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Coal transitions in South Africa

Understanding the implications of a 2ºC-compatible coal phase-out plan for South Africa

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Executive summary

South Africa is highly coal and energy intensive, and has an economy characterized by extremely high levels of inequality and poverty (with more than half of the population living in poverty. In the long run, sustainable growth and development in South Africa will depend crucially on the transition away from a coal-intensive energy system and economy. This study has examined the challenges already facing the coal sector and highlights the risks of a development strategy that continues to rely on the sector for energy security, employment, and growth. Nonetheless, mitigating the effects of the energy and coal transition on vulnerable workers and communities means understanding the challenges already facing the sector, planning to make the transition one that is just for workers and communities in coal-dependent areas, and implementing strategies for the country to diversify into new sectors and maximise employment.

The difficulty of the transition is exacerbated by South Arica's very high dependence on coal for energy and coal's role in the economy in general and Mpumalanga in particular. At the same time, the coal sector is already facing challenges and crises due to cost increases, energy security risks, export demand risks, and low local demand growth. These are already having profound implications for South African electricity consumers. For example, Eskom's primary energy costs have increased by 300% in real terms over the past 20 years. The large increases in Eskom's primary energy costs have, along with cost overruns at new coal fired plants under construction, contributed to rapidly increasing electricity prices that have put Eskom, and the economy, under increasing pressure. Demand for electricity has thus stagnated over the past decade even as Eskom continues to bring new coal-fired generating capacity online. At the same time, new renewable capacity is now considerably cheaper on a levelised cost and system basis than either new Eskom coal-fired power plants (under construction) or proposed privately owned coal plants (CSIR, 2016; Steyn, Burton, & Steenkamp, 2016).

From an employment perspective, coal mining employment peaked in 1981, and has declined as mines have increasingly mechanised their operations. The sector employs far fewer workers than in the past, and has become more skills-intensive over the past 20 years. Around half of the coal mining workforce is unskilled, and the trend has been towards higher numbers of skilled and semi-skilled workers. This could be exacerbated as mining technology develops and autonomous mining becomes the norm. There is already an employment crisis in mining in general and coal mining in particular that requires intervention from the state to manage and resource.

The scenarios

The study examines three future pathways for South Africa's coal sector that allow us to assess key risks and opportunities in South Africa's coal transition. First, we examine a least-cost energy pathway that assumes no climate change mitigation policy is implemented beyond a gradual phase down of coal power as stations reach the end of their lives or become uncompetitive with new generation technologies. In this scenario, South Africa meets its nationally determined contribution (NDC) under the Paris Agreement in 2025 and 2030, and also achieves average annual GDP growth of 3.3%.

The largest users of coal are the electricity and liquid fuels sectors, where alternative supply options and mitigation costs are also considerably lower than in end-use sectors such as industry. As our results show, meeting South Africa's NDC is possible through decarbonising electricity and liquid fuels, but without large scale mitigation in the industrial sector. By 2050, wind and solar PV provide 71% of electricity.

The trend is towards higher growth in the electricity sector, And this is also reflected in the employment numbers, where the net job effects in the electricity sector are positive, even as the number of workers employed in coal plants decreases as stations are decommissioned (since only Medupi and Kusile are online in 2050).

Employment in coal mining decreases

by 28,200 workers by 2050, relative to 78,000 workers in 2015. The impact on total coal mining employment is limited by the increased use of coal directly by the industrial sector, which grows over the period. However, overall, coal production in the NDC scenario declines by 1.1% per year between 2017 and 2050 in a least cost energy pathway for South Africa. This points that there is a need for planning for South Africa's due to the relative economics of new supply options alone. Even with limited implementation of climate change policy, coal is no longer South Africa's future.

Compatibility with 2oC will require large scale and rapid switching away from coal in the electricity sector and liquid fuels sectors, and also requires industrial fuel switching. Meeting the low-PPD emission budget to 2050 results in the installation of substantially more renewable energy in the electricity sector, where, because of its lower cost, most mitigation still takes place. By 2040, the share of coal in the electricity sector is zero with both Medupi and Kusile coming offline before then. Unlike the older coal plants that are surplus in the 2020s but have been paid off, Medupi and Kusile will only be online by 2022, and their retirement by 2040 results in both economic and technical stranding of the stations. Given this, calls for the last 2 units of Kusile not to be completed make economic sense given South Africa's climate mitigation policy commitments and the need for least-cost mitigation planning.

By 2050, solar PV and wind make up 80.2% of electricity generated, and gas 16% (with hydro 1.3%, and imports 1,5%). As in the NDC scenario, industrial use of coal increases, making industry the largest emitter of GHG emissions by 2050. The sector grows slightly more slowly than in the NDC scenario (0.3% lower on average per year, or 3.6% average annual growth. By 2050, employment in the coal mining sector has decreased to just below 30,000 jobs, as a more rapid transition away from coal in the electricity sector takes place.

Implementing NDCs

South Africa's NDC pathway described above, although it is a least cost energy pathway to 2050, is unlikely be achieved unless several conditions are met. While a least cost energy pathway is consistent with the upper range of South Africa's NDC, it will require policy and planning to implement, in particular if South Africa aims to achieve the lower range.

Firstly, it depends on the release of a least-cost integrated resource plan. An IRP that includes new coal-fired power stations is not consistent with a least cost electricity plan, nor is it consistent with South Africa meeting the lower range of its NDC and low-PPD. Indeed, South Africa will exceed the lower range of the NDC even if it does not build new coal plants. The inclusion of either new coal plants or the life extension of older plants in the IRP will not only prevent South Africa from achieving the low range of its NDC (398 Mt CO_2-eq in 2025-2030), but will potentially raise greenhouse emissions to a level that exceeds the upper range of the NDC in 2025.

South Africa will already exceed the lower end of the NDC commitment range in 2025 and 2030. The inclusion of new coal-fired power, for example the planned coal IPPs Thabametsi and Khanyisa, or the full new coal capacity envisaged in the IRP 2010, would further reduce the likelihood that the country could move towards the low range of its NDC (and thus it's PPD).

At the same time, an IRP should explore the implications of allowing coal-fired power plants to retire because they are surplus to capacity needs, no longer economic to run, or cannot be environmentally compliant. This is also necessary to understand the rate of South Africa's coal transition even without climate change mitigation policy. In previous iterations of the IRP, the plants were committed to run for 50 years, but as we have seen, it is already feasible from both an economic and energy security perspective to retire some plants due to their high costs (Steyn, Burton, Steenkamp, 2017).

Secondly, unless credible plans to support workers at coal plants and communities in coal areas are put in place, achievement of the NDC will elude South Africa. Already, calls have been made by Eskom and organised labour to keep stations open longer because of their socio-economic importance to towns in Mpumalanga. Eskom faces plants closing and a financial crisis that already means that retrenchments are likely to happen in the coming years, but it has no plans for decommissioning plants or for retraining, reskilling, and supporting workers to migrate to other stations or into new industries.

Even without any climate policy impacts, the closures of power plants are inevitable, and worker retraining, reskilling, and regional development initiatives are required to ease the transition and mitigate the closures of stations in Mpumalanga. The potential risks placed on workers by increasing productivity through autonomous mining could have severe impacts on employment in the coal-mining sector.

Opportunities and challenges

As we have shown, the current state of the coal sector, both coal-fired electricity and coal mining, is one of crisis, with rising costs and energy insecurity, and coal becoming increasingly less competitive for electricity.

A number of myths about the coal sector are debunked: that coal is cheap, that it employs vast numbers of people and that those people are unskilled. Coal is no longer a cheap and bountiful resource that can ensure security of supply for Eskom power plants. As the trends already show, closures (of plants and mines) are inevitable—the question is not if closures will happen, but when. South Africa is already facing a coal transition.

The economic results show that it is possible to both meet climate change targets and grow the economy. The large investment in new renewable energy will also have positive spin-offs for the country, including net positive employment impacts in the electricity sector.

While the net job effects of a large scale rollout of RE are positive, there are risks for workers at coal-fired stations, mines, and the communities that depend on these assets if there is no orderly and properly resourced transition.

Overall, a transition away from coal is accompanied by many benefits, including cheaper electricity, improvements in air quality, and fewer impacts from extraction. Nonetheless, the concentration of coal fired stations and upstream mines in the Mpumalanga region pose a threat to socio-economic stability in those regions.

Both a least cost energy pathway for South Africa and a more ambitious scenario that considers climate change result in declining employment in coal mining to 2050. Evidence from previous transitions, from this study, and from recent coal sector trends suggests that unless supported, the effects on Mpumalanga's (and to a lesser extent, Limpopo's) coal workforce are serious.

While subsidies for Eskom are an option, the ability of the state to continue to prop Eskom up is limited, and the money is better spent in supporting workers and regional development initiatives to diversify the structure of the Mpumalanga economy to make it more robust.

Planning for the transition and for the possible impacts on coal workers requires a plan on which plants will close and when, who can be redeployed, who is retrained and who pays. These are all considerations that need to be addressed with immediacy given that the transition is already underway.

Introduction

South Africa is highly coal and energy intensive, with an economy characterized by extremely high levels of poverty. More than half of the population lives in poverty[1] and the country is the most unequal society in the world. In the long run, sustainable growth and development in South Africa will depend crucially on the transition away from a coal-intensive energy system and economy. How this happens, and what the transition looks like for different actors and over different time scales, is thus key to understanding the challenges and opportunities of South Africa's energy transition. While competitive alternatives to coal-fired electricity and coal-to-liquids exist, the transition away from coal and towards these alternatives is resisted by powerful economic and political actors; this includes Eskom, which remains committed to coal, while others raise concerns about the economic impacts for existing firms (especially job losses), and support the development of smaller Black Economic Empowerment (BEE) firms in the coal sector.

At the same time, the coal sector is already facing challenges and crises due to cost increases, energy security risks, export demand risks, and low local demand growth. These are already having profound implications for South Africa electricity consumers. But while the socio-economic implications of a coal transition are frequently alluded to as a barrier for a transition, relatively little work exists on what meeting a 2 degrees Celsius (2ºC) consistent pathway[2] means for South Africa. What are the distributional effects of transitions away from coal? What are the opportunities presented by the transition? South Africa faces significant development challenges and the issue of a rapid coal phase-out is one that must be balanced against socioeconomic development imperatives and the short and medium-term protection (and transition) of workers and communities that depend on coal. A key issue is thus one of timeframes, and how best to plan and prepare the ground for an orderly and just transition away from coal.

1 This is calculated using the upper-bound poverty line (UBPL) of 76 US$ per person per month in 2015 prices.

2 A 2 degrees Celsius consistent pathway is defined in this paper as one that limits the increase in global temperatures to 2o less than relative to pre-industrial levels (UNFCCC, 2010).

This study examines the current dynamics of the coal sector in terms of its role in the energy system, the economy and in society, and how this role has shifted over time. Key drivers of the future pathways of the sector such as cost increases and energy security for particular power stations, the relative competitiveness of coal compared to alternatives, and international demand issues are also discussed.

The study examines three future pathways for South Africa's coal sector that allow us to assess key risks and opportunities in South Africa's coal transition. First, we examine a least-cost energy pathway that assumes no climate change mitigation policy is implemented beyond a gradual phase down of coal power as stations reach the end of their lives or become uncompetitive with new generation technologies. In this scenario, South Africa meets its nationally determined contribution (NDC) under the Paris Agreement in 2025 and 2030.

Secondly, we examine a scenario where we assume that South Africa commits to meeting the lower range of its domestic climate change policy in the long term. In this scenario, South Africa meets a greenhouse gas (GHG) emission constraint at lowest cost. This includes early closures of Eskom power plants and Sasol's Secunda plant. We then undertake a sensitivity analysis where we commit to running Sasol's Secunda to the end of its (stated) life, and examine the effects on other energy supply and demand sectors when that carbon space is allocated to Sasol's coal-to-liquids process. This assesses the trade-offs between South Africa's two largest supply sectors by assessing the higher mitigation burden placed on the electricity sector when Secunda is allowed to emit for longer.

The largest users of coal are the electricity and liquid fuels sectors, where alternative supply options and mitigation costs are also considerably lower than in end-use sectors such as industry. As our results show, meeting South Africa's NDC is possible through decarbonising electricity and liquid fuels, but without large scale mitigation in the industrial sector. Compatibility with 2oC will require large scale and rapid switching away from coal in the electricity sector and liquid fuels sectors, and also requires industrial fuel switching.

In South Africa, no independent analysis of the socio-economic effects of a coal transition exists. This paper fills this gap through the analysis of the potential social-technical coal transition in the South African context. The comparison between the scenarios highlights the substantial effort required to transition out of coal. While South Africa has started its coal transition already, moving to a 2ºC compatible world will require political commitment and planning. This paper offers an initial analysis of how the pathway may look like, the economic effects on coal miners, and the benefits of approaching this transition in an orderly manner. An orderly and just transition will minimise negative impacts on workers and communities while leveraging the benefits of structural changes in the economy, the deployment of cheaper low carbon technologies, and improvements in air and water quality in coal-dependent regions.

Coal in the national context

Role of coal in the national energy system

South Africa is highly dependent on coal as an energy source; the fuel provides approximately 73% of primary energy. South African coal production has hovered between 250-260 Mtpa over the past 15 years, peaking in 2014 at 261 Mt (CoM, 2016). Between 70-75% of production is used domestically and around 25–30% is exported.

National consumption is concentrated in the state-owned monopoly power utility, Eskom (65% of local sales in 2014), and the coal-to-liquids energy company, Sasol (22%) (DMR, 2015), who use much lower calorific value (CV) coal than the product that is exported (~20MJ/kg *versus* 24MJ/kg). Coal currently accounts for 91% of electricity production (Eskom, 2017a) and 25-30% of liquid fuels consumption through the conversion of coal-to-liquids (CTL) by Sasol (where coal is also an important input into the chemicals sector). Eskom consumes around 110 Mtpa and Sasol around 40 Mtpa. From a final energy perspective, direct coal use in the economy is concentrated in the industrial sectors (~10% of local sales). Coal is used across the industrial sector in boilers as well as in furnaces or kilns in the iron and steel, cement, or other metal sectors, as both an energy source and as a reductant. A small portion is used in the commercial and agricultural sectors. Finally, a small (in energy terms) but important (from a health impact and energy service perspective) portion is used in the residential sector. This is concentrated in, though not limited to coal mining areas, where merchants sell coal and local communities are sometimes permitted to collect coal off of mine dumps. More than 200,000 households use coal for heating and more than 100,000 households for cooking (StatsSA, 2011), with extensive negative health impacts; the fuel is thus an important part of household energy strategies particularly in coal mining areas.

