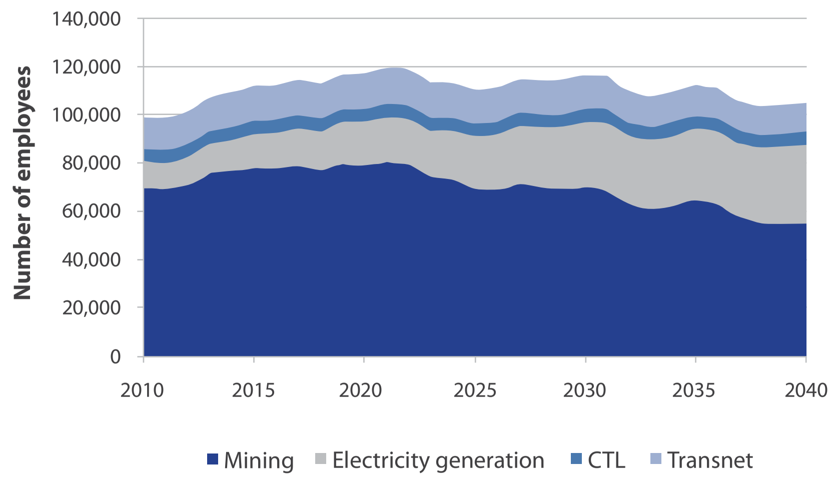

Figure 36: Total employment (At the Forefront)

3.5.3 Broader socio-economic considerations

- Indirect employment: a vast array of material and service inputs supporting the coal value chain would no longer be required in the case where coal production reduces (**At the Forefront** and **Low Carbon World**). However, at the same time new opportunities open up in these scenarios through development of a renewables and nuclear sector.
- Localisation of socio-economic impacts: **More of the Same** and **Lags Behind**, which will involve development of mines, power stations and CTL plants in the Waterberg, will contribute to economic growth in these areas, with an increase in the sizes of communities in these areas. At the same time, effective planning is required to ensure that suitable facilities are established in these areas to support growing communities.
- Impact of mine and power station closure: Provision also needs to be made for the post-2030 period in Mpumalanga, when many mines are closed and power stations are decommissioned, potentially resulting in significant unemployment in this region. Strategic planning is required to ensure that interventions such as relocation of employees to the Waterberg (in **More of the Same** and **Lags Behind**) and reskilling of employees contribute to minimising this impact.
- The environmental costs of mining and coal-fired power generation to the economy and society have not been quantified in this study.

3.6 Water demand

Given the importance of water demand at a regional level rather than a national level, water demand (from mining, electricity generation and CTL) is presented separately for the Central Basin and in the Waterberg in the graphs below.

3.6.1 Water demand in the Central Basin

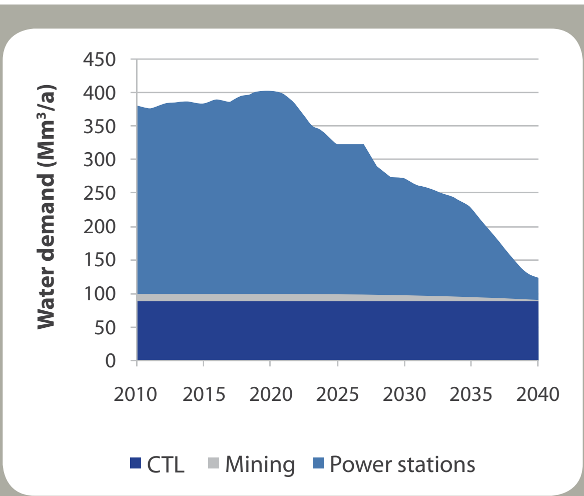

Figure 37: Water demand in Central Basin (Lags Behind)

