Economy wide implications of stranding power sector assets in South Africa

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1. Introduction

Increasing attention is being given internationally to the risks associated with unburnable carbon and stranded assets (UNEP 2015, IEA, 2014; Citi, 2015). Stranded assets are defined as assets that "have suffered from unanticipated or premature write-downs, devaluations or conversion to liabilities" (Caldecott et al, 2014). This can arise from environmental regulation or other regulatory shifts, market forces, and other causes, including the falling costs of competing technologies.

Much of the research on stranded assets thus far has examined the potential financial risks to investors of stranding fossil fuel assets and wasted exploration and extraction capex (Carbon Tracker Initiative, 2011, 2013, 2015; Caldecott et al 2014). For example, McGlade & Ekins (2015) estimated that a third of oil, half of gas and over 80% of coal reserves cannot be burned in future emission scenarios consistent with limiting temperature rise to below 2^{o}C. Policy interventions to limit warming have been estimated to result in $100 trillion worth of stranded fossil fuel resources to 2050 (Citibank 2015). On the production side, potential wasted capex on fossil fuel projects that exceed the fossil energy requirements for scenarios consistent with 2^{o}C is in the order of $1.9-2.2 trillion, including an estimated $8.6bn in coal mining capital expenditure in South Africa (CTI, 2015).

These are significant (mis)investments globally and in South Africa, with potentially substantial impacts on companies and investors. There are, however, other systemic impacts of stranding assets, especially for an energy-intensive economy such as South Africa's with a large coal-based capital stock and growing energy demand[1]. These include, but extend beyond, the 'operator carbon risk' facing Eskom, Sasol, or independent coal power producers, or the "carbon asset risk" facing companies and investors in private and state-owned generators (UNEP, 2015). In South Africa, these include the national risks to energy security (including supply, affordability and acceptability), macro-economic impacts on the demand side (for energy-intensive industry and poor consumers) and welfare risks as a developing country with high levels of poverty and inequality

[1] As pointed out by Rozenberg et al (2014) the "irreversibility" of pre-existing assets imposes a short term abatement cost when accumulated high carbon infrastructure is high. Mitigation costs are comprised of technical costs (new technologies with potentially higher costs) and 'transition costs', the costs associated with abatement in a context of 'excessive' high carbon infrastructure i.e. the costs associated with investment that has already been made in polluting capital.

(StatsSA, 2014).

Given that the recently negotiated outcome of the UNFCCC's Paris Agreement will require commitment even from developing countries to reduce their greenhouse gas emissions, continued investment in high-emitting infrastructure may create costly risks for South Africa in the future. The energy sector, which in South Africa accounted for 80% of emissions in 2010 (DEA 2014), will need to meet decarbonisation targets in the medium to long term; indeed, as argued by Johnson et al (2013) in their global analysis of coal-fired power and mitigation, "limiting warming to 2°C over the course of the century will require the complete phase-out of coal-based electricity generation without CCS by 2050". Investing in new coal-fired assets in the short-term may well prove costly in the longer-term, as the risk associated with not recouping those investments due to policy shifts or technology changes grows higher, especially for plants built after Medupi (Bazilian et al, 2011).

This paper aims to understand the implications of South Africa reducing emissions as part of a global agreement to limit temperature rise to below 2°C and to examine the potential risks of stranded assets in the energy sector. Can South Africa meet carbon constraints without stranding assets? Given the structure of the energy sector and existing infrastructure, what are the potential effects of the country stranding energy assets to meet mitigation targets? What are the cost implications of investing in power plants that are later underutilised? What is the impact of ignoring non-electricity emissions on the costs of transition?

This study has 3 objectives, outlined below with brief rationales for each part of the analysis, the overall aim of which is to examine the effect of stranding power sector assets in South Africa.