Reserves and resources

South Africa's coal reserves and resources were estimated to be approximately 9.8 Gt and 56.8 Gt respectively in 2011 (CGS, 2012). The majority of reserves are concentrated in the Central Basin (comprising the Witbank, Highveld, and Ermelo coalfields), with a smaller portion (3 Gt) found in the Waterberg coalfield. The latter accounts for the majority of the remaining coal resources in the country (45 Gt), yet only a single mine operates there currently. Opening up the Waterberg for coal extraction remains a key goal of the state, the industry, and Eskom, but depends on the development of new power plants, water, and rail infrastructure (Burton & Winkler, 2014; SACRM, 2011).

Dynamics of the local market

Coal's importance to South Africa's energy economy can be attributed to the availability of abundant and low cost resources and a history of exploiting low-cost labour to extract it, and state support for low-cost electricity generation and energy-intensive mining and industry (Christie, 1985). In the past 10-15 years, however, domestic prices have risen rapidly, especially for power generation. In 2016, local prices (i.e. including industrial users) reached 50% of export prices for the first time since 1970

(CoM, 2018). This compares against a long-run average of around 35% (1970-2015), and occurred during an export price spike. It thus represented a very large increase in local prices more generally (Platts, 2017).

This price increase highlights costs associated with more difficult geological conditions (the best resources have been mined out and operating costs in mining in general have risen rapidly) (SACRM, 2011), but has also been driven by Eskom's coal procurement practices. These practices have become increasingly complex and include poor contract management, poor planning, increased trucking of coal, and corruption. Eskom's cost of coal has increased from R42,79/ton in 1999 to R393/ton in 2017 (Eskom, 1999; 2017b). This translates into a real price increase of around 300% over the past two decades (World Bank, 2018).

Dynamics of the export market

While exports have made up a smaller portion of production than local use, they have historically been much higher value. The development of coal beneficiation ("washing") technology in the 1970s, along with close co-ordination between the state and mining houses, resulted in the development of an integrated system where higher CV coal was exported while lower CV coal was used domestically, especially in power generation (as run-of-mine product or 'middlings' coal that was a by-product of washing for exports). The swing of exports away from Europe (as European demand for coal collapsed) and towards the Pacific market upset this integrated system, causing prices to increase towards export parity pricing, for the reasons noted below.

The lower CV coal demanded in the Pacific market potentially changes the quality of middlings coal available to Eskom in some mines. Beneficiating coal for lower CV exports alters the quantities and qualities of coal available for the electricity sector. This affects those mines where Eskom is the secondary offtaker and changes market dynamics. It has led to competition for resources that previously had captive product streams for the domestic market but can now potentially find alternative, more lucrative markets elsewhere (though this comes with changes in beneficiation and yield).[3] Infrastructure constraints, in particular limited rail capacity to the primary export terminal at Richard Bay (RBCT), have limited the potential full impacts of this dynamic to some extent, and only mining companies with access to export capacity are able to benefit. From an emphasis on the local market in 2016, the strategies of miners have shifted as export prices have risen in the past two years. Planned upgrades to the rail line will potentially expose Eskom to increased competition with the export market for some of the coal that the utility procures, especially on the spot market or on short-term contracts. Thus, while the export market in general supports lower cost coal in the power sector, the current high export prices and lack of security of supply facing Eskom after years of under investment in tied mines, means that Eskom is looking to procure coal on the short term market (at export parity prices) at far higher cost than their average cost of coal. Nonetheless, this short term limitation on supply and therefore price increase, should not mask the longer term risk that if export demand falls and multi product mines cannot rely on higher returns in the export market, that domestic prices for the power sector will not rise.

The switch to lower grade exports and rising costs has also meant that earnings from exports fell to less than 50% of total earnings in the sector, down to 45% in 2016 (CoM, 2018). Nonetheless, a weaker Rand has offset recent falls in the seaborne coal price, and FOB prices at RBCT have hovered around R800/t since 2011/2012, with higher spikes driven by the collapse of the currency in 2015-2017, as well as volatility in commodity prices.

Of South Africa's exports of an estimated 76 Mt in 2017, 81% was exported to Asia, which has become the dominant market for South African coal exports (Moneyweb, 2017). India alone has grown to account for more than half of South Africa's exports since 2007, making that country's coal market and its energy policy and energy system transitions of central importance to the future of South African exports. Other key export destinations are Pakistan, South Korea, Turkey, and the UAE. However, global coal plant closures and cancellations of projects in the pipeline (India and China have cancelled more than 50% of their planned coal plants) point towards a long-term stagnation of export demand, if not outright decline as coal becomes increasingly uncompetitive (UNEP, 2017).

The large increases in Eskom's primary energy costs have, along with cost overruns at new coal fired plants under construction, contributed to rapidly increasing electricity prices that have put Eskom, and the economy, under increasing pressure. Demand for electricity has

3 One extreme example is the Optimum Mine, which has failed to deliver the contracted volumes to Eskom but has instead re-routed coal for export at much higher value (Cowan & Skiti, 2018).

thus stagnated over the past decade even as Eskom continues to bring new coal-fired generating capacity online. At the same time, new renewable capacity is now considerably cheaper on a levelised cost basis than either new Eskom coal-fired power plants (under construction) or proposed privately owned coal plants (CSIR, 2016; Steyn, Burton, & Steenkamp, 2016). Eskom's average bulk tariff (which is based substantially on depreciated assets and the operating costs of the existing fleet) is now also higher than new renewable energy prices (NERSA, 2018).

Role of coal in national GHG emissions

Due to South Africa's high dependence on coal for primary energy and its inefficient conversion into electricity and liquid fuels, and direct use in various end-use sectors, coal also accounts for the major share of South Africa's greenhouse gas emissions. Indeed, the core of South Africa's mitigation challenge is a coal challenge, though it is seldom described as such in official policy. Despite international commitments and domestic climate change mitigation policy, the Department of Energy in 2015 stated that "The government has no intention of abandoning coal as an energy source, but is determined to find cleaner technologies that will reduce the adverse environmental impact associated with greenhouse gas emissions from coal generation." (DoE, 2015).[4] This is reflected in the 2010 Integrated Resource Plan (DoE, 2011), which includes new coal-fired power plants totaling 6 GW[5] and in the inclusion of new coal in the IRP 2018.

Role of coal in the economy

Coal is an important foreign exchange earner, accounting for around 12% of total merchandise exports from South Africa over the period 1993-2015 (CoM, 2016). Loss of coal export revenues is frequently invoked as a risk to the South African economy if it moves away from coal (CoM, 2018; SACRM, 2011). Total sales values in 2016 were R112bn, of which R50,5bn were export sales (CoM, 2018).

Importantly, several of Eskom's power stations depend on mines where export revenues support low cost coal contracts for Eskom. Price or volume risks in the export market have a direct knock-on effect on those mines (for example Optimum, Wolvekrans and Grootegeluk collieries) and this has serious economic and, ultimately, energy security implications for Eskom's stations supplied from those mines. At least one of these mines has already gone into liquidation (Optimum),[6] and the mine that supplies Duvha (Middelburg/Wolvekrans colliery) makes no margin on the Eskom contract. Falling export revenues run the risk of undermining stable supply to Eskom at these four stations, and could also impact low-cost contracts from multi-product mines with short/medium-term contracts with Eskom.

The state benefits *via* taxes and royalties associated with coal mining. Coal royalties are around 18% of total mining royalties; some misclassification meant there was revenue foregone/subsidy in 2013/14 (Lott *et al.*, 2016), but royalties have grown as the sector has recovered. The value of the state take can be seen in **Table 1.** The total tax take from the coal sector is not reported annually disaggregated from other sectors (petroleum or mining). In 2012, corporate and income taxes from the coal mining sector totalled R623m (2012 ZAR) (van Seventer *et al.*, 2016).

Table 1. Royalties from coal mining (2012-2017) (Nominal Rand) (National Treasury/SARS, 2016, 2017)

	Rm
2012/13	No royalty
2013/14	392
2014/15	713
2015/16	702
2016/17	1097

Employment in the coal sector

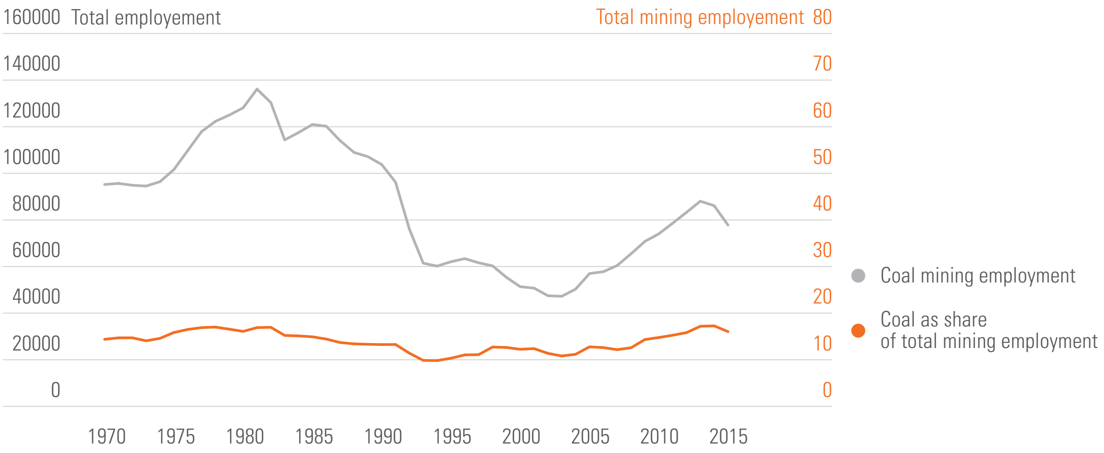
More than 80% of coal mining by volume takes place in Mpumalanga, where mining is the largest contributor to gross domestic product (GDP) (TIPS, 2016).

4 Note that an assessment of carbon capture and storage by the industry-funded South African Coal Road Map acknowledged that the technology was not feasible in South Africa, both from the point of view of cost and the lack of storage capacity (SACRM, 2011).

5 The IRP 2013 and 2016 was never adopted by government, and the state continues to make decisions on the basis of the IRP 2010, including for example, upholding the environmental authorization of a new coal-fired plant (Thabametsi) by the Department of Environmental Affairs. The minister of the environment upheld the authorization of the plant on the grounds that IRP had considered emissions and other trade-offs.

6 Glencore sold the mine under dubious circumstances, but at the time of the sale Glencore claimed that it could no longer supply Eskom at the price of the contract because of a decline in the value of exports.

Figure 1. Employment in the coal sector 1970- 2015 (Quantec, 2016)



Nonetheless, Mpumalanga performs poorly on several economic indicators when compared to the rest of the country, reporting higher household poverty levels and a lower human development index than the national average. This is consistent with other coal-mining regions globally, highlighting that economic diversification for regions with intensive coal dependency is important for socio-economic development. In Mpumalanga, 47% of households lived below the poverty line in 2009, higher than the national average.[7] And although mining is a large contributor to provincial GDP, it is a relatively smaller employer; mining as a whole accounts for only 6.7% of Mpumalanga's employment (MTP, 2015, p. 11; Stats SA, 2016). However, workers tend to support several dependents—an average of almost three per worker in key mining areas (MTP, 2015).

More generally, South Africa faces severe development challenges: extremely high levels of unemployment (officially at 26.5% in 2016, with an expanded unemployment rate of 35.6%), inequality, and a poor schooling system (StatsSA, 2016). The real economic costs of a rapid and unplanned transition could be dire for the workforce and for the communities in coal areas that depend on the industry.

Employment and the role of the coal sector in mining regions have thus become increasingly important in discussions of South Africa's energy transition. **Figure 1** shows employment in coal mining and the stability of coal mining employment as a share of total mining employment since 1970. The total employment numbers highlight that employment peaked in coal mining in the early 1980s, and declined as mines mechanised in the late 1970s and early 1980s (even as production grew substantially) (Marquard, 2006). Coal mining employed around 77,000 workers in 2015.[8] For comparison, the entire mining sector employed roughly 457,000 workers in 2016 (Chamber of Mines, 2016), out of a total employed workforce of 15,8 million people (StatsSA, 2017). Coal jobs therefore account for roughly 0.5% of the national workforce.

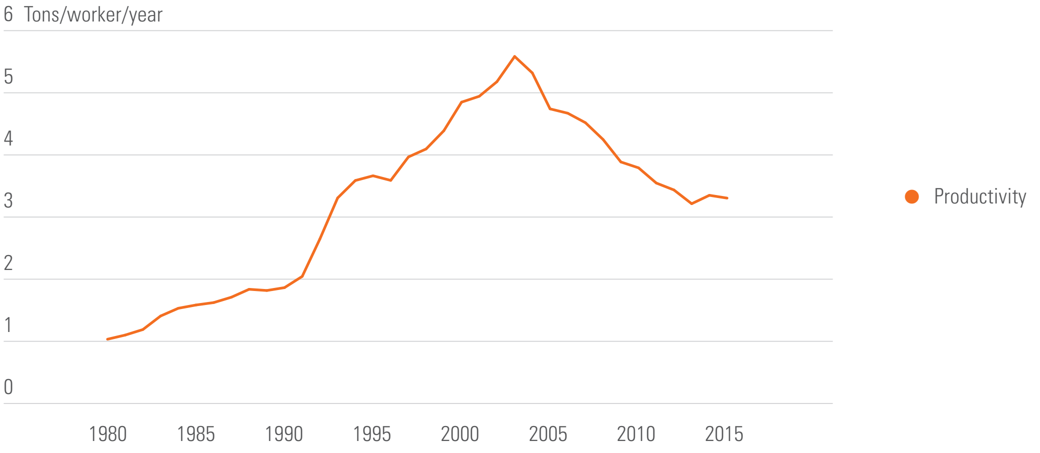
Employment trends in mining as a whole have shown a large decline, in particular in the late 1980s and early 1990s when gold production collapsed. The relatively static share of coal employment as a portion of total mining employment highlights the concomitant decline in coal employment. The experience of declining industrial areas globally and former gold mining regions in South Africa has lessons for the future of coal communities in Mpumalanga, especially as regards the scale and pace of potential risks to direct and indirect employees of the sector.

Labour productivity in coal mining increased substantially even into the 1990s (by 128% over the period 1990-1993) (Hardman, 1996). The strong improvement

7 It is likely that this has worsened given that statistics on national levels of poverty show an increase in the number of people living in poverty between 2006 and 2015.