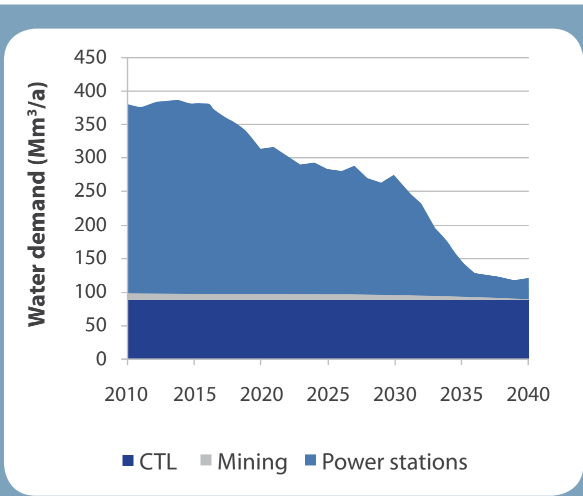

Figure 38: Water demand in Central Basin (Low Carbon World)

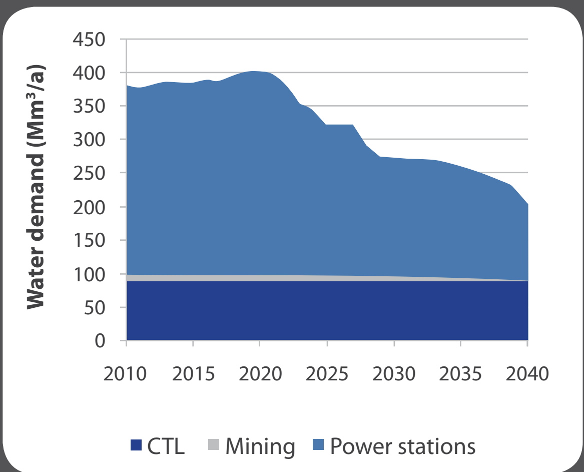

Figure 39: Water demand in Central Basin (More of the Same)

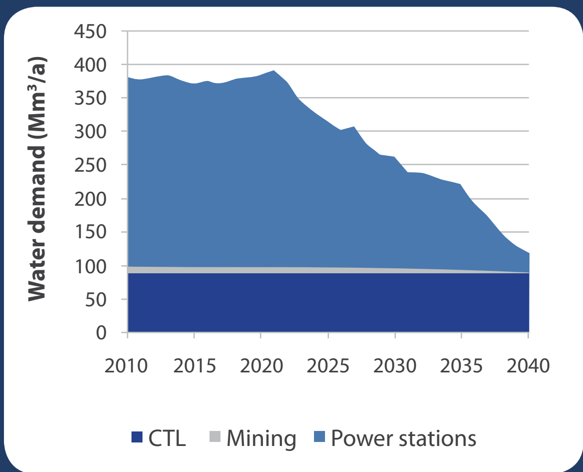

Figure 40: Water demand in Central Basin (At the Forefront)

Observations

- Water demand for CTL stays constant at 88 Mm³/a (and represents around a fifth of total water demand from the coal value chain in the Central Basin in 2010), increasing to between 43% and 73% of total water demand for the value chain in 2040 in that coalfield depending on the scenario, because of declining water demand for electricity generation as coal-fired power stations are decommissioned.
- Water demand for mining contributes around 5% to the total in 2010. Demand peaks in 2020, after which it declines to between 15% and 30% of 2010 levels by 2040, depending on the scenario.
- Water demand for the coal-fired power stations dominates water demand in the Central Basin currently, but declines steadily over the period as power stations are decommissioned, the rate of decline depending on the particular scenario.
- Water demand is highest in **More of the Same** at the end of the period due to the extended life of power stations in the Central Basin.

3.6.2 Water demand in the Waterberg

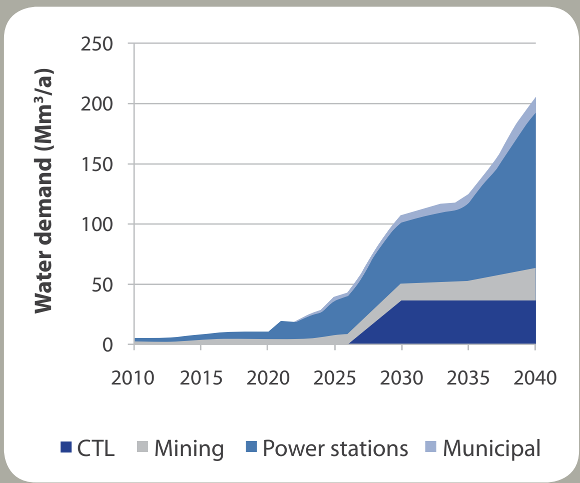

Figure 41: Water demand in the Waterberg (Lags Behind)