1.1 Research Objectives

Firstly, we analyse the effect on the energy sector of meeting various carbon constraints. This has two parts. We first briefly describe the effect on the energy sector of decreasing South Africa's cumulative carbon budget (2015-2050) from 14 Gt CO_2-eq to 12 CO_2-eq and to 10 Gt CO_2-eq. Under a 14 Gt CO_2-eq constraint on the energy sector, Altieri et al (2015) found that there was no stranding of supply side infrastructure in the energy sector, even though a 14Gt budget does already represent a constrained emission trajectory). We therefore examine the effects of more stringent carbon targets on fuel switching, new technology investment choices and infrastructure utilisation, with a view to understanding the potential stranding of assets under more stringent mitigation scenarios.[2]

[2] We conceptualise stranded assets in the power sector as plants that are either mothballed or retired early as in the definition in Caldecott et al (2014). If new plants were not run at all or at low load factors, then capital costs would not be recovered. We also draw on the concept of stranded capacity as in Johnson et al (2013) where capacity is underutilised; for the latter, as carbon constraints are imposed, fossil plants are run at lower load factors, and fixed operating and maintenance costs are therefore not recoverable. In Altieri et al (2015; 2016), the authors assumed an economic life of 30 years for new power assets. Eskom depreciates new assets on its balance

South Africa has put forward a Nationally Determined Contribution that reiterated the country's 2009 Copenhagen pledge and which aligns with domestic mitigation policy - the National Climate Change Response White Paper (RSA, 2015; DEA 2011). Current energy planning processes in South Africa are not fully integrated with each other or with mitigation planning processes and national targets (DoE 2011a, 2011b; DEA 2011). Supply sectors have assumed (for example in the case of electricity planning) that certain portions of emissions space will be available to those sectors. This is not premised on national least-cost mitigation planning, and the Integrated Resource Plan for electricity implicitly assumes higher levels of decarbonisation will take place in other sectors to meet national emission targets. Furthermore, Caetano & Burton (2015) highlighted that South Africa's fair share of a global carbon budget could be considerably lower than its domestic policy commitments would suggest, and we therefore examine the effects of meeting lower cumulative constraints. These are intended to be indicative scenarios that highlight future implications of investment decisions and drivers of stranded assets.

Secondly, we analyse the impact on the electricity sector of constraining overall energy sector emissions while maintaining carbon-intensive liquid fuels production from Sasol's coal-to-liquid plant (CTL). In short, we analyse how quickly the electricity sector decarbonises under different energy sector carbon constraints and the effect of more or less carbon-intensive liquid fuels production on the levels of decarbonisation the electricity or other sectors must achieve.

While National Treasury has released several carbon tax policy documents and a Carbon Tax Bill was released in November 2015 (National Treasury 2010; 2013; Republic of South Africa 2015), few policies to meet mitigation targets (except in the regulated electricity sector) are being implemented. In this part of the analysis, rather than allowing the model to optimise (i.e. undertake least-cost planning for the energy sector as a whole) which typically results in the closure of the CTL plant to maintain a least-cost system, we "fix" the output of the plant to 2040. This requires other sectors to decarbonise more quickly than they would have otherwise, notably electricity, but also requires fuel switching in demand sectors such as industry and commerce. The CTL plant accounts for roughly 25% of liquid fuel consumption and 10% of national emissions and there is considerable uncertainty and political sensitivity around assuming closure dates for the plant. The 'fixed' scenarios provide an indication of the potential

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sheet over 30 years (DoE, 2013: 68). However, electricity tariffs are regulated through the MYPD process using a rate of return methodology and a modern equivalent asset valuation of the RAB. This assumes an asset base wherein the useful economic life of an asset is equivalent to its technical life i.e. 50 years, as per the Integrated Resource Plan update (DoE, 2013: 18). Depreciation is calculated (in the revenue requirement) over the operational life of the asset. There is thus an opportunity cost to stranding capacity with longer operational lifetimes (Johnson et al, 2013). The mismatch means that assets that may not be stranded on the balance sheet are nonetheless considered stranded by Eskom due to the earnings foregone for the utility, i.e. Eskom claims that the "true economic value" of the group's assets are not reflected on the financial statements (Eskom, 2015: note 52) costs to electricity users and the economy of not implementing mitigation policy beyond the carbon cap in the Integrated Resource Plan for the electricity sector. The trade-offs between mitigation in different sectors has not been explicitly acknowledged at a national level.