8 StatsSA (2017a) on the other hand, reports that mining of coal and lignite employed 97,952 people in 2015. We note that despite the primacy accorded employment issues in the energy transition, there are highly divergent statistics on employment in the coal sector. The Mining Qualifications Authority reported around 62,864 workers in the coal mining sector in 2013 (MQA, 2014), and the Chamber of Mines figures align with the Quantec numbers we cite here.

Figure 2. Productivity of coal mine workers (1980 to 2012) (tons/worker/year) *



** Calculated using Quantec employment data in the coal mining sector (Quantec 2016) and coal production data from the International Energy Statistics (EIA, 2018).*

in labour productivity was driven primarily by job shedding and mechanisation and Fedderke *et al.* (1997) thus conclude that the improvement in labour productivity reflected a "growing capital intensity of production, rather than labour augmenting technical change." There is limited analysis in South Africa examining why the workforce increased during the commodities boom or why it has since declined once again. We hypothesise that while overall production remained relatively flat, there was an increase in the workforce driven by the development of new mines to meet demand from Eskom, which was returning mothballed stations to service and facing procurement challenges in tied mines, i.e. while overall coal production remained roughly the same or increased slightly, this was coming from more mines. From 2013, employment in coal mining has started to decline once again.

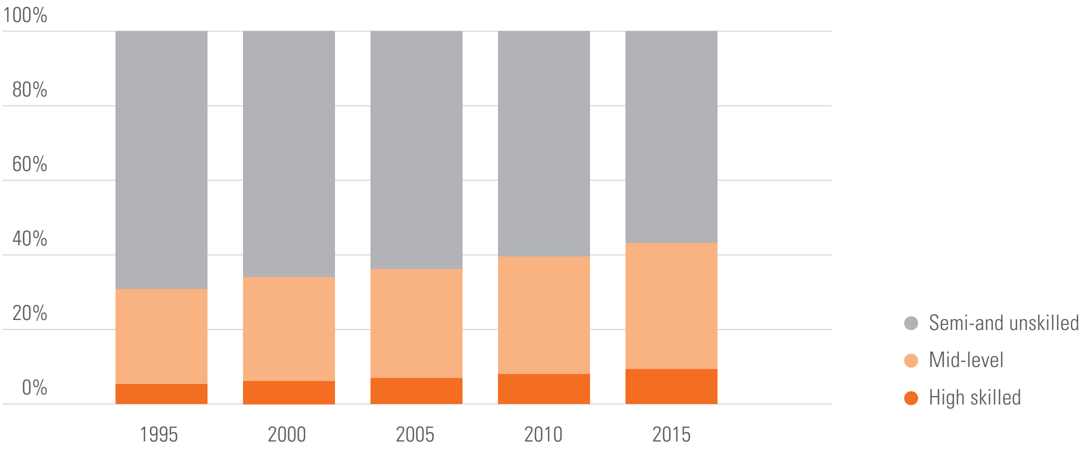
While South Africa produces roughly half the tons/worker/year as Australia, this is to some extent defined by the geology of the reserves being mined (opencast *versus* underground, longwall *versus* continuous miner). The type of mining in the future therefore defines the relative changes, with opencast mining typically employing fewer workers. Baartjes (2009) considers the increase in employment during the commodities boom was due to demand from China and India for export coal, but given that exports at the time were constrained by rail line limits (Sylvester, 2009) and did not increase dramatically, we offer the competing explanation on local demand growth. Baartjes also notes that the fragmentation of supply into smaller suppliers is a driver of increased employment because larger mines are more mechanized. He also shows that the relationship between output and employment in coal is less of a driver of employment changes than the rand/dollar exchange rate which defines capital investments in coal mining.

Although there is limited research on future labour productivity projections in coal mining in South Africa, interviews with an industry expert indicated that even incremental business process improvements are expected to lead to reduced workers/ton mined in South Africa. Autonomous mining, digitalisation, and other trends in mining more generally furthermore have the potential to further diminish the workforce required. Overall, significantly more research is required to understand employment trajectories in the coal sector and how these may evolve over time even without the implementation of climate change policies.

Besides the trends in overall numbers, there has also been an increasing shift towards higher-skilled workers in the sector. In 1995, semi- and unskilled workers made up 70% of the coal-mining workforce, while high-skilled workers were about 5%. By 2015, high skilled workers made up around 10% of the workforce, mid-level workers a further 35%, and the share of semi- and unskilled workers had shrunk to 56% (Quantec, 2015). The trend towards higher skills and falling employment means that in absolute terms, unskilled and semi-skilled workers make up approximately 40,000 workers.[9]

9 Bhorat *et al.* (2016) have called this "skills-biased labour demand" and have highlighted that it has been driven by an increase in the capital intensity of production in mining and agriculture over the period 2001-2012.

Figure 3. Skills trend in coal mining employment over the period 1995-2015 (Quantec, 2015)



Coal employment has also shifted from permanent employment to contract labour. Over the period 1987-2009, contract labour has grown from 5% to 43% of the coal workforce (Baartjes, 2009). Some of this is related to specialist skills but also relates to the types of mines being developed, and the mining ownership/finance models in smaller mines where contract miners are used to mine. Even at larger mines, many workers are not permanent employees of the mining company, though they are a relatively stable workforce.

Job losses for unskilled workers are frequently used as the primary argument against closures of coal stations and the accompanying upstream mines. However, the Mpumalanga provincial Treasury reports that mining in Mpumalanga has already shed jobs, with the loss of 42,204 jobs between 2008 and 2015 (MPT, 2015b). Clearly, transition planning in the province is long overdue, particularly in light of Eskom's plants reaching the end of their lives.

Coal mining paid wages of R21,1bn in 2016. Measured as average earnings per month, coal mining earnings were around R22,000 per month in 2016 (CoM, 2016). Average wages in the coal sector are much higher than median wages in mining, highlighting the large differential between the highly skilled and low- and semi-skilled workers in the sector. Comprehensive wage data for coal mining is limited, and median wages for coal mining are not reported separately from mining in general. There is limited data on median wages for coal mining, but mining employees in general earn higher median wages than other sectors according to the Chamber of Mines. Median monthly wages in the mining sector in 2015 were R7,500; this makes median wages in mining, along with the utilities sector, the highest by sector in the country (CoM, 2016:14). Compared to median monthly wages in the economy of R3,100 in 2015, mining appears well paid (a trend also found elsewhere in the world, where coal workers often earn higher salaries than other workers in those economies). Of course, the difference highlights not so much how highly coal-mining workers are paid but rather how poorly paid most workers in the South African economy are. In other countries, this wage differential has created a barrier to worker transition schemes for coal workers.

On the other hand, this is a potentially important aspect of South Africa's energy transition. Mpumalanga's coal mining workforce, which, as **Figure 3** shows, is increasingly higher skilled, provides an opportunity for the region to develop new industrial capabilities. This requires industrial policy planning and implementation in the region.

Given that the average miner in Mpumalanga supports around three dependants, the social implications of closures of mines are an important consideration in managing the transition. Since agricultural and other earnings are substantially lower than mining wages, closures of mines will need to be matched with job opportunities in sectors with concomitant incomes to protect miners, their families, and the communities that depend on their earnings.

Coal-related investments

Several large investments in fossil fuel infrastructure are planned or underway, including new coal-fired power plants, rail infrastructure expansions/upgrades, and new mining capacity.

South Africa is currently building two large super-critical power plants, Medupi and Kusile (4.8 GW each). A procurement process for a further 2.5 GW of coal IPPs was launched in 2014, and two preferred bidders have been announced thus far (863 MW), the Thabametsi and Khanyisa projects. Several other smaller projects are in the planning/feasibility stage, though no procurement process has yet been announced. Currently, legal challenges by environmental groups to the IPPs, the decline in electricity consumption (a result of the steep increases in costs of Eskom's new plant, and hence electricity prices), and Eskom's dire financial position, mean that procurement of further rounds may not materialise.

Mining investment has been constrained in the last few years due to a variety of factors, primarily political and policy uncertainty (Atteridge & Burton, forthcoming). Large new investments in Eskom-tied mines have not materialised, and substantial shortfalls in coal supply from key mines supplying large power plants are expected in the coming years (indeed, in April and May 2018 shortages of coal have led to the threat of load-shedding). This investment crisis has been driven by political pressures and corruption, including the Minister of Public Enterprises' refusal to allow Eskom to spend capital to ensure security of supply at some of the large mines that supply it (where Eskom's provision of capex is part of the coal supply agreements) (Steyn, Burton, Steenkamp, 2016). This failure to invest timeously in new mining areas has resulted in significant quantities of coal having to be trucked in to stations by road, adding considerable transport costs to Eskom coal costs.

The major mining houses have continued to invest in their multi-product mines where the potential for higher export earnings support the capex. But majors have also indicated their exit from South African or Eskom coal. Anglo has recently sold all of its Eskom thermal coal assets to Seriti Resources (Kriel, New Denmark, and New Vaal, as well as the New Largo resource). South 32 has impaired its South African thermal coal assets and is considering spinning them off. Capital for junior miners has been limited and support from the state-owned development finance institution, the Industrial Development Corporation, has been necessary to encourage investment in the sector. Sasol has been an outlier in this regard, having invested several billion in new mines to support its coal-to-liquid and petro-chemicals plants.

Policy aspects of the transition

South Africa is already in the early stages of its "coal transition", driven by endogenous factors in the coal-mining sector, exogenous global shifts in energy markets, and dynamics in the electricity sector. As discussed already, new coal-fired power plants are no longer cost-competitive with alternatives in the electricity sector, while Sasol has announced that it will not be building further coal-to-liquids capacity given the costs of the technology and the emission impacts (Crooks, 2017).

As in other countries (India and China) a generation surplus caused by over-investment in new coal-fired power stations is the primary driver of the 'early' closure of older, less efficient plants. The time and cost overruns at the large Medupi and Kusile power stations have led to:

- levelised costs of electricity at the stations of R1,70/kWh and R1,90/kWh[10] respectively (2017 ZAR) (Steyn, Burton & Steenkamp, 2017);
- dramatic real price increases in the regulated electricity tariff since 2007, causing a collapse in demand for electricity. Industrial demand is 10% lower than it was a decade ago, and overall demand has been flat for ten years, with overall reduction in sales of 7.2%.

This has led to a large generation surplus, with a reserve margin of over 35% in the current financial year (NERSA, 2018), and several units at Medupi and Kusile still to come online before 2022. At the same time, Eskom periodically faces issues with supply reliability and unplanned outages as it has failed to recover from under-spending on maintenance over the past 20 years, and continues to under-maintain some capacity (the energy availability factor for the fleet in late 2017 and early 2018 was below 70%). Nonetheless, Eskom has already said publicly that it will put three power stations into "cold reserve" (i.e. turned off but able to be called back on a timeframe of around a week) and the National Energy Regulator (NERSA) has deemed two stations (Arnot and Hendrina) unnecessary, disallowing costs for the plants from being included in the tariff (NERSA, 2018).

All of the least cost electricity scenarios developed by various modelling teams in the country exclude new coal and new nuclear from the electricity build plans (Ireland & Burton, 2018; ERC, 2018; IFPRI 2017; CSIR 2016, CSIR 2017). An assessment of the new independent power producer coal plants shows that if they are built, they will

10 Compared with an average tariff of 93.79c/kWh for 2018/19 (NERSA, 2018)

increase the discounted system costs in the electricity sector by R19,6 billion (2018 Rand), or between R2-R4bn per year over their lifetimes (Ireland & Burton, 2018).

More importantly, costs for Eskom's existing fleet of coal plants continue to rise, in particular primary energy costs, but also future capex and opex needs. Older plants typically require increased maintenance costs as well as refurbishment costs, even to reach their planned "end of life". For example, an assessment of Hendrina found that substantial investment would be required just to get the stations to its planned decommissioning date (Siemens, 2015). This is consistent with experience in other countries (e.g. AGL's Liddell plant, or the assessment in Carbon Tracker, 2017).[11] Only two plants (Kendal and Majuba) are younger than 30 years, and an Eskom assessment found that most of the fleet has exceeded its turbine and boiler design life (Dentons, 2015).

The Eskom fleet also requires retrofits for compliance with environmental laws, especially for air quality legislation and the Minimum Emission Standards. Eskom has indicated that full compliance of the coal fleet with the National Environmental Management: Air Quality Act (no 39 of 2004) would cost around R350bn (Steyn, Burton, & Steenkamp, 2017). Thus, while primary energy costs are increasing, so too are opex and future capex costs. Already, Steyn, Burton & Steenkamp have shown that Eskom can save money through the early retirement of three of the older stations (Grootvlei, Hendrina, and Komati)—in line with Eskom's own findings—given the high costs of the stations. Essentially, these older coal stations have already become stranded assets by virtue of Eskom overestimating the future demand for electricity.[12] The analysis of our results supports this, showing that even with relatively optimistic demand forecasts, several of the older plants are run at low load factors as Medupi and Kusile come online in the short/medium term.

11 CTI includes costs for refurbishment for plants over 30 years over and above normal opex and maintenance. We have not modeled this for the fleet in this study, but note that it should be included in future analyses.

12 Depending on the definition the plants could be economically stranded or the capacity may be stranded (see Burton *et al.*, 2016, for discussion on Eskom assets). The stranding of these assets has been masked by the subsidies Eskom has received, totaling roughly R100bn (2016) in the form of a bailout and an interest free loan (Burton, Lott, Rennkamp, 2018). A large portion of Eskom's debt is also guaranteed by the state (up to R350bn), lowering its costs of debt; a default would trigger a much larger economic crisis for the country.

Primary cost increases and energy security risks in coal

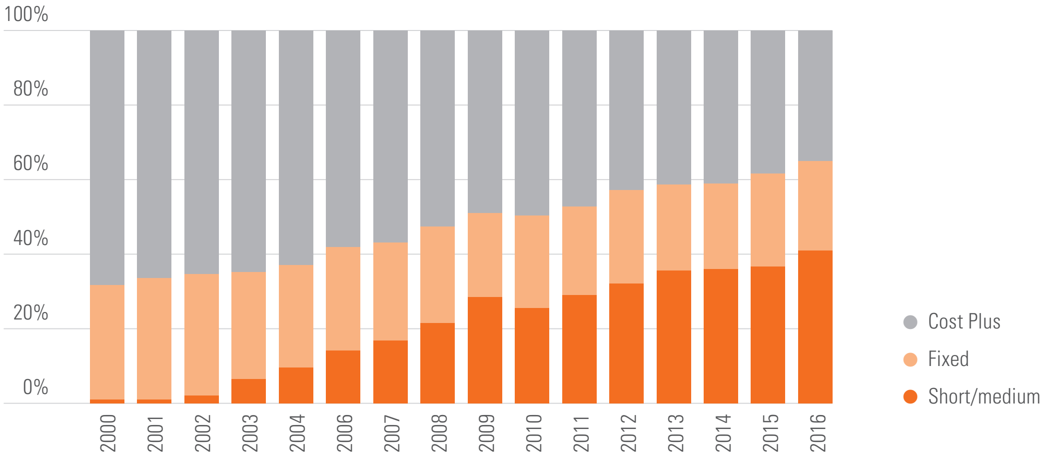
As mentioned, primary energy costs have increased by 300% in real terms over the past 20 years. To some extent, this has reflected above inflation cost increases in mining in general (Oberholzer & Daly, 2014), but it also reflects a fundamental break with the historical contracting models and relationships between Eskom and its major coal suppliers.