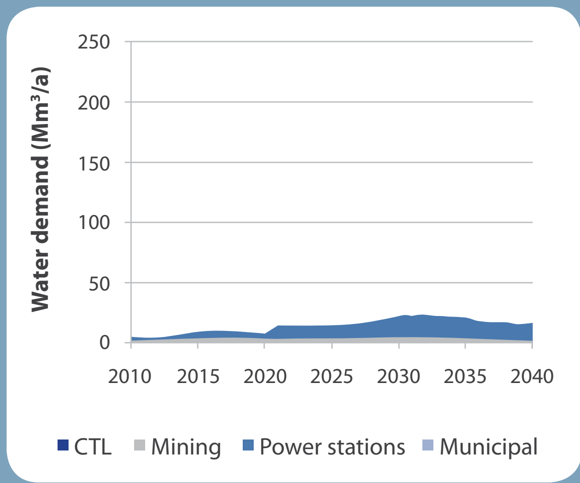

Figure 42: Water demand in the Waterberg (Low Carbon World)

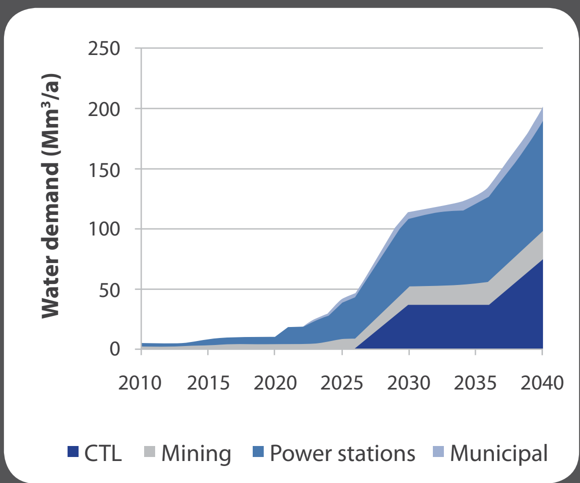

Figure 43: Water demand in the Waterberg (More of the Same)

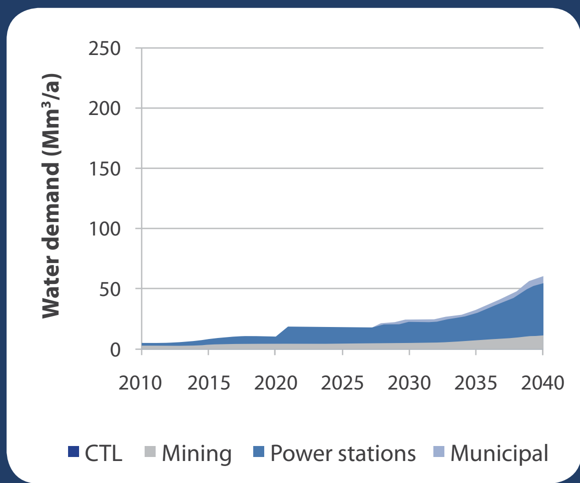

Figure 44: Water demand in the Waterberg (At the Forefront)

Observations

- **More of the Same:** water demand for electricity generation, mining and CTL ramp up somewhat proportionally to levels comparable to just over half of 2010 water demand in the Central Basin.
- **Lags Behind:** water demand for electricity generation, mining and CTL ramp up somewhat proportionally up to 2030, when new power stations coming online are fitted with CCS, causing an increase in water demand for electricity generation.
- **At the Forefront:** relatively low water demand in the Waterberg, with no CTL component. The retrofit of FGD to Medupi causes a noticeable increase in water demand but levels are low compared to other scenarios.

- **Low Carbon World:** very low water demand compared to the other scenarios with no additional water required beyond the needs of Matimba and Medupi power stations.