Third, we examine the effect of varying levels of decarbonisation in the electricity sector on the electricity price and the portion of national investment (measured as gross fixed capital formation) in the electricity sector, i.e. we unpack the investment required to meet increasingly stringent carbon constraints given current levels of installed coal-fired generation capacity. This allows us to describe the effect on electricity prices of either stranding assets or under-utilising existing coal plants and replacing them with lower carbon supply options; it also highlights the electricity price effects of national mitigation policy that does not address non-electricity energy supply sectors such as liquid fuels production in a carbon-constrained future. For this latter part we used a linked energy and economy-wide model.

Finally, we analyse the downstream effect of the electricity price on electricity intensive industry in South Africa under the different scenarios described above, examining rates of sectoral growth or decline. This is important in the South African context since the risks of stranding energy intensive industry in the future could be significant, leaving South Africa with a “stranded economy” that has developed in response to energy and industrial policies that have ignored climate change. This paper assumes that global mitigation policy is implemented and that South Africa contributes its fair share of the mitigation effort. The study is intended to highlight the potential risks of policies that do not take this possible future into account. Global carbon constraints could result in significantly higher electricity prices, but coupled with on-going investment in fossil fuel sectors and energy intensive industry, this could have substantial macro-economic effects. Depending on how the energy sector mitigates greenhouse gases and how short-term investment decisions on new coal-based energy infrastructure are made, the costs of meeting mitigation targets may be increased if short-term decisions are made assuming that no mitigation policy will be implemented in the medium to long-term.

2. Modelling Technique

The study is based on modelling that uses both an inter-temporal bottom-up optimisation energy model of South Africa (SATIM -F) and a partially linked energy and economic model (SATIM - e-SAGE). In the energy and economic model, an optimisation model of the South African electricity sector (SATIM-E) is linked to a dynamic recursive computable general equilibrium model e-SAGE. The modelling is completed in two steps. Firstly SATIM-F is run to generate a profile of CO_2-eq emissions for the electricity sector. Secondly the linked model is run to explore the economy wide impact of meeting the mitigation required from the electricity sector. As the full sector model (which is explained in more detail below) includes fuel switching and options for improving energy efficiency in all sectors, the CO_2-eq constraint that is applied in the linked model is assumed to represent the maximum emissions that can be allocated to electricity generation if South Africa is to meet the cumulative emissions targets imposed in 2050.

2.1 SATIM-F

SATIM-F is a full sector TIMES model that includes both the supply and demand side of the South African energy system. SATIM can be run using linear or mixed integer programming to solve the least-cost planning problem of meeting projected future energy demand, given assumptions such as the retirement schedule of existing infrastructure, future fuel costs, future technology costs, learning rates, and efficiency improvements, as well as any constraints such as the availability of resources. Demand is specified in terms of useful energy representing the energy services needed by each sector or subsector (e.g., demand for energy services such as cooking, lighting, and process heat). Final energy demand is then calculated endogenously based on the mix of supply and demand technologies (e.g., capacity, new investment, production, and consumption) that would result in the lowest discounted system cost for meeting energy demand over the time horizon, subject to any system constraints that are applied. The model allows for trade-offs between the supply and demand sectors, it explicitly captures the impact of structural changes in the economy (i.e., different sectors growing at different rates), process changes, fuel and mode switching, and technical improvements related to efficiency gains (Altieri et al, 2015).

The model has five demand sectors and two supply sectors, which can be analysed individually or together. In SATIM-F the demand sectors are industry, agriculture, residential, commercial and transport, and the supply sectors are electricity and liquid fuels. SATIM-E utilises only the electricity supply module of SATIM-F. The technical, economic and demand projection data for each sector is contained in a set of databases accessible to the public. [3]

2.2 e-SAGE

E-SAGE was developed by UNU-WIDER and is based on the 2007 South African Social Accounting Matrix (SAM). The SAM is a set of accounts that represents all of the productive sectors and commodities in South Africa, as well as factor markets, enterprises, households, and the 'rest of the world.' The 2007 SAM has 61 productive sectors (industries) and 49 commodities. The seven factors of production include land, four labour groups disaggregated according to level of education, and there is a distinction between energy and non-energy capital (Arndt et al, 2011). The government, enterprises, 14 household groups based on their per capita expenditure, and interactions with the rest of the world[4] are all represented. The behaviour of industries and households is governed by rational expectations (Thurlow, 2004; 2008). Industries and producers aim to maximize profits while households aim to maximize their utility subject to their budget constraint. Product and factor market equilibrium are maintained.