Historically, Eskom contracted coal on two models: cost-plus and fixed price contracts. In the cost-plus tied collieries, capital expenditure was shared between Eskom and the mining houses; Eskom paid all the operational costs of mining while mining companies earned a return (around 9% p.a., Merven & Durbach, 2015) on their capital input and a fee for mining. Eskom secured access to the resource but bears all capex and opex risks (with planning oversight). At mines where the resource could support both exports and Eskom supply of coal, miners would export the higher-grade coal and supply the middlings fraction—the intermediate grade product described above—to Eskom at marginal cost. This typically resulted in very cheap coal, amongst the cheapest contracts on the system. Essentially, company returns were supported from higher value exports (Burton & Winkler, 2014).

However, Eskom has increasingly purchased coal on short and medium contracts, rising from around 2 Mtpa in in 2000 to over 40 Mtpa in 2016 (Dentons, 2015). Short/medium term contracts now make up over 40% of Eskom's coal supply by volume (**Figure 4**) (own calculations).

The reasons for this change in procurement strategy are manifold, but include new, politically driven procurement rules to encourage new entrants in the sector (Burton & Winkler, 2014) and the need for higher coal purchases to match increased generation. The latter was due to the return to service of stations without long-term contracts, higher burn rates, and mining above contractual volume specifications at cost-plus mines over the period 2003-2009, which later led to those mines no longer being able to meet their contractual supply volumes. From 2012 onwards, the cost-plus mines also required new capital investment from Eskom that the utility did not provide, leading to shrinking output at tied mines (Dentons, 2015). Eskom's refusal to recapitalise the cost-plus mines has led to very large price increases at some of the mines as volumes have declined (e.g. Ar-

Figure 4. Eskom coal contracts by type, 2000-2016 (Authors' own calculations from Eskom 2015 and Eskom 2017c)



not), and has had the effect of making short/medium term contracts appear competitive at certain stations even on a delivered basis. This has resulted in allowing coal procurement to move to 'cheaper' short/medium term suppliers, including from mines owned by politically connected persons.

It is important to note that many of the short/medium contracts are not that much more expensive than the long-term contracts at the mine mouth; in fact, across all contracts in 2015, S/M contracts on average cost roughly the same as long-term contracts (Dentons, 2015). However, when transport costs are included, S/M contracts increase by a further 50% on a delivered basis. Transport, specifically trucking, is thus a large driver of cost increases in primary energy. Transport interests, in particular coal trucking groups, have become an increasingly vocal group opposed to the procurement of renewable energy, including having launched legal action to prevent Eskom signing power purchase agreements with renewable energy project companies.

Eskom's refusal to recapitalise tied mines is partly a function of the current capital constraints facing Eskom, but the earlier limits to the provision of capital was informed by a political intervention by the then Minister of Public Enterprises. The end result has been declining volumes from cost-plus mines, which can no longer meet their contractual volumes without substantial investments. This is the case for several large power plants, which are now supplied with top up coal from multiple, often short-term or spot sources. Supply issues are faced at Matla, Kendal, Kriel, and Tutuka due to tied mine under deliveries. Majuba has always faced supply issues because of the failure of the tied mine, and there are issues with coal supply at the older stations: Arnot, Camden, Grootvlei, Hendrina, and Komati. The latter may be due to quality or price issues, or is linked to the failure to supply contracted volumes to Eskom at mines owned by the corrupt Gupta family.

As can be seen in **Table 2**, there are different coal supply issues facing different stations. Fundamentally, however, for many stations a stable supply of coal has not been contracted, increasing the risks of supply interruptions and likely raising costs. In many cases, the tied mines have sufficient reserves or resources to match the end of the contract, though this will require further investment. On the other hand, this means that coal costs are not yet sunk costs for various stations, and may offer an opportunity to avoid lock-in costs at plants and stranded assets at mines in line with what is required for a 2ºC compatible pathway. This issue is discussed further in the results section where we show the difference in coal needs between our reference scenario (where stations run for 50 years or until outcompeted by alternative supply options) compared to two 2ºC-compatible scenarios with substantially less coal use in the electricity sector. Currently, Eskom is also struggling to provide the necessary capital to the cost-plus mines. Not only has this driven up prices as elaborated above, but it may result in physical supply risks, as we have seen in April/May 2018 at tied mines (Matla, Kriel, and others). Should mining houses provide capital for re-investment in mines or in greenfields operations that would likely require a renegotiation of the coal supply agreements to reflect the higher risk/return requirements of differently structures

Table 2. Summary of coal supply risks by station

Power plant	Primary Mine (if relevant)	Contract end	Decommissioning per IRP 2016/ 50 year LOPP *	Cause of supply risk
Arnot	Arnot/Optimum/multiple	2015/ 2023	2029	Eskom refusal to recapitalise/invest at Arnot mine; Corruption; Short-term contracting.
Camden	Usutu/multiple		2023	Insufficient supply from co-located mine.
Grootvlei	Palesa/multiple		2028	Full volumes not secured; Limited supply options; high transport costs.
Hendrina	Optimum		2026	Export risks - fixed price contract; Mine in business rescue; corruption; Under delivery of contractual volumes; Limited alternative supply options (transport infrastructure constraints at the station).
Duvha	Wolvekrans	2034	2034	Export risks – fixed price contract (no margin for mining company on the contract).
Kendal	Khutala	2033	2043	Under delivery of contractual volumes; Contract does not match end of station life; Life of mine is approaching and requires new investment; No agreement or extension to CSA negotiated yet for new open cast; Large shortfall in volumes from early 2020s when mine reaches end of life; Financing, contracting, timing risks of new investment.
Kriel	Kriel	2019	2029	Contract does not match end of station life; Life of mine reached 2019; New capex required or new contract/tender; Mine development risks; Potential higher costs of coal at new mine.
Komati	Koornfontein		2028	Higher cost supply (corruption); Under delivery of contracted volumes; Mine in business rescue.
Kusile	New Largo			Station volumes not secured; Tied mine not yet developed; Transport constraints and costs of imports.
Lethabo	New Vaal	2029	2040	Contract does not match end of station life.
Majuba	multiple		2051	No long-term supply; Rail line construction delays; Multiple contracts including Tegeta (business rescue).
Matla	Matla		2033	Eskom failure to recapitalise the mine; Under delivery of contractual volumes from cost-plus contract; Switch to multiple short-term contracts; Mining right lapses 2025.
Matimba Medupi	Grootegeluk	2038	2041	Supply risks associated with single mine supply to two stations; Export risk: fixed price contract.
Tutuka	New Denmark Multiple top up contracts	2029	2040	Long-term undersupply from cost-plus contract; Multiple short-term contracts; Contract does not match end of station life.

** Note that in 2016, Eskom indicated that it was pursuing a fleet renewal strategy that would extend the lives of power station from 50 to 60 years (according to the then head of Generation, Matshela Koko) (Creamer, 2017).*

contracts. This could therefore herald a sharp upward shift in coal prices, even if financed by the majors using corporate debt (since Eskom's cost of capital is lower). Export risks would raise the costs from fixed-price or medium term contracts, as miners would no longer be able to supply coal to Eskom at marginal cost.

The coal model is based on publicly available contract information from Dentons (2015) and supplemented by interviews.[13] Essentially, stations will continue to face coal cost increases. We have modelled this by building in the existing contracts into the model, so that when existing contracts end, the stations face higher costs associated with new mine supplies, with costs based on expert elicitation in Merven, Durbach & McCall (2016).

National debates on the future of coal

Public discussion about the future of coal and South Africa's coal transition has increased substantially in the last two years, driven by various factors. These include the rapidly decreasing costs of alternatives in the rest of the world, Eskom's failure to sign off on renewable energy projects, financial crisis and generation surplus, a public protest and legal challenge against REIPPs by the Coal Transporters Forum (an organisation representing

13 A further set of contracts were released in September 2017 but these were not included in our modeling; for some stations, the uncontracted coal requirements will therefore be slightly smaller. However, the volumes of these contracts are still insufficient to meet demand at stations, as evidenced by the supply shortages being experienced by Eskom in May 2018.

coal trucking interests) and other union-led legal challenges, and by the utility's sudden announcement in early March 2017 that it would shut 5 power stations[14] (Slabbert, 2017; Fin24, 2017).

Eskom's announcement was accompanied by limited consultation with labour or other stakeholders. Eskom claims that the closures were necessary because of new renewable energy projects coming online and forcing the early closure of the stations, rather than declining demand for electricity and an existing generation surplus exacerbated by overestimation of demand in the IRP 2010 and large units at Medupi and Kusile coming online. All IPPs (i.e. not only REIPPs) currently account for 11,5 TWh or 5% of Eskom sales of 214 TWh (Eskom 2017a). In 2016, renewable energy IPPs produced 6.9 TWh or 2.9% of system load (Calitz & Bischof-Niemz, 2017). Each unit at Medupi and Kusile will produce approximately 5 TWh/year once online, or approximately 60 TWh when both are fully commissioned (12 units x 5 TWh each). Eskom's public statements linking plant closures to REIPPP supply cannot be backed up by quantitative analysis. The stranding of older coal plant capacity is primarily a function of declining demand and the commissioning of Eskom's new coal stations.

Eskom's announcement had the effect of quickly polarising the discussion about how to deal with excess capacity in the system, the rising costs at the oldest stations in the fleet, and Eskom's financial instability and dire need to curb costs.

The Congress of South African Trade Unions (COSATU) released a public statement that Eskom's unilateral closure announcement "is not just an arrogant decision, but a hostile act of provocation directed at workers and their unions." (COSATU 2017). The National Union of Mineworkers (NUM) delivered memoranda of grievances at Eskom power plants, while Irvin Jim, the General Secreatry of the National Union of Metalworkers (NUMSA) said that "If necessary we will go on strike and if that means plunging the country into darkness, then that is the strategy we must adopt." (quoted in Seeth, 2017). The Coal Transporters Forum (CTF) organised thousands of striking coal truck drivers to blockade highways with their coal trucks and shut down Tshwane in protest. They also claimed that renewable energy producers were driving the coal plants out of business.[15] The CTF also launched a legal challenge in June 2017 to interdict Eskom from signing PPAs with the REIPPs, followed by an urgent interdict brought by NUMSA in March 2018 to prevent the new government from signing PPAs the following day (Creamer, 2018).

Subsequent to Eskom's sudden closure announcement, the utility announced in its integrated report (Eskom, 2017a) that it would place units at power plants into cold storage and no longer run three stations (Grootvlei, Hendrina, and Komati), bringing them offline in the next few years. However, it has also not set aside funds for decommissioning stations, or planning for station decommissioning (Eskom 2017d). The national energy regulator, recognising the large generation surplus, has since disallowed revenues and costs (primary energy, opex, and maintenance) associated with two stations (Arnot and Hendrina) for the 2018/19 financial year (NERSA, 2018). What this means in terms of closure and decommissioning, and the future of workers and local communities at those stations is not clear. Eskom is also currently running both Arnot and Hendrina, so whether and how they will reduce the costs associated with those stations is also not clear. While much of the public debate is around the costs or the drivers of closures (REIPPPs, new coal, or a political strategy to undermine particular coal interests) and the future of the electricity market, much of the public debate has also centred on the costs of the transition and the socio-economic impacts thereof.

Many actors have now started to call for a just transition for South Africa, echoing the calls made by unions for many years—though of course what this actually means, and the scale, scope, and process of the transition is often not well defined. Even business interests have increasingly called for a just transition (e.g. the Energy Intensive Users Group), as well as many civil society organisations. In response, the national planning commission (NPC) has launched a social dialogue on the just transition, aiming to develop pathways for South Africa to 2050. This process commenced in May 2018.

14 Reported variously as Grootvlei, Komati, Arnot, Hendrina, Camden, or Kriel, and either as 4 or 5 stations.

15 Coal trucks are of course a result of the political and financial challenges facing Eskom, caused by under-investment in the cost-plus mines; in the long term, trucking of large quantities of coal is not feasible because of road deaths, damages, pollution, and cost. Eskom has recognised this through the development of a road-to-rail scheme to migrate coal from truck to train. Nonetheless, many drivers face extremely difficult working conditions, long hours, and debt for their trucks (Hallowes & Munnik, 2017).

In response to the public pressure around shutting excess stations, Eskom commissioned several socio-economic impact studies examining the importance of the coal stations to local economies. Eskom's position seems clear: they will use the threat of job losses and economic impacts to advocate for retaining their dominance in the sector, even though the stations touted for closure are surplus to requirements, are approaching the ends of their technical lives, and Eskom does not have the money to pay for them. Former head of Generation Matshela Koko stated that "We hope that, once the studies are complete and we see the social and economic impact for those plants, we will think twice and we will put all our efforts into ensuring that we don't close these power stations" (Creamer, 2017).

The jobs impacts of the rollout of RE has become a rallying cry for unions, who increasingly blame the roll out of the REIPPPP for the closure of Eskom's older stations and thus potential job losses. There are limited independent analyses that have looked at the questions of employment effects of closures, except several booklets commissioned by Eskom from KPMG that the unions regularly cite (e.g. NUMSA, 2018). That work has neither methodological nor data assumptions that are public, but claims that the closure of 5 stations would result in the destruction of 92,000 jobs. Thus, the employment effects of the energy transition, and in particular the effects on existing workers, is of the utmost importance for South African politics.