Observations in overall water demand

- The decline in water demand in the Central Basin is taken up by new water demand in Waterberg under **More of the Same** and **Low Carbon World**.
- Overall water demand declines slightly between 2010 and 2040 even with the substantial increase in power generation capacity as the water intensity of electricity generation falls by at least 66% in all scenarios.
- CCS increases water demand when applied to power stations, and from a water demand point of view CCS is far better suited to CTL. Nonetheless, electricity generation in **Lags Behind** still has a lower water intensity than **More of the Same** due to its more efficient ultra-supercritical power stations.

3.7 Infrastructure

Development of appropriate transport infrastructure is critical both to transport export coal to the markets, and to ensure supply of coal to power stations and other industrial users. Here, consideration is given here to:

- RBCT port capacity and rail capacity on the rail line from the Central Basin to RBCT; and
- Capacity on the Waterberg line to transport coal for use in Central Basin power stations, and for exports via RBCT.

In addition, water supply infrastructure is likely to be required to support developments in the Waterberg and is discussed here.

3.7.1 Port capacity and rail capacity on the RBCT line

Figure 13, showing South African exports, is repeated in Figure 45, with the addition of lines indicating a possible evolution of the port capacity at RBCT and capacity on the Central Basin to RBCT rail line. The latter two lines were developed based on the Transnet 2013 National Infrastructure Plan, as well as personal communication with individuals at Transnet.

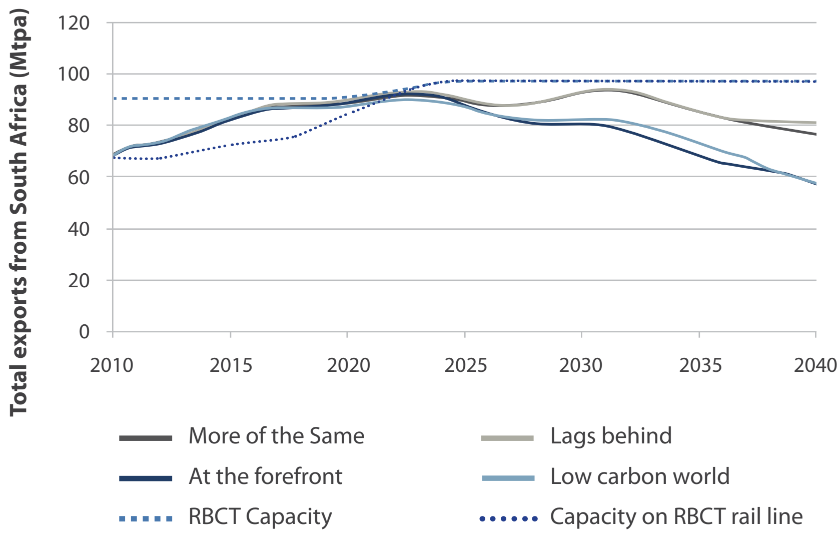

Figure 45: Total coal exports (5 year rolling average) showing evolution of infrastructure to RBCT

Observations

- Given that not all exports are transported through RBCT (with small amounts exported through Matola, the Richards Bay dry bulk terminal and Durban), there is likely to be sufficient port capacity in South Africa for exporting coal, even without the expansion of RBCT or Matola.
- There is, however, potential for stranded port and rail infrastructure after about 2032, unless existing capacity is used for export of other bulk commodities or the potential of the Waterberg as a viable source of exports is realised.
- It is thus critical that the justification for expansion of the port facility at Matola be fully explored, unless this facility is intended to process coal from other countries such as Botswana and Mozambique.
- The challenge to South Africa in achieving the levels of exports predicted under the four scenarios relates to the on going limitation in provision of rail infrastructure to transport coal from the Central Basin to RBCT, rather than port capacity. Even with Transnet's planned upgrade to this line, exports will still be constrained by rail infrastructure limitations at least until the early 2020's,

while it appears the planned expansion may be excess to requirements as soon as it is commissioned unless export-only mines from the Waterberg prove viable. Both the immediate need for rail infrastructure and the potential misalignment between proposed investment and long-term export levels need to be urgently addressed.