E-SAGE is a dynamic recursive model and as such has two periods, the

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[3] The detailed documentation of SATIM can be found at: http://www.erc.uct.ac.za/Research/esystems-group-satim.htm

[4] These are based on an external account that includes: global commodity prices, foreign financial flows, payments for imports and revenues from exports, and trade elasticities.

"within-period" and the "between period". The static run of the CGE model makes up the within period, in which the economy adjusts to an annual shock. Some variables and parameters are updated based on the new equilibrium during the between period, with capital accumulation and re-allocation being determined endogenously with exogenous forecasts for population growth, factor productivity and technical change in the energy sector from SATIM-E (Alton et al, 2014; Altieri, 2015).

CGE models are governed by a set of closure rules that are used to ensure that macroeconomic balances and constraints on the economy are abided by in the model. In other words, decisions are made as to which variables are endogenous and which are exogenous and this governs the way that the model adjusts so that all of the accounts 'close'.

The following closures are applied for all of the e-SAGE model runs:

- **Savings and investment:** Previous studies have found that the savings-driven investment closure is most appropriate for South Africa. [5]
- **Government:** Uniform sales tax rate point changes are allowed for selected commodities, while government savings remain fixed.
- **Foreign:** South Africa has a flexible exchange rate, therefore a fixed trade balance is assumed and the exchange rate is able to adjust and maintain equilibrium between the payments to and from other countries. [6]
- **Factor market:** A large portion of the low-skilled workforce in South Africa is unemployed, and some of this unemployment is structural. Therefore, it is assumed that low-skilled labour is not fully employed and that there are rigidities in the labour market.[7] Skilled labour and semi-skilled labour is assumed to be fully employed and mobile. Factor prices (i.e. rent or wages) are allowed to adjust to ensure equilibrium is reached and demand equals supply. Capital is assumed to be fully employed and activity- or sector-specific. Land is fully employed and mobile, that is, it can be used for different purposes.

Finally, a key feature of the e-SAGE model is that non-energy industries can react to energy price changes during the between-period by shifting their investments

[5] The relationship between savings and investment continues to be a highly debated and controversial topic in macroeconomics (Nell, 2003). Neo-classical along with new endogenous growth theory maintains the view that it is former savings that decide an economy's investment and output (Thurlow, 2004). Conversely, from a Keynesian perspective, it is investment that is exogenous and savings that adjust accordingly (Thurlow, 2004). Although, according to Nell (2003), recent works have established that in the case of South Africa, the long-run savings and investment relationship is associated with exogenous savings and no feedback from investment. In light of this, the SAGE model assumes a savings-driven closure (Arndt at al, 2011). This implies, amongst other things that the deficit (foreign debt) is kept constant.

[6] The IMF projections show South Africa maintaining a current account deficit similar to the current deficit to 2020 – this is in-line with the assumptions made in the model.

[7] To simulate unemployment, an upward sloping supply curve was assumed for low-skilled labour. Low real wage supply elasticities were also assumed to indicate that their unemployment is structural.

to less energy intensive capital and technologies, the ease of which is specified exogenously (Alton et al, 2014)[8].

2.3 The Linked Model

The linked model draws on features of both models to improve the modelling outcome. The energy model is able to capture the temporal use of electricity as well as detailed supply side investment options in a wide range of technologies. e-SAGE on the other hand, captures changes in economic structure and price responses due to shifts in the energy sector and emission constraints.