While South African climate policy has the notion of a just transition embedded within it (RSA, 2011), no detailed sector specific plans for coal companies, workers, or communities exist. Eskom's failure to engage with relevant stakeholders, set aside budget for planning and decommissioning, and their unilateral announcement of closures has created mistrust and no doubt fear amongst coal plant, trucking, and mine workers. Thus, even though unions were historically a driving progressive force around climate change and justice—they have called for a just transition towards a low-carbon economy for many years, and have noted the risks of climate change since at least 2009 (COSATU, 2011)—they are now opposing the closures of stations and the roll out of renewable energy. The unions view the REIPPPP partly as a cause of job losses and closures of older stations, but also as privatisation of the electricity sector, which they have been opposed to since the 1990s (Baker *et al.,* 2016; Baker & Burton, 2018). How to transition workers at the older stations in particular has been rolled up into a broader political battle about the future of the industry and the ownership models of and working conditions at new renewable energy plants.

Rather than a public discussion about how to transition, the distribution of costs and benefits, and the policies required to support workers and communities through a transition that has already begun, the debate is still centred on whether South Africa requires new coal and whether the old plants should even be closed (Spencer *et al.*, 2017). In this, coal interests and Eskom are using the risks to workers and local economies to block the implementation of a transition policy and planning process.

Coal transition scenarios for South Africa

South Africa's coal sector is facing issues of rising costs, reduced competitiveness, and potential energy security issues. The following section describes the results of three scenarios that examine the future of the coal sector in South Africa to 2050.

The first scenario traces the energy system effects of a gradual decline on coal-fired power in South Africa through retirement of existing capacity according to an assumed 50-year life for power stations. It is in line with South Africa's nationally determined contribution (NDC) to 2030. In the scenario, we assume conservative cost reductions in renewable energy, which results in limited economic stranding of coal plants and capacity in later years and no new coal built after Medupi and Kusile. The scenario essentially shows the decline of coal power and the growth in coal use in other sectors without the implementation of any explicit climate change mitigation policy.

The second and third scenarios highlight the impacts on the coal sector of South Africa meeting the lower range of its climate change mitigation objectives. We consider this consistent with South Africa's fair share contribution to limiting warming to 2ºC, given the existing analyses on equity and burden sharing. In this scenario, a carbon

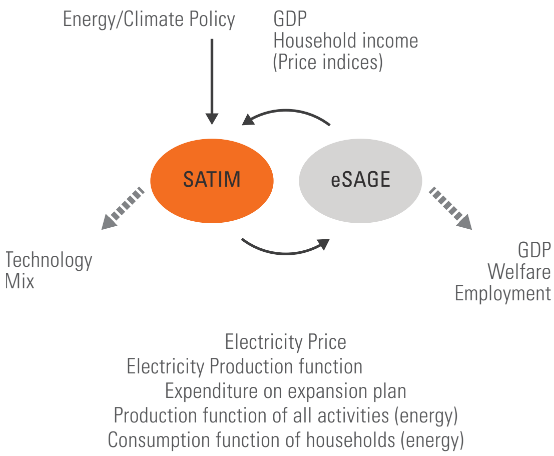
budget consistent with the lower-PPD is imposed on the model, and a phase out plan consistent with the greenhouse gas emission constraint can be analysed.
The two scenarios highlight the need for steady diversification away from coal in key supply sectors—electricity and liquid fuels—if South Africa is to meet low-PPD. In both cases, mitigation is achieved primarily through decarbonisation of the electricity sector, but the third scenario also shows the key role played by coal-to-liquids in the economy and the need to balance large emitting sectors. In both scenarios, direct industrial use of coal continues to grow. This limits the impacts on the coal sector directly, but as we discuss, requires increased policy attention in non-electricity sectors if South Africa is to achieve a 2ºC-compatible pathway.

Quantitative coal scenarios

Methodology

The coal scenarios were quantitatively analysed using the Energy Research Centre's linked energy and economy-wide model (SATMGE[16]). The analysis below required a detailed coal sector, and a number of model developments were undertaken to include detail on the power sector and the coal supply sector (by building in supply contracts and new supply options).
A linked modelling framework has the benefit of containing detailed bottom-up information for South Africa's energy demand and supply as well as economy-wide data and information on all sectors and agents in the economy. In addition, the feedback between the models captures the response of economic agents to changes in energy prices and investment requirements as well as the energy system implications of changes in final energy demand.
The economic model, eSAGE, is a Computable General Equilibrium (CGE) model of the South African economy. eSAGE is included in the linked model framework and therefore uses inputs from SATIM to determine the effect of the coal phase out on economic growth, employment (at sector level) and employment (by skill level) as well as the overall impacts of inequality in South Africa. The impacts of the coal scenarios on sector growth and household income (as a result of fuel price changes and electricity sector investment requirements) are seen in the economy-wide model and are passed through to the energy model.

Figure 5. Schematic diagram of the model



The energy model (SATIM) is a full sector TIMES model that includes the dynamics of both the supply and demand sides of South Africa's energy system. SATIM, depending on the problem, uses either linear or mixed integer programming to solve for the least cost energy supply to meet projected future energy demand, given assumptions on future fuel and technology costs, retirement of existing infrastructure, learning rates, and efficiency improvements. Scenarios also take into account any specified constraints, such as the availability of resources or constraints on greenhouse emissions.
The demand for energy services (e.g. lighting, heating, cooking and process heat) are allocated for each sector and sub-sector, therefore SATIM captures useful energy demand. Final energy demand is calculated endogenously using the mix of supply and demand technologies (e.g. capacity, new investment, production and consumption) that would make up the lowest discounted system cost for meeting energy demand to 2050.
As previously mentioned, there were a number of model developments in the power sector component of SATIM as well as the upstream supply of coal. Coal supply in SATIM was disaggregated based on existing coal contract information, drawn primarily from contract data contained in Dentons (2015). This was supplemented with coal supply data collected for Steyn, Burton & Steenkamp's (2016) analysis of early decommissioning and station by station coal costs, interviews with coal industry experts, company annual reports, mineral reserve and resources

16 For a full model description of the linked energy model and economy-wide model, please see ERC (2018).

reports, investment reports for new mining costs, and parliamentary questions. The individualised coal prices are based on existing and proposed contracts, and future investments. Unlike other electricity sector modelling with static prices or a single price of coal across the fleet, the SATIM model now has station specific prices that are built up from existing contracts, future resource availability and investments at tied mines, and future mine investment requirements. The latter is based on public information or interview data where available (e.g. announced capex requirements at a particular mine such as Matla or Khutala). In the cases where mine/resource cost data was not available, representative future mining costs developed by Merven, Durbach & McCall (2016) are used. This allows the future costs of coal at specific stations to be assessed, and shows the cost optimal coal plant phase-out plan. Plant and mine specific results also indicate where new investments should not take place and where assets will be stranded if South Africa is to follow a least cost coal phase-out compatible with 2ºC.

Current NDC-based scenario and implications for coal

South Africa's NDC is based on the long-term benchmark emissions trajectory range contained in the National Climate Change Response Strategy White Paper (DEA, 2011). The NDC commits to limiting emissions to a range between 398 and 614 Mt CO_2-eq between 2025 to 2030 (including LULUCF). Known as the Peak, Plateau, and Decline trajectory (PPD), the goal is to peak emissions between 2020 and 2025, plateau for approximately a decade and decline in absolute terms thereafter (RSA, 2016). The national climate change policy framework thus extends the NDC commitment to 2050, with a goal to reduce emissions to between 212 and 428 Mt CO_2-eq (including LULUCF) in 2050 (DEA, 2011). Climate Action Tracker rates South Africa's NDC as "highly insufficient" to meet 2ºC, though their assessment is based only on the upper end of the range. The lower range of the NDC in 2030 and of the PPD in 2050 are both considered compatible with 2ºC according to CAT (April 2018).

The NDC scenario modelled here is consistent with a least cost energy system to 2050, with no greenhouse gas emissions constraint imposed on the model. The key finding of the NDC/reference scenario is that South Africa can meet its NDC and mid-PPD primarily through decarbonising the electricity sector. This reflects that new coal investments in electricity and CTL—South Africa's largest emitters—are no longer competitive with alternatives. By 2050, in the power sector only Medupi and Kusile are still running, and coal makes up only 11% of electricity supply (60 TWh). In the liquid fuels sector, Sasol's coal-to-liquids plant at Secunda runs to 2050.[17]

The contribution of coal to electricity generation is broadly consistent with the planned closure dates of the fleet, in line with the 'official' IRP decommissioning schedule that assumes a 50-year life of power plants (DoE, 2016). Majuba comes offline in 2045, slightly ahead of its IRP 2016 decommissioning dates (see **Table 4** for a comparison of stations end of lives under future scenarios). There is stranded capacity at all of the older plants in the early and mid-2020s, consistent with the surplus in capacity discussed above. Arnot, Camden, Grootvlei and Hendrina all run at very low load factors. Furthermore, several of the larger stations are also run down as Medupi and Kusile come online. Because we have modelled existing coal contracts as take-or-pay contracts, the least cost option is to run those stations with committed coal supply. This explains why the older stations are run partially, up to the level indicated by the committed coal supply. When we excluded the coal costs as 'committed' (through the existing contracts), then the older stations are run even less and stations with cost-plus contracts are run at higher load factors. Importantly, the stations are not only being used for load following, but are being dispatched due to the committed coal contracts. This highlights the extent to which coal contracts are potentially an important aspect of carbon lock-in.

The scenario results in 71% of electricity generated from wind and solar PV by 2050. There is substantial investment in gas capacity because of a conservative assumption that renewable energy cannot be considered firm capacity during the peak, though the gas plants contribute relatively less to electricity generated (14%). Uptake of electric vehicles increases from 2030 when we assume they become capital cost competitive with conventional vehicles; by 2050, EVs make up 67% of private vehicle-kilometres.

While electricity and liquid fuel supply become far less coal intensive, demand for coal from the industrial sector increases substantially, and thus emissions from industry (**Figure 6**). Emissions from the electricity sector decline

17 The plant retirement date was extended to 2050 in ERC (2018).

to 85Mt CO_2-eq in 2050, but total emissions excluding AFOLU and waste are flat to 2050 as industrial use of coal increases. The industrial sector grows by 3.9% average annually, with coal remaining the lowest cost option for process heat requirements in general manufacturing. Industrial demand for coal increases by 3.6% per year from 2015 to 2050, accounting for most domestic coal use by the end of the period. Most of the energy-intensity reductions come from fuel switching to electricity for scrap-metal arc-furnaces in iron and steel. Further work is required to explore whether uptake of coal in the industrial sector at this scale is plausible given alternative energy options that may become more competitive in the future, or regulatory constraints such as the proposed carbon tax and air quality legislation.

Figure 6 shows the greenhouse gas emissions from energy supply and use and industrial process emissions to 2050. As can be seen, even with waste and AFOLU emissions excluded, South Africa already exceeds the lower range of its NDC over the period 2025-2030. The emissions trajectory of the NDC scenario corresponds roughly to the mid-way of South Africa's emissions 'range' over the period to 2050.

The development of the coal supply model highlights where Eskom faces coal supply shortages in the following years. In particular, secure contracts at Kusile, Tutuka, Majuba, and Lethabo are missing. The mismatch between the assumed lives of the stations—50 years, as per the IRP—and the original coal supply agreements (often 40 years) can be seen in **Figure 7**. Lethabo and Tutuka in particular require extension of the coal contracts to match the station end of lives, as well as new

Figure 6. Electricity generation by source (TWhs) and share of coal in generation (%) 2015-2050 (NDC scenario)

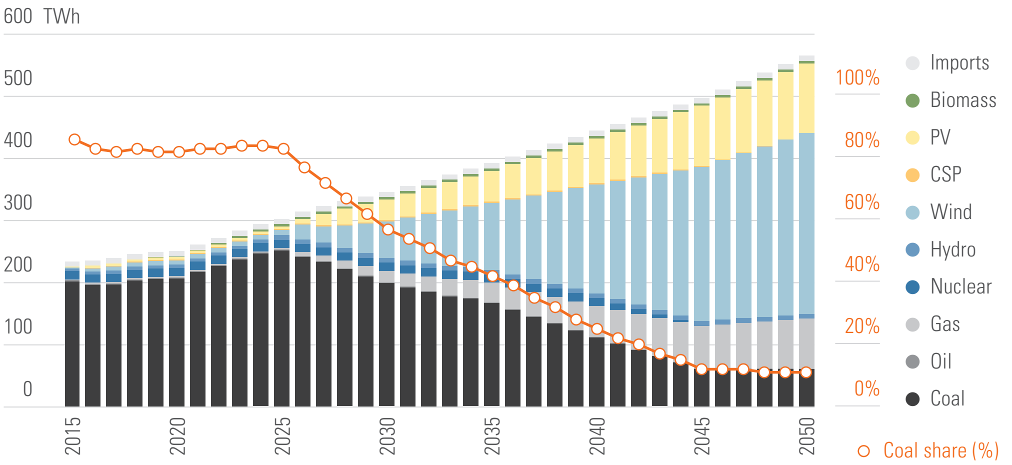
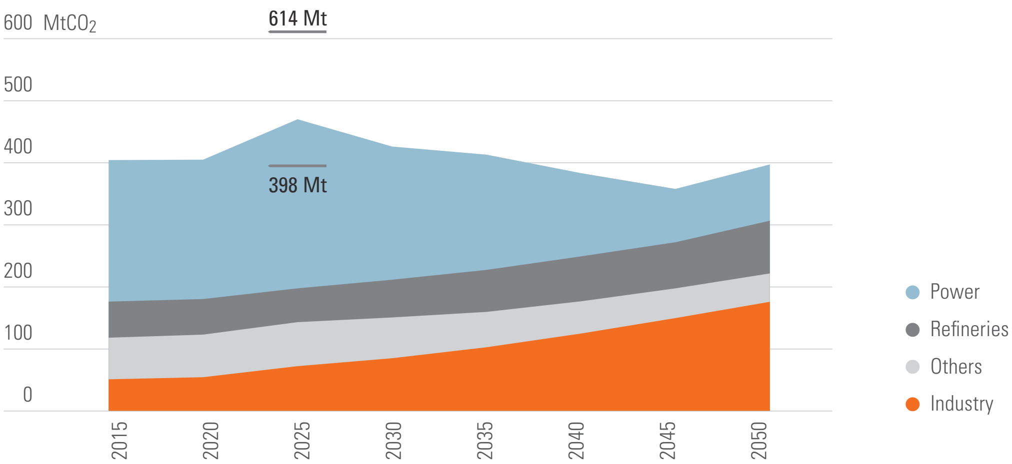


Figure 7. Greenhouse gas emissions from energy supply and use (2015-2050) by sector (Mt CO2-eq) (NDC scenario)



investments in those resources to meet that demand. We have assumed that existing contracts for Kusile run to their end dates, and that New Largo is developed and supplies half of the station. The recent announcements that the Kusile coal contract will run for 60 years may need to be reassessed. Smaller volumes of uncontracted coal at the older stations can also be seen in **Figure 7**. This excludes shortfalls at existing contracts such as the continued under supply from Tegeta at Optimum, Komati, and Brakfontein. The current threats of coal supply shortages—due to Eskom taking large stations offline for maintenance and not returning them to service on time, or supply failures at tied mines such as Matla—should not encourage signing of long term contracts at the older stations which would then "commit" the stations to run.[18]

In the NDC scenario, South Africa achieves average annual GDP growth of 3.3%. The sector contribution of agriculture (including forestry and fishing) increases to 2050, from 2% in 2012 to 4% in 2050, in-line with government goals of increased regional trade in agricultural goods. Industry's total contribution to GDP remains the same (29%). The electricity sector grows 0.92% faster than the average growth rate of other industrial sectors, due to increased investment in renewable energy over the period.