It is reiterated that the coal export projections are based on assumptions about allocation of coal to Eskom in the Central Basin, that future mines open on time and at the capacities captured in the models, that local non-Eskom demand remains strong and that Waterberg mines need to produce a low-grade utility coal in addition to exports to operate profitably. If any of these assumptions do not hold, the above picture will change. In particular, if the country wishes to continue to substantially grow exports or reduce the risk of coal shortfalls against planned export infrastructure capacity, the feasibility of establishing export only mines in the Waterberg needs to be explored.

3.7.2 Coal transport on the Waterberg to Central Basin line

To reduce supply risks of high-grade coal, coal needs to be transported from the Waterberg to Central Basin for supply to Eskom power stations, as well as for export coal to be transported onwards to RBCT.

Observations

- Under the assumptions made in the SACRM scenarios and from a purely resource-supply point of view, coal is only required to be transported from the Waterberg to the Central Basin power stations under **More of the Same**, from after 2035, where 4 Mtpa will be required in 2035, rising to about 10 Mtpa in 2040. Under the other scenarios, supply from the Central Basin is sufficient to sustain the existing power stations over their lifetimes. However, supply options are very constrained from 2025, and managing to meet the demand of the Central Basin power stations will require that all of the Central Basin mines are opened on time, to the capacities and qualities specified in the SACRM study, and to the markets allocated (i.e. to supply Eskom and not to supply other local users or exports). Already it appears that some of these projects are not on track to being operational by the time coal is required by Eskom. Thus from a risk and cost point of view, provision should be made for transport of coal from the Waterberg to Central Basin from the early 2020s in all scenarios other than **Low Carbon World**.
- The need for new rail infrastructure from the Waterberg to support access to export markets differs between the scenarios. Under **More of the Same** and **Lags Behind**, as new power stations are opened in the Waterberg, the volume of exports that is produced in multi-product mines will rise, with the new capacity being planned by Transnet starting to be required by 2017. The currently planned capacity will be exceeded by the late 2020s, after which new capacity is required to support exports. If this infrastructure is also required to transport coal to Central Basin power stations as seems possible, the capacity on this rail line will be exceeded by 2025 at the latest, and additional upgrades on the RBCT line will be required earlier.
- Under **At the Forefront** and **Low Carbon World**, export levels from the Waterberg are significantly lower, reaching a peak of just over 10 Mt per annum under **At the Forefront** and then declining. New coal transport infrastructure built from the Waterberg to the Central Basin coalfields would thus need to be carefully considered, to avoid it becoming a stranded asset. Under **At the Forefront**, the currently planned upgrade would be required to transport coal from the Waterberg to the Central Basin power stations from the 2020s, although the planned capacity of the line could be reduced. Under **Low Carbon World** the upgrade is not required. However, under these two scenarios the development of export only mines in the Waterberg are essential to maintaining South Africa's coal export revenues and to avoiding port capacity becoming stranded. Should export only mines become economically feasible in the Waterberg, then the upgrade on the Waterberg rail line will be required to get this coal to market. Thus even in **Low Carbon World** there is a reasonable possibility that the upgrade will still be required, but only from the 2030s.

Overall, transport requirements are found to differ substantially between scenarios and to be highly assumption dependent. Early strategic planning is thus required to ensure that there the country does not over- or under-invest in transport infrastructure..

3.7.3 Water supply infrastructure

Water demand in the Central Basin is the same across all scenarios and it is assumed that this can be met with existing infrastructure, although with the recognition that the water catchments in this area are already under considerable stress.

Water demand in the Waterberg is considerable in **More of the Same** and **Lags Behind** (220 and 240 Mm^3/a, respectively by 2040), as compared to **Low Carbon World** and **At the Forefront** (approximately 20 and 60 Mm^3/a, respectively by 2040). To meet this water demand will require significant infrastructure, particularly through pipelines to allow inter-basin transfers. The significant issue is largely one of cost and who finances the required water supply infrastructure. Water supply to the Waterberg is likely to rely on transfers from the Upper Vaal to meet the demand, although there is the potential for knock-on effects in other catchments supplying the Upper Vaal.