In the linked model, alternate runs of SATIM-E and e-SAGE are performed from 2006 to 2050, in 5-year increments, and information is passed between models after each instance, shown below in figure In each iterative loop SATIM-E uses the sectoral demand for electricity from e-SAGE to compute an investment plan, and an electricity price projection. The investment plan and electricity price are passed to e-SAGE to determine the impact that the new price projection has on sectoral demand for electricity. The price-adjusted demand from e-SAGE is then passed back to SATIM-E in the next iteration. By linking the two models, the economic model replicates an electricity supply mix that is determined by SATIM-E and meets the cumulative carbon constraint, and SATIM-E in turn, invests only in sufficient capacity to meet the electricity demand of an economy that is reacting to any increase in electricity prices due to new investment and mitigation. Although only the electricity sector of SATIM (SATIM-E) links to e-SAGE at this point the linked model still offers insights which are not possible using the standalone energy and economic models (see Arndt, 2014 for full model description).

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[8] Energy is considered an intermediate input and the interaction between intermediates and factors is governed by a Leontief production function. To decrease the rigidity of using a Leontief production function, there is ‘response elasticity’ that governs the amount sectors are able to change in their energy inputs per unit of output based on energy prices.

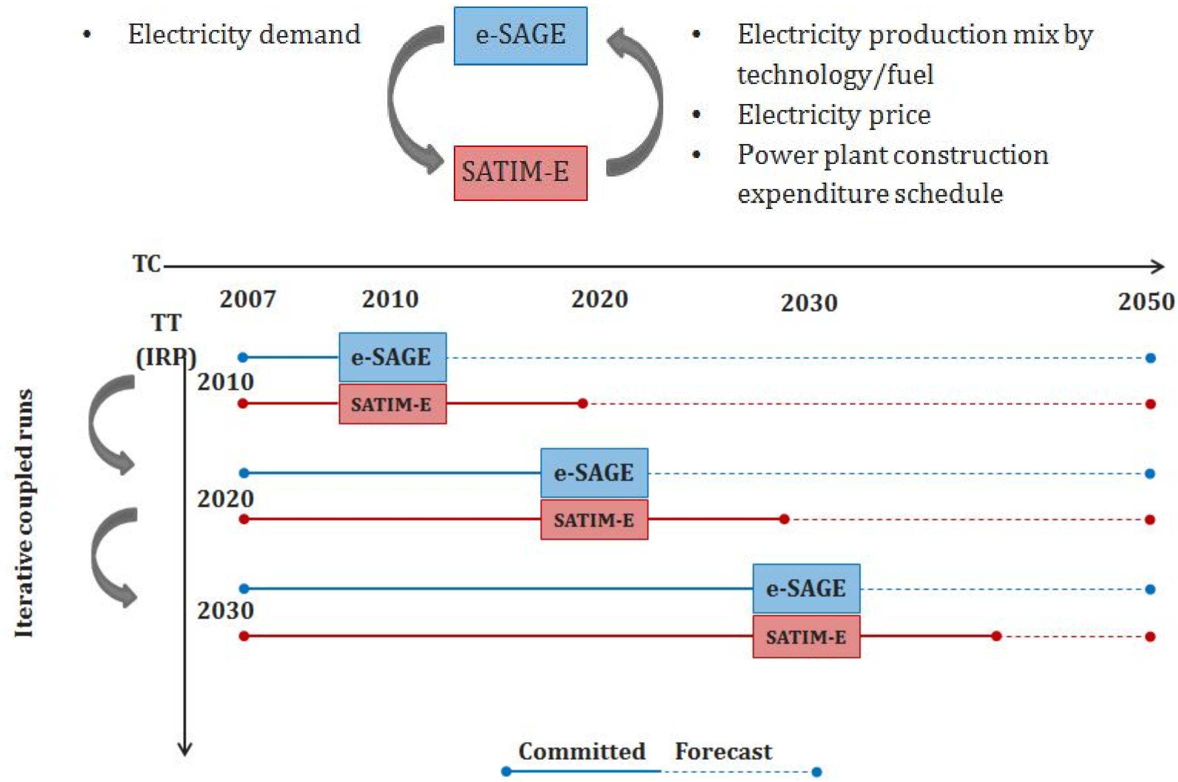

Figure 1 Iterative feedback process between SATIM and e-Sage

Unlike the modelling undertaken by the Department of Energy for the Integrated Energy Plan and the Integrated Resource Plan, the linked model allows feedback between the economy and the energy system (though currently limited to the electricity sector only). There remain key areas for future work, however, and with further linking the model could be used to illustrate the economy-wide impacts of price increases or changes in other sectors. For example, switching from coal-to-liquid to imported crude-based liquid fuels, or the price effects of fuel switching in demand sectors (for example from coal to gas in industry, or liquid fuels to gas in transport). We therefore report the result of increasing the mitigation constraints for the energy sector as a whole but note that the results we report on the economic effects are for the electricity sector only.