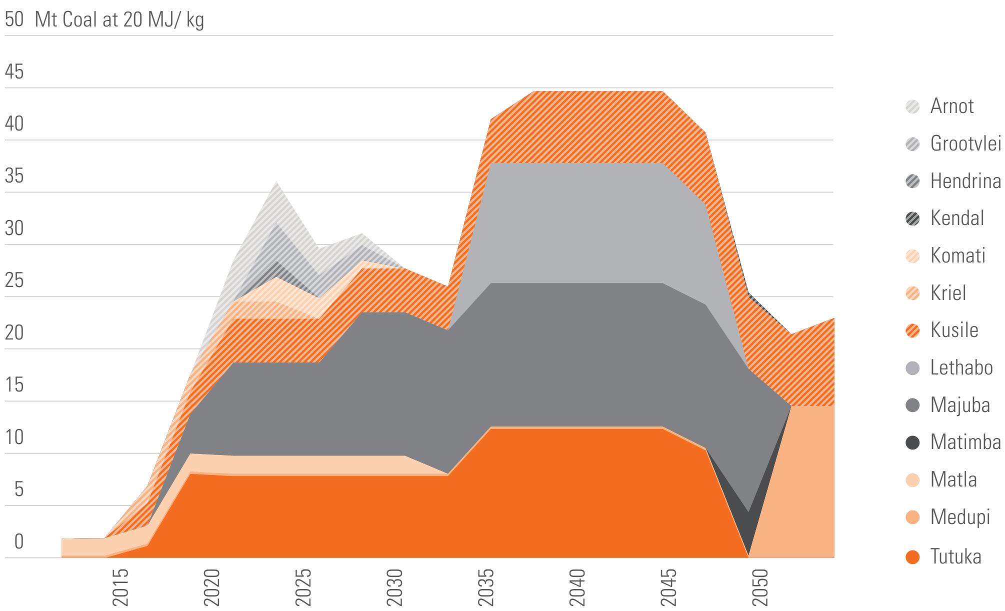
The trend towards higher growth in the electricity sector is also reflected in the employment numbers, where the net job effects in the electricity sector are positive, even as the number of workers employed in coal plants decreases as stations are decommissioned (since only Medupi and Kusile are online in 2050).

Employment in coal mining, as shown in **Figure 8**, decreases by 28,200 workers by 2050, relative to 78,000 workers in 2015. The impact on total coal mining employment is limited by the increased use of coal directly by the industrial sector, as discussed above; this offsets the decline in use of coal for electricity to some extent. The impacts could be substantially larger if lower growth rates in industrial sectors materialise, or if alternative energy sources in industry become competitive (through incentive schemes or market developments).

As discussed above, the NDC scenario shows a relatively stable coal production pathway despite the decrease in demand from electricity and liquid fuels, due to the increase in demand for coal in the industrial sector. However, the coal sector declines to 2050 due to the lack of competitiveness of coal compared to alternative technologies in the electricity sector.

18 Because stations are not endogenously retired in the model, the fixed costs still accrue to the stations until their official retirement dates; this partly explains why they continue to run even though there is a large generation surplus, along with the lock-in from existing contracts.

Figure 8. Uncontracted coal by station, NDC scenario



Coal production in the NDC scenario declines by 1.1% per year between 2017 and 2050 in a least cost energy pathway for South Africa. For comparison, the Chamber of Mines Coal Strategy examines 4 scenarios for the future of coal in South Africa. In their worst-case scenario, "Extinguisher", they state that coal sector production declines by 0.5% per year to 2050.[19] Our analysis suggests that both the coal sector and the state should be planning for a potentially even more rapid decline in coal use, though this is subject to uncertainties around future exports.

In our analysis, exports decline over the period by 4.6% per year or 80% over the period. By 2050, South Africa is exporting only 13 Mtpa. Even though we assume an export price increase over the period, this is not sufficient to encourage higher exports since production costs for higher-grade washed coal are also increasing (Merven, Durbach & McCall, 2016). Higher export prices could encourage higher export volumes, which would offset the decline especially up 2030. This would not dramatically alter the overall decline in demand for coal to 2050, however.

19 They also state that this scenario "describes a future in which the coal industry is disenfranchised to the point of near obsolescence" (CoM, 2018).

2ºC consistent coal transition scenarios for South Africa

For South Africa to meet its 'low-PPD' emission trajectory to 2050—which as discussed below can be considered consistent with 2ºC according to some equity consid-

Figure 9. Coal mining employment in the NDC scenario

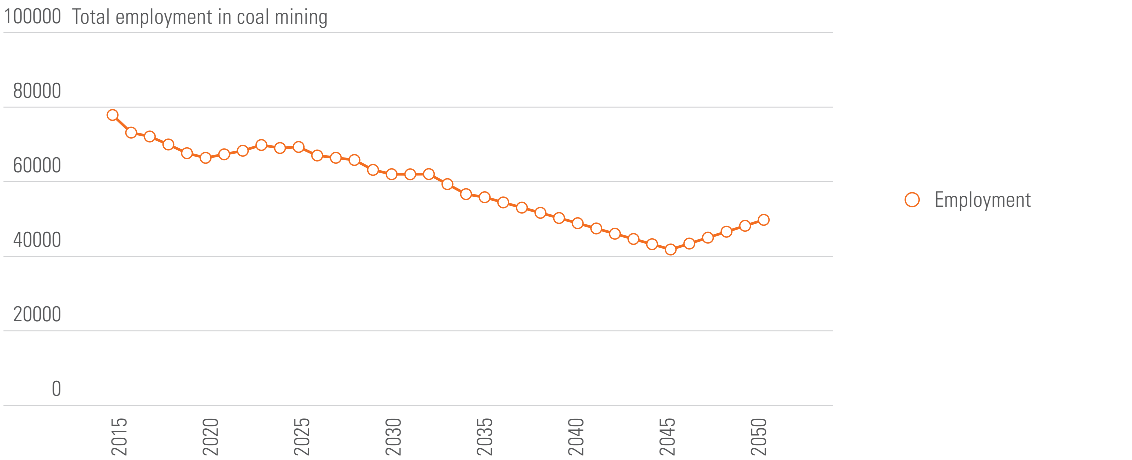
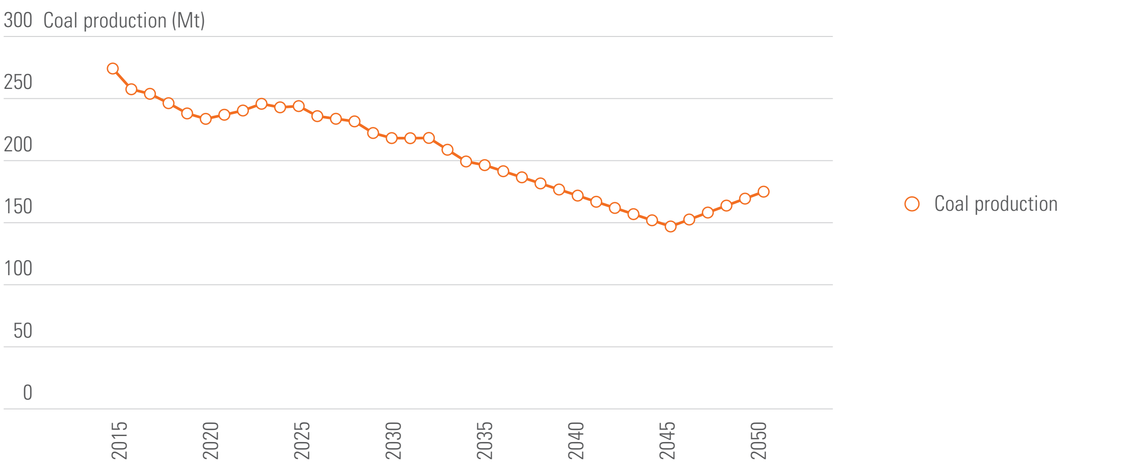


Figure 10. Coal production in the NDC scenario



erations—requires substantially quicker transformation away from coal than in the NDC scenario.

As discussed, CAT's assessment of the upper trajectory of South Africa's emissions pathway is that it is not sufficient as a fair contribution to limiting warming to below 2°C. However, the low-PPD trajectory corresponds to a cumulative national GHG emission budget of 12,7 Gt from 2015-2050 and represents an ambitious decline in emissions to 212 Mt CO_2-eq in 2050. This lower end of the emissions trajectory range is considered consistent with CAT's assessment of a 2°C compatible pathway. As will be discussed in the following section, meeting this trajectory requires early retirement of existing fossil fuel assets in liquid fuels and electricity supply, and we therefore consider it an ambitious pathway for South Africa given current technology assumptions. Nonetheless, along with all signatories to the Paris Agreement, South Africa may have to lower its emissions beyond the 2050 target in the National Climate Change Response White Paper, especially given key uncertainties around negative emission technologies.

Below we present the results of two 2°C scenarios. In each, a greenhouse gas emissions constraint consistent with the low-PPD is imposed on the model for the period 2020-2050. Excluding waste and AFOLU and updating the budget to reflect the period 2020-2050 results in a GHG cap of 9,5 Gt CO_2-eq (ERC, 2018). In the first scenario, we examine the effects on the energy system and economy of meeting low-PPD cost optimally. In the second, we commit Sasol's CTL plant to run to 2040, and examine the effects on the rest of the energy sector and economy of committing this emissions space to the Secunda plant (2°C_Secunda sensitivity). We examine this sensitivity because of key uncertainties around the future supply of liquid fuels. A cost optimal carbon-constrained pathway typically sees the retirement of the Secunda plant earlier in the period, but committing to Sasol's plant (as per Sasol's stated plans) highlights the increased mitigation required by other sectors in the economy to meet the low-PPD while maintaining a CTL plant.

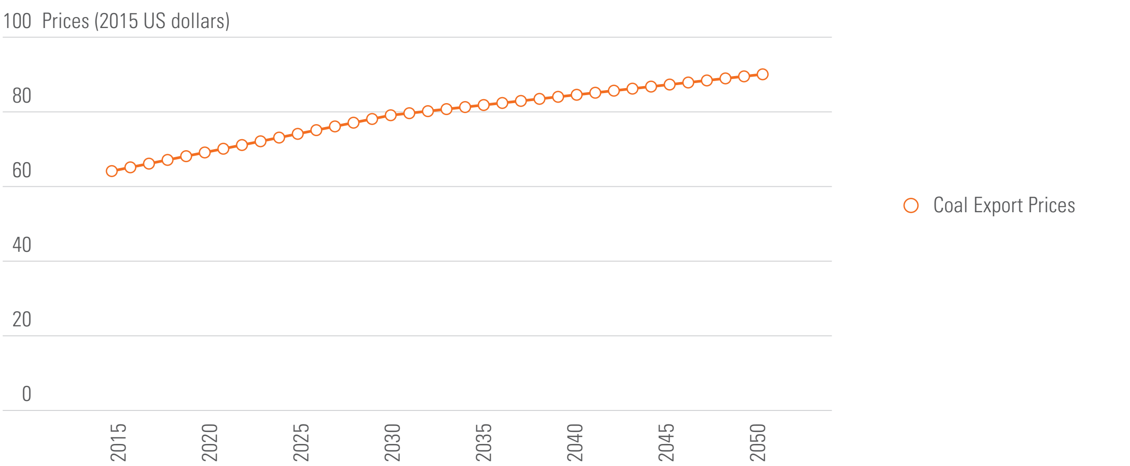
2°C scenario

The economy grows at an average annual rate of 3.3% per year to 2050. Electricity sector growth is higher relative to the NDC scenario by 0.24% on average per year to 2050.

Meeting the low-PPD emission budget to 2050 results in the installation of substantially more renewable energy in the electricity sector, where, because of its lower cost, most mitigation still takes place. By 2040, the share of coal in the electricity sector is zero with both Medupi and Kusile coming offline before then. Unlike the older coal plants that are surplus in the 2020s but have been paid off, Medupi and Kusile will only be online by 2022, and their retirement by 2040 results in both economic and technical stranding of the stations. Given this, calls for the last 2 units of Kusile not to be completed make economic sense given South Africa's climate mitigation policy commitments and the need for least-cost mitigation planning.

By 2050, solar PV and wind make up 80.2% of electricity generated, and gas 16% (with hydro 1.3%, and imports

Figure 11. Coal export prices from 2015 to 2050



1.5%). The earlier closure of the coal fleet is primarily made up from higher renewable energy penetration. Emissions in the electricity sector also drop significantly with the decline in coal use, with 39.5 Mt of GHG emissions in 2050 coming solely from gas (**Figure 12**).

As in the NDC scenario, industrial use of coal increases, making industry the largest emitter of GHG emissions by 2050 (**Figure 13**). The sector grows slightly more slowly than in the NDC scenario (0.3% lower on average per year, or 3.6% average annual growth). The same caveats apply to the industry results; further research is required to understand options for decarbonising industry in terms of both process emissions and heat requirements.

As can be seen in **Figure 14**, emissions from the energy and industrial sectors stay upper the low range of South Africa's NDC in the early years, although this excludes waste and AFOLU. By 2050, emissions at 258 Mt are much lower than in the NDC scenario (which are close to 400 Mt CO_2-eq in 2050). Most of the emission savings come from the earlier retirement of assets in the electricity sector, but the retirement of Secunda in the period 2030-2035 also results in substantial savings.

There are potential environmental and health benefits from moving to a 2ºC compatible pathway other than the potential reduction in GHG emissions. Such benefits include, in particular, reductions in pollutants such as SOx and NOx, which is especially relevant given the high concentration of coal-fired electricity plants in Mpumalanga and Limpopo. **Figure 15** shows indexed SOx and NOx emissions from power and industry sectors for the NDC and 2oC scenarios. Notably the 2oC scenario results in a decrease in emissions from earlier on in the period as coal-fired plants are run at lower load factors and then towards the end of the period as they come offline earlier than their scheduled retirements.