3.8 Contribution to greenhouse gas emissions

Greenhouse gas emissions from the use of coal in South Africa make up approximately 60% of South Africa's total emissions of 510 to 520 Mt CO_2e per annum. The greatest single contributor (229 Mt CO_2e per annum) is from coal power generation, followed by 46.7 Mt CO_2e per annum from CTL. Understanding how future GHG emissions could evolve is therefore important, particularly in light of the stated intention in South Africa's National Climate Change Response White Paper to reduce national greenhouse gas emissions to 2050.

3.8.1 GHG emissions and GHG intensity of electricity generation

Annual greenhouse gas emissions from power generation, expressed both in terms of total emissions and as an emissions intensity, are shown below.

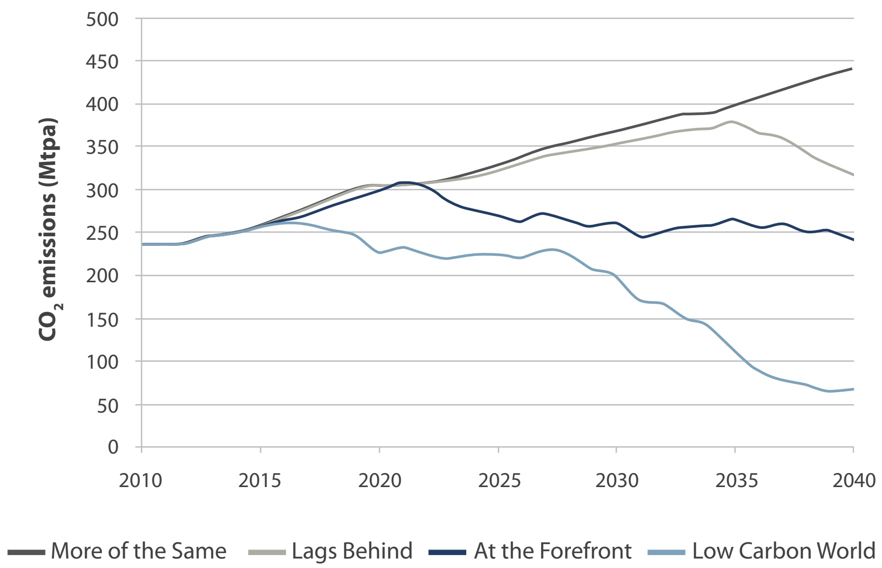

Figure 46: CO_2 emissions from electricity generation

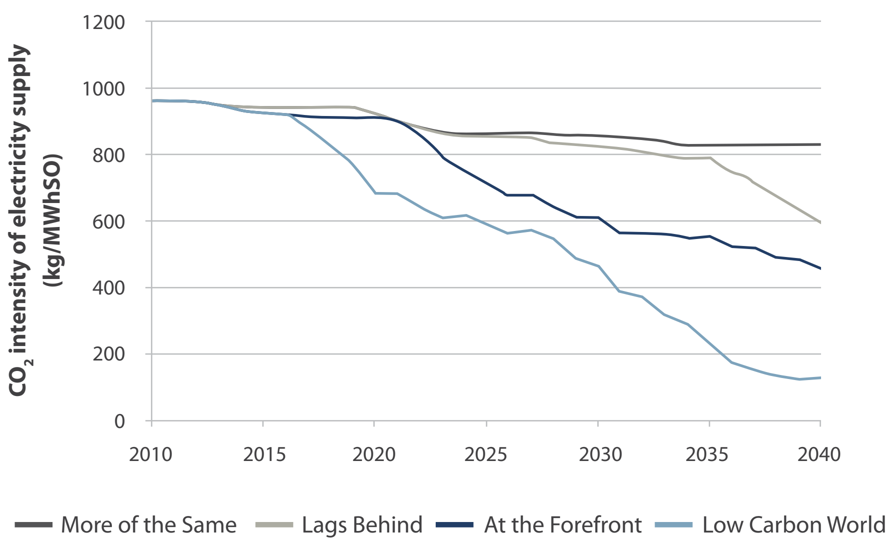

Figure 47: CO_2 emissions intensity from electricity generation

Observations: CO_2 emissions from electricity generation

- In terms of contributing to South Africa's commitment to follow a peak, plateau and decline trajectory of GHG emissions between now and 2050, it seems likely that **More of the Same** and **Lags Behind** will cause the country to deviate from this trajectory after about 2025 (assuming electricity generation retains its share of the remaining emissions space).
- **At the Forefront** will likely fall within the trajectory to 2035, although will begin to exceed emissions during the decline period post 2035.
- Only **Low Carbon World** affords the possibility of remaining within the proposed emissions trajectory.

Observations: CO_2 emissions intensity

- All scenarios show a reduction in emissions intensity as old power stations are replaced by new, more efficient power stations.
- The scenarios in which coal-fired power generation dominates (**More of the Same** and **Lags Behind**) are, as expected, more CO_2 intensive than **At the Forefront** and **Low Carbon World** – with the former diversifying electricity supply and the latter building no further coal-fired power stations.
- The impact of installing CCS on power stations built from 2034 under **Lags Behind** in helping to reduce emissions can clearly be seen, as can the impact of retrofitting Medupi and Kusile with CCS in **Low Carbon World.**

3.8.2 GHG emissions from CTL

- These are lowest in Low Carbon World, where no additional CTL plants are built, whilst the CCS retrofit to Secunda decreases emissions from CTL to 23 Mt per annum from 2025.