3. Scenarios

South Africa has two key challenges that informed the development of scenarios for this analysis. Firstly, the country has very high levels of poverty and inequality (StatsSA 2014; NPC, 2011). A central challenge in achieving a reduction in poverty is the high unemployment rate (24% using the strict definition or 37% using the broad definition) and low skills base, and it is imperative that job losses are minimised across sectors. Secondly, South Africa is a carbon- and energy-intensive economy with high dependency on coal, and has committed to global agreements to reduce emissions to avoid dangerous anthropogenic interference in the climate system. Much of South Africa's industrial base is premised on energy and carbon intensive mining, minerals beneficiation or chemicals processes. Higher electricity prices are therefore viewed as a risk to those sectors. While they account for a relatively small portion of total GDP, they are still large employers and are viewed as key to industrial development in the country. Understanding the effects of mitigation and the potential to alter the development trajectory of the economy to make it more pro-poor and structurally able to meet mitigation goals is a key area of work (see Altieri et al, 2015, 2016; Baker et al, 2015; Winkler & Marquard, 2009). In order to model these two goals, scenarios are modelled in e-SAGE and in SATIM. In SATIM, emissions constraints are applied. In e-SAGE, we simulate a structural change in the economy in the future.

In the economic model, we simulate a structural change in the economy by increasing openness to trade (as per Altieri et al, 2015; 2016)[9]. This simulates an increase in agricultural exports to the region, meeting a key policy goal in the National Development Plan (NPC, 2011) to increase regional exports. This offsets to some extent the negative impact on GDP of an increase in electricity prices experienced by energy-intensive industry, which may experience lower growth rates as prices increase. This economic pathway is intended to indicate that the South African economy can grow even as it meets mitigation targets - including stringent ones – but that this depends on a structural change in the economy and higher growth in sectors with lower energy and carbon intensities.

In SATIM-F, 5 scenarios are run in order to develop the emissions constraints that are applied to electricity supply within SATIM-E. Three of the scenarios simply represent increasingly stringent cumulative carbon constraints applied within SATIM-F. In the first three scenarios the level of CO_2-eq in the model is not allowed to rise above a cumulative (2015-2050) level of 14Gt, 12Gt and 10Gt respectively. Under these scenarios, an existing coal to liquid plant (Sasol's Secunda plant), which is responsible for roughly 10% of current emissions and 25% of current liquid fuels supply shuts down prematurely. Given the uncertainty and political sensitivity around assuming that closing this plant is possible, two additional scenarios are run in which the coal to liquid plant is forced to run at full capacity until the end of its assumed economic life in 2040. This forces other sectors to reduce their emissions further. All the sectors in SATIM-F can react to provide the mitigation required, switching for instance from coal to gas where possible, or from coal-based to lower-carbon electricity. The electricity sector, however, absorbs the majority of additional emissions reductions required to meet the target (because it is the lowest-cost option to do so).

The assumptions used (for example related to technology costs, learning, GDP growth and the like) are based on the assumptions in Altieri et al (2015), but with one key difference related to the coal supply options in the model. Here, we have used a disaggregated coal supply as in Merven & Durbach (2015). The rationale for the change in the way the coal supply is modelled is to represent in more detail the spatial and contractual differences in coal supply in South Africa

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[9] In more technical terms, in order to simulate trade openness in the model the CET function for agriculture was changed.

(Figure 9in the Appendix for further detail on how coal supply is represented in the model). The new coal supply model differentiates between Central Basin and Waterberg coal supply (including transport and logistics costs), existing long-term contracts and the costs of coal from new mines (investment and running costs were separated out, including the costs of beneficiation of coal for Eskom or for export markets).[10]

Table **1** provides a summary of the scenarios. Figure 1 below shows how the full energy sector constraint is translated into an electricity sector constraint for each scenario.