However, the slightly lower growth rates across the economy, except in the electricity sector, lead to lower employment in 2050 compared to the NDC scenario. As is to be expected, there is also a faster decline in coal mining employment as coal use declines more rapidly. **Figure 16** shows the impact of the 2ºC scenario on coal mining employment. By 2050, employment in the coal mining sector has decreased to just below 30,000 jobs, or 22,000 less in 2050 compared to the NDC scenario. The uptick in employment from 2040 corresponds to the increase in coal demand from industry. However, as discussed above, the increased coal use in industry may not materialise, and these numbers could therefore underestimate the impacts on coal mining workers.

2ºC Secunda sensitivity

While the overall results are relatively similar in that the electricity sector is the site of most mitigation, in the 2ºC_Secunda case, there is less carbon space for the rest of the energy system as Secunda runs for longer. As a result, the coal power stations are run at lower load factors over the period, shown in **Figure 17** and the coal fleet is retired even earlier than in the 2oC scenario (where Secunda is retired by 2035 due to cost optimal mitigation planning).

Overall, if Secunda runs to 2040, this results in Eskom's coal stations closing between 2 and 6 years earlier than in the case where Secunda is closed earlier. There is

Figure 12. Electricity generation by source (TWhs) and share of coal in generation (%) 2015-2050 (2°C scenario)

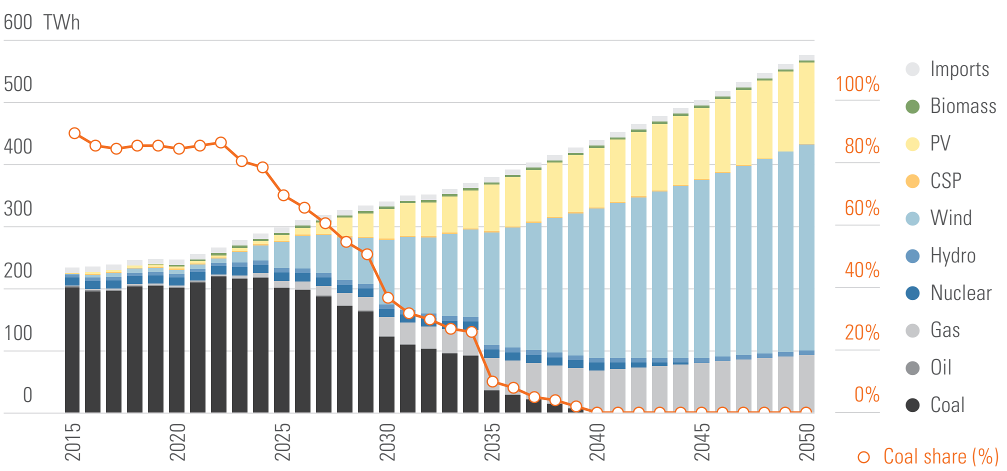


Figure 13. Electricity sector emissions in the 2°C scenario

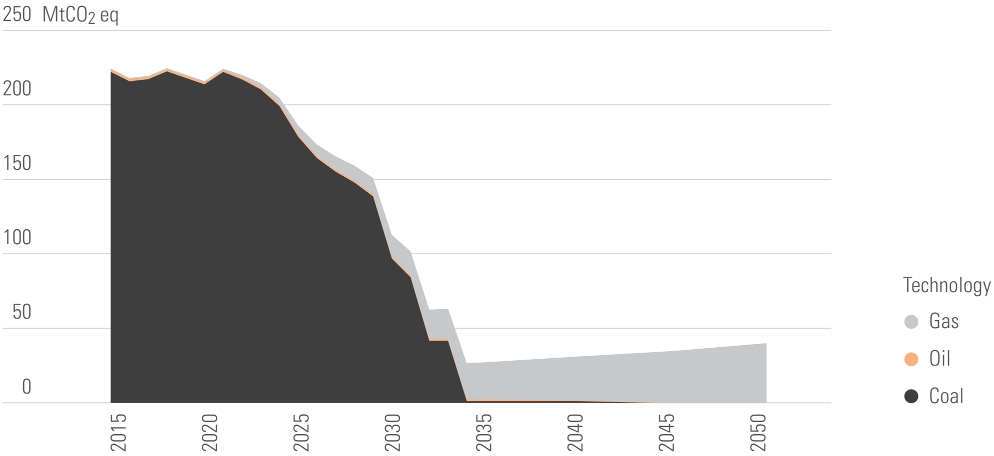


Figure 14. Greenhouse gas emissions by sector, 2015-2050, 2°C scenario

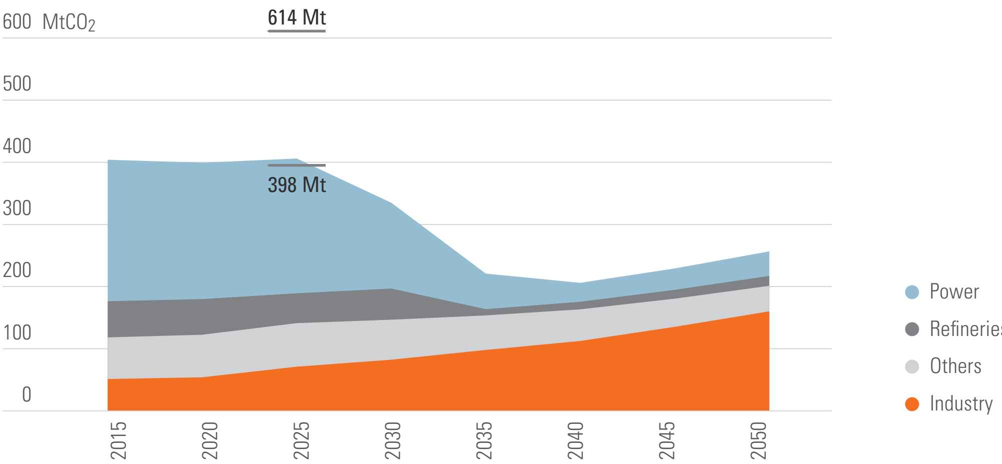
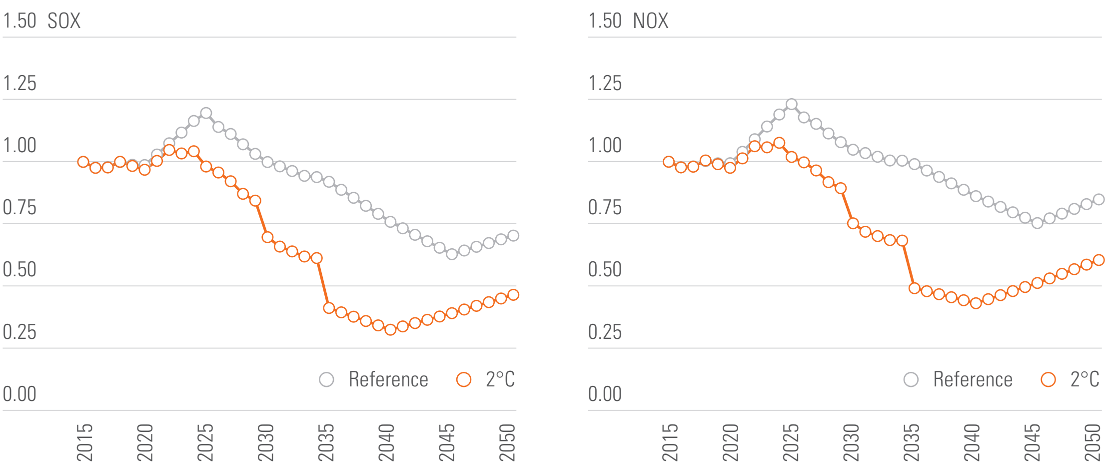


Figure 15. Indexed SOx and NOx emissions from power and industry (excl CTL) for the NDC and 2°C scenarios



therefore less demand for coal by the electricity sector from 2020. The earlier closures of Eskom plants would be exacerbated if Secunda ran to 2050.

The demand for coal however is slightly higher in absolute terms because of the demand for coal for the production of synfuels throughout the period, shown in **Figure 18**. The coal mining sector grows by 0.04% more per annum on average in comparison to the 2ºC scenario, but still 0.3% less on average per annum compared to the NDC scenario, shown in **Table 3**.

This is reflected in employment in the coal-mining sector, shown in **Figure 19**, where unemployment in the short to medium term is slightly less than the 2ºC scenario, but not as high in the late 2030s to 2050 when there is a higher demand for coal due to forcing Secunda to run.

Table 3. Coal sector average annual growth rates

	2017 to 2030	2017 to 2040	2017 to 2050
Reference	-1.16%	-1.69%	-1.12%
2°C	-3.38%	-5.44%	-2.84%
2°C Sensitivity	-3.85%	-3.79%	-2.99%

Table 3 shows the average decline in the coal mining sector per year between 2017 and 2050 for each scenario. The results of our analysis show that the coal sector faces an average decline of 1.12% from 2017 to 2050 even in a scenario without climate change mitigation policy.

Figure 16. Difference in employment from 2°C Scenario relative to the reference case

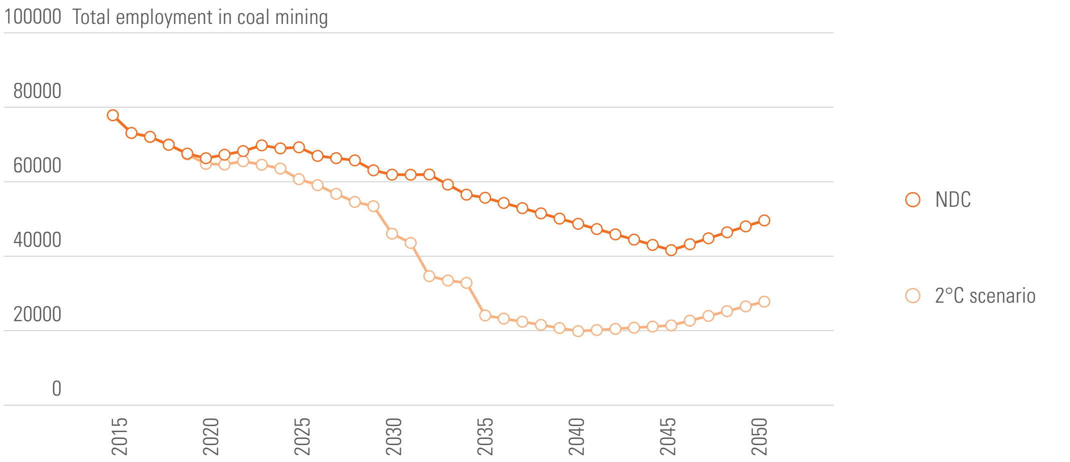


Figure 17. Average coal fleet load factors in all scenarios

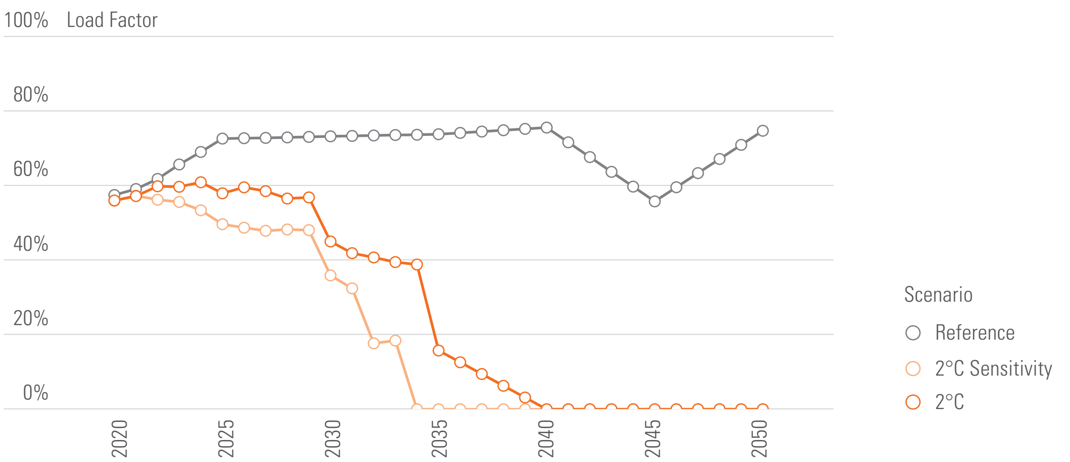


Figure 18. South Africa's coal production by scenario (for all sectors and exports; excludes imports)

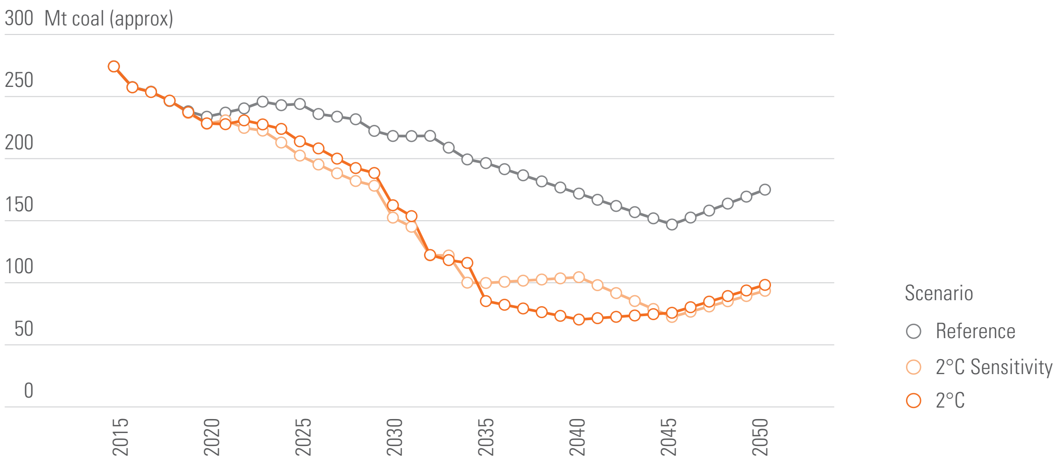
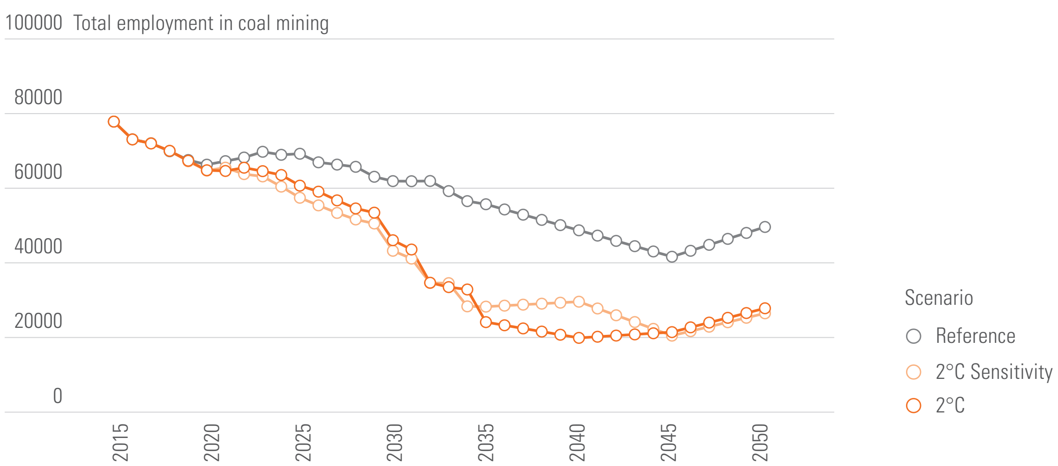


Figure 19. Employment in coal mining by scenario



Coal-related policy dimensions for achieving NDCs and moving to 2°C scenarios

Implementing NDCs

South Africa's NDC pathway described above, although it is a least cost energy pathway to 2050, is unlikely be achieved unless several conditions are met. While a least cost energy pathway is consistent with the upper range of South Africa's NDC, it will require policy and planning to implement, in particular if South Africa aims to achieve the lower range.