- CTL emissions are highest in More of the Same, with two new CTL plants and no CCS resulting in total GHG emissions from CTL of 93 Mt per annum from 2028 for this scenario.

3.9 Environmental implications

3.9.1 Water provision, land and biodiversity

WATER, LAND AND BIODIVERSITY IMPLICATIONS

LAGS BEHIND

Extensive mining in Central Basin, with associated impacts on already stressed catchments, biodiversity in the grasslands biome and air quality. Impacts primarily from surface mines, potentially exacerbated towards 2040 – lower resource quality leading to larger discard dumps, and lower outputs potentially leading to eroding buffers preventing spontaneous combustion.

Mining in the Waterberg leads to extensive surface disruption, with associated impacts on water catchments in an already water-scarce region and disruption to sour bushveld habitats. Considerable discard dumps and spoil heaps with potential for spontaneous combustion.

LOW CARBON WORLD

Impacts associated with extensive mining in Central Basin as for **Lags Behind**, with pressures towards 2040 reduced due to early decommissioning of power stations.

Large land requirements for wind, solar and nuclear, with potentially large opposition from public for siting. Land footprints extensive but without the associated water and biodiversity impacts of mining.

MORE OF THE SAME

Impacts associated with extensive mining in Central Basin as for **Lags Behind**.

Mining in the Waterberg leads to extensive surface disruption, with associated impacts on water catchments in an already water-scarce region and disruption to sour bushveld habitats. Considerable discard dumps and spoil heaps with potential for spontaneous combustion.

AT THE FOREFRONT

Impacts associated with extensive mining in Central Basin as for **Lags Behind**.

Large land requirements for wind, solar and nuclear, with potential opposition from public for siting. Land footprints extensive but without the consequent water and biodiversity impacts of mining.

3.9.2 Waste generation

Spoils and discards produced during mining and beneficiation are the major sources of solid wastes on mines. The former is only a consideration in surface mines, whilst the latter are a by-product of coal washing. Discard is quantified in the models based on washing yields.

Four categories of solid wastes from electricity generation were considered in the scenario models:

- Ash (fly ash and bottom ash from PF and FBC)
- Solid waste from flue gas desulphurisation
- High level nuclear waste (spent fuel)
- Low/intermediate level nuclear waste