Firstly, it depends on the release of a least-cost integrated resource plan. Minister of Energy Jeff Radebe has indicated that the IRP will be gazetted in August 2018 following a period of public comment in July 2018. An IRP that includes new coal-fired power stations is not consistent with a least cost electricity plan, nor is it consistent with South Africa meeting the lower range of its NDC and low-PPD. Indeed, South Africa will exceed the lower range of the NDC even if it does not build new coal plants. The inclusion of either new coal plants or the life extension of older plants in the IRP will not only prevent South Africa from achieving the low range of its NDC (398 Mt CO_2-eq in 2025-2030), but will potentially raise greenhouse emissions to a level that exceeds the upper range of the NDC in 2025.

Currently, Eskom continues to explore life extension of the fleet through its "fleet renewal strategy", including extending the lives of plants to 60 years. This would raise emissions over the period substantially and put the long-term achievement of the PPD at risk. Similarly, South Africa will already exceed the lower end of the NDC commitment range in 2025 and 2030. The inclusion of new coal-fired power, for example the planned coal IPPs Thabametsi and Khanyisa, or the full new coal capacity envisaged in the IRP 2010, would further reduce the likelihood that the country could move towards the low range of its NDC (and thus it's PPD).

At the same time, an IRP should explore the implications of allowing coal-fired power plants to retire because they are surplus to capacity needs, no longer economic to run, or cannot be environmentally compliant. This is also necessary to understand the rate of South Africa's coal transition even without climate change mitigation policy. In previous iterations of the IRP, the plants were committed to run for 50 years, but as we have seen, it is already feasible from both an economic and energy security perspective to retire some plants due to their high costs (Steyn, Burton, Steenkamp, 2017).

Secondly, unless credible plans to support workers at coal plants and communities in coal areas are put in place, achievement of the NDC will elude South Africa. Already, calls have been made by Eskom and organised labour to keep stations open longer because of their socio-economic importance to towns in Mpumalanga. Eskom faces plants closing and a financial crisis that already means that retrenchments are likely to happen in the coming years, but it has no plans for decommissioning plants or for retraining, reskilling, and supporting workers to migrate to other stations or into new industries.

Even without any climate policy impacts, the closures of power plants are inevitable, and worker retraining, reskilling, and regional development initiatives are required to ease the transition and mitigate the closures of stations in Mpumalanga. One important insight from our analysis is that South Africa's coal transition, at least with current technologies, is focused primarily in the electricity and CTL sectors. Industrial demand for coal continues to grow to 2050, ameliorating the risks of a rapid phase-out for workers, especially in the upstream mining sector. On the other hand, if industrial demand for coal does not materialise (for example, GDP growth rates in industry are lower than modelled in this study), then the upstream impacts could be severe. We have also assumed that labour productivity in the coal sector remains constant to 2050. An increase in labour productivity through increased mechanisation or even automation could have severe impacts on employment in the coal-mining sector, and as discussed above, there are likely to be improvements in productivity.

Moving from NDCs to 2°C compatible transitions for coal

For South Africa to meet a carbon budget consistent with the long-term low-PPD trajectory requires the production and implementation of climate change mitigation policy beyond the least cost electricity pathway described above. The low-PPD is not achievable without focused attention on both energy supply and end-use sectors, and it implies the need for a concomitant transition policy process and plan for coal plant and mine workers.

Moving from the NDC scenario to the scenario with emissions consistent with low-PPD will require an accelerated phase out of large emitting infrastructure. While the rate of this phase out will also be defined by industrial use of coal, lower industrial use will not dramatically alter these findings. South Africa, along with the rest of the world, will have to become more ambitious to limit warming to below 2ºC. Our analysis shows that industrial energy pathways require focused research, including analysis of technical options, economic feasibility and policy and incentive packages to assist factories across the country to meet their energy needs through low-carbon technologies.

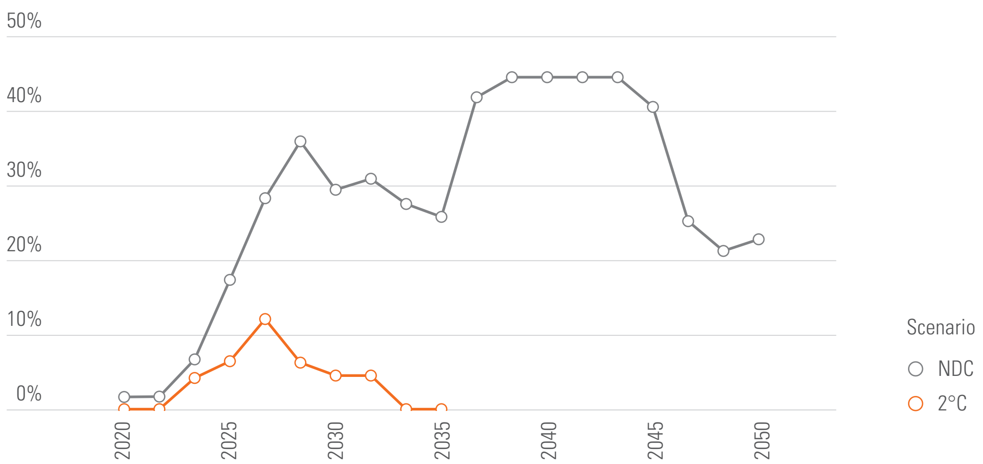
The economic results show that it is possible to both meet climate change targets and grow the economy. The large investment in new renewable energy will also have positive spin-offs for the country, including net positive employment impacts in the electricity sector. While the net job effects of a large scale rollout of RE are positive, there are risks for workers at coal-fired stations, mines, and the communities that depend on these assets if there is no orderly and properly resourced transition.

Our analysis shows one possible pathway for the transition away from coal in the electricity sector. As can

Table 4. Comparison of coal plant retirement in low-carbon scenario and analysis of coal supply

Station	IRP Retirement	20C - completely offline by: *(italic = early)*	Implications for upstream assets/mines
Arnot	2029	2029	
Camden	2023	2023	
Duvha	2034	2034	
Grootvlei	2028	*2025* – 3 years early	
Hendrina	2025	*2024* – 1 year early	
Kendal	2043	*2035* – 9 years early	New mine required for long-term supply; could be sized appropriately for shorter life.
Komati	2028	*2024* – 4 years early	Komati's coal contract ends in 2024 (already undersupplied from the Tegeta-owned mine).
Kriel	2029	2028 – 1 year early	
Kusile	2050	*2035* – 15 years early	No long-term contract signed for full volumes.
Lethabo	2040	*2029* – 11 years early	New Vaal contract expires 2029.
Majuba	2049	*2027* – 22 years early	No secured long-term contracts.
Matimba	2041	*2035* – 5 years early	Contract exceeds early retirement date.
Matla	2031	2031	Contract exceeds early retirement but mine requires new investment to meet the 2031 date.
Medupi	2050	*2035*-2040 – 10-15 years early	Contract exceeds early retirement date.
Tutuka	2037	*2030* – 7 years early	Undersupply from tied long-term contract and full volumes not secured.

Figure 20. Comparison of uncontracted coal requirements for least-cost/NDC versus 2°C scenario



be seen in **Table 4**, plants will need to close between 1 and 22 years earlier than Eskom currently anticipates. While the plants may be 'stranded' in that they are retired earlier than Eskom expects, this does not automatically translate into economic stranding, nor into stranded upstream assets. For several of these stations the early retirement coincides with the end of an existing contract or need for new investment which can be more appropriately planned for. Since Kusile is not yet complete, and no coal contracts for the full demand for the station has yet been signed, this suggest that not completing the last two units is important both for Eskom's current financial crisis and in terms of meeting climate mitigation targets. Furthermore, the reduction in coal needs between the NDC and the 2ºC scenario suggests the possibility that Eskom can access coal that is lower on the cost curve for specific stations and for the fleet in general.

For example, the difference in uncontracted coal between the NDC scenario and the 2oC scenario can be seen in **Figure 21.** The 'coal cliff' facing Eskom is greatly reduced when electricity sector planning accounts for climate policy and stations close earlier. While Eskom still needs to contract coal for the 2020s—in particular at Kusile—the quantities required are much lower. Coal contracting needs to take into account the long term energy planning choices that will be made in a future carbon constrained world; if not, Eskom will be locked in to coal contracts that are surplus to its needs.

What is now required is an analysis of the age and skills profiles of coal plant and mine workers in line with a retirement schedule that takes into account the real costs of new and existing coal stations (for example, future capex requirements for environmental compliance and for the aging fleet). This schedule also needs to consider South Africa's climate change commitments and how to meet them at the lowest cost to the economy.

There are also important lesson to be learned from South Africa's existing mining transitions, in particular the work on the Free State goldfields. Here, rapid and unplanned closures led to large job losses and socio-economic dislocation over a short period of time. These areas have never recovered from the rapid and disorderly transition that took place. The impacts were so severe that Marais (2013) has argued that "the scale and nature of mine downscaling in the Free State Goldfields is of such a magnitude that a national-level strategy is required, in addition to local efforts, to address the plight of communities in areas that have undergone rapid mine downscaling." (Marais, 2013).

South Africa can look to other countries undergoing energy transitions to learn at the institutional frameworks created for managing the transition for workers and communities. Ad hoc, unplanned transitions have typically been worse for coal dependent communities (Caldecott *et al., 2017).*

It is also clear that subsidies for the transition should be aimed at protecting workers, their dependents and the communities that are affected by the transition, rather than for Eskom and the coal sector. This is especially in light of the uncertainty around the state's ability to keep Eskom afloat and the potentially severe consequences on Mpumalanga livelihoods if no transition plan is put in place, institiuionalised, and resourced.

Conclusions

This study examines the current dynamics of the coal sector in terms of its role in the energy system, the economy and in society. As we have shown, the current state of the coal sector, both coal-fired electricity and coal mining is one of crisis, with rising costs and energy insecurity, and coal becoming increasingly less competitive for electricity.

A number of myths about the coal sector are debunked: that coal is cheap, that it employs vast numbers of people and that those people are unskilled. Coal is no longer a cheap and bountiful resource that can ensure security of supply for Eskom power plants. As the trends already show, closures (of plants and mines) are inevitable—the question is not if closures will happen, but when. South Africa is already facing a coal transition.

Secondly, this study analysed the socio-technical coal transition in the South African context. We examine a scenario where we assume that South Africa commits to meeting the lower range of its domestic climate change policy in the long-term.

Our analysis shows one possible pathway for the transition away from coal in the electricity sector. Moving from the NDC scenario to the scenario with emissions consistent with low-PPD will require an accelerated phase out of large emitting infrastructure. While the rate of this phase out will also be defined by industrial use of coal, lower industrial use will not dramatically alter these findings. South Africa, along with the rest of the world, will have to become more ambitious to limit warming to below 2ºC. Our analysis shows that industrial energy pathways require focused research, including analysis of technical options, economic feasibility and policy and incentive packages to assist factories across the country to meet their energy needs through low-carbon technologies.

The inclusion of either new coal plants or the life extension of older plants in the IRP will not only prevent South Africa from achieving the low range of its NDC (398 Mt CO_2-eq in 2025-2030), but will potentially raise greenhouse emissions to a level that exceeds the upper range of the NDC in 2025.

A further insight from our analysis is that South Africa's coal transition, at least with current technologies, is focused primarily in the electricity and CTL sectors. Industrial demand for coal continues to grow to 2050, ameliorating the risks of a rapid phase-out for workers, especially in the upstream mining sector. On the other hand, if industrial demand for coal does not materialise (for example, GDP growth rates in industry are lower than modelled in this study), then the upstream impacts could be severe. We have also assumed that labour productivity in the coal sector remains constant to 2050. An increase in labour productivity through increased mechanisation or even automation could have severe impacts on employment in the coal-mining sector, and as discussed above, there are likely to be improvements in productivity.

The economic results show that it is possible to both meet climate change targets and grow the economy. The large investment in new renewable energy will also have positive spin-offs for the country, including net positive employment impacts in the electricity sector. While the net job effects of a large scale rollout of RE are positive, there are risks for workers at coal-fired stations, mines, and the communities that depend on these assets if there is no orderly and properly resourced transition.

Overall, a transition away from coal is accompanied by many benefits, including cheaper electricity, improvements in air quality, and fewer impacts from extraction. Nonetheless, the concentration of coal fired stations and upstream mines in the Mpumalanga region pose a threat to socio-economic stability in those regions. Both a least cost energy pathway for South Africa and a more ambitious scenario that considers climate change result in declining employment in coal mining to 2050. Evidence from previous transitions, from this study, and from recent coal sector trends suggests that unless supported, the effects on Mpumalanga's (and to a lesser extent, Limpopo's) coal workforce are serious. While subsidies for Eskom are an option, the ability of the state to continue to prop Eskom up is limited, and the money is better spent in supporting workers and regional development initiatives to diversify the structure of the Mpumalanga economy to make it more robust.

Planning for the transition and for the possible impacts on coal workers requires a plan on which plants will close and when, who can be redeployed, who is retained and who pays. These are all considerations that need to be addressed with immediacy given that the transition is already underway.

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