SOLID WASTE IMPLICATIONS

LAGS BEHIND	LOW CARBON WORLD
Large land footprint, and potentially also high salinity effluent, associated with managing large volumes of solid waste: 1.7 billion tonnes tons of discard produced in the Central Basin between 2010 and 2040, and 3.4 billion in the Waterberg due to low yielding Waterberg coals; 1.6 billion tonnes of ash produced between 2010 and 2040 as new-build power stations burn poor quality coal with high ash content; 84 million tonnes of potentially saleable gypsum from FGD waste. In addition to land requirements, discard management poses land sterilisation and spontaneous combustion risks.	Lowest volumes of solid waste overall with no new mines or power stations in the Waterberg after Medupi, but highest cumulative discards in Central Basin (at 1.8 billion tonnes in 2040 due to producing more for export towards 2040 than the other scenarios). Lowest levels of ash and FGD wastes, although waste management impacts still appreciable with 1.0 billion tonnes ash and 30 million tonnes FGD waste produced between 2010 and 2040. Concern over management of nuclear waste and especially the lack of a dedicated high-level nuclear waste storage facility in SA: 34 million tonnes low/intermediate level nuclear waste and 9,600 tonnes high-level waste produced between 2010 and 2040
MORE OF THE SAME	**AT THE FOREFRONT**
Large land footprint, and potentially also high salinity effluent, associated with managing large volumes of solid waste: 1.7 billion tonnes tons of discard produced in the Central Basin between 2010 and 2040, and 3.4 billion in the Waterberg due to low yielding Waterberg coals; 1.7 billion tonnes of ash produced between 2010 and 2040 as new-build power stations burn poor quality coal with high ash content; 84 million tonnes of potentially saleable gypsum from FGD. In addition to land requirements, discard management poses land sterilisation and spontaneous combustion risks.	Low discards overall as only modest growth in the Waterberg and the highest installed capacity of FBC power stations (and so the highest use of discard), resulting in cumulative discards of 1.5 billion tonnes in the Central Basin in 2040). Intermediate levels of ash and FGD wastes, with waste management impacts still a concern at 1.3 billion tonnes ash and 41 million tonnes FGD waste produced between 2010 and 2040. Concern over management of nuclear waste and especially the lack of a dedicated high-level nuclear waste storage facility in SA: 27 million tonnes low/intermediate level nuclear waste and 7,900 tonnes high-level waste produced between 2010 and 2040.

3.9.3 Non-GHG emissions

Other emissions to air associated with electricity generation and considered in the scenario models included SO_2, NO_x and particulates.

NON-GHG EMISSIONS FROM ELECTRICTY GENERATION

LAGS BEHIND	LOW CARBON WORLD
SO_2 emissions peak in 2020, and then decline 70% by 2040 (compared to 2010 levels) as older power stations are decommissioned and replaced by power stations with FGD, with the extensive drop after 2030 due to CCS installed on new power stations. The lower NO_x emissions intensity of new ultra-supercritical power stations allows NO_x emissions to remain constant, even with increasing installed capacity. Particulate emissions decline by 25% between 2010 to 2040 indicating the improved particulate collection efficiency and higher thermal efficiency of the new-build ultra-supercritical power stations.	SO_2 emissions decline to 90% of current levels by 2040, and NO_x and particulates decline by more than 75% of current levels by 2040, as power stations are decommissioned and replaced by nuclear and renewables with much lower emissions intensities. The higher drop in SO_2 emissions relative to emissions of NO_x and particulates can be attributed to the retrofit of CCS to Medupi and Kusile.
MORE OF THE SAME	**AT THE FOREFRONT**
SO_2 emissions peak in 2020, and then decline 37% by 2040 (compared to 2010 levels) as older power stations are decommissioned and replaced by power stations with FGD, allowing a drop in SO_2 emissions even with increasing installed capacity. NO_x emissions increase by 18% between 2010 and 2040 as the new-build supercritical power stations have only marginally better NO_x emissions intensity than the older stations they are replacing. Particulate emissions increase slightly (6%) between 2010 and 2040 as the improved particulate collection efficiency of the new-build power stations are countered by the higher-ash Waterberg coals.	SO_2 emissions increase slightly to 2020, and then decline 70% by 2040 (compared to 2010 levels) as older power stations are decommissioned and replaced by new power stations with FGD, FBC with in-situ desulphurisation and nuclear and renewables. For the same reason, NO_x emissions decline 44%, and particulate emissions by 54% between 2010 and 2040.