Table 1: Summary of Scenarios

Scenario	Satim full sector constraint, 2015-2050
1 – 14 Gt Constraint	Cumulative 14 Gt CO_2-eq
2 – 12 Gt Constraint	Cumulative 12 Gt CO_2-eq
3 – 10 Gt Constraint	Cumulative 10 Gt CO_2-eq
4 – 12 Gt Constraint SAS	Cumulative 12 Gt CO2-eq CTL fixed to 2040
5 – 10 Gt Constraint SAS	Cumulative 10 Gt CO_2-eq CTL fixed to 2040

As can be seen in Figure 2, the carbon constraints imposed on the electricity sector are in a wide range, to highlight the potential for stranded assets under different climate change policy targets. In the most stringent case (10 SAS), the electricity sector must start to decarbonise immediately to make room for the emissions associated with carbon-intensive liquid fuels production while meeting a lower emissions constraint. At the other end of the range, the 14Gt scenario allows for some growth in electricity sector emissions, which decline slowly after 2020. The sector reduces emissions but continues to emit even in 2050. The 12Gt and 12Gt SAS both allow some space for growth in emissions but with steep declines. In all the scenarios, the rate of reduction possible before 2020 is limited by the lead times for commissioning new infrastructure.

[10] This had the effect of increasing investment in coal-fired capacity in our 14Gt scenario compared to the study by Altieri et al (2015; 2016), where no coal-fired power was built after Kusile.

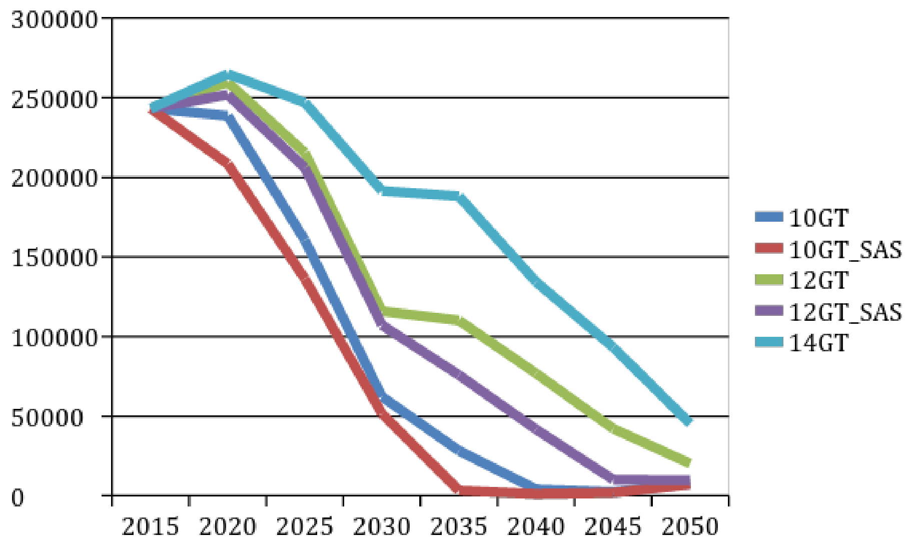

Figure 2 Carbon constraints applied to the electricity sector in each scenario

The following section discusses the results in detail, outlining the stranding of power sector assets under different mitigation constraints and policies.

4. Results

The effects on the electricity sector of meeting various carbon constraints are outlined below. We first briefly describe the effect on the energy sector of decreasing South Africa's cumulative carbon budget (2015-2050) from 14 Gt CO_2-eq to 12 CO_2-eq to 10 Gt CO_2-eq. We then outline the highly constrained 10 and 12Gt scenarios with the output of the coal-to-liquids (CTL) plant fixed to 2040, and the effects this has on the rate of decarbonisation in the rest of the energy system. We focus on the electricity sector but include liquid fuel supply, as well as results for commercial, industrial and transport demand for the various scenarios in the Appendix.

Whether assets are stranded in each scenario depends on the assumptions made about the useful economic life of assets, commissioning dates of new plants, and the concept of "stranded capacity" related to the average annual load factors for the Eskom fleet.

We consider assets as stranded when they are closed before reaching the end of an economic lifetime of 30 years for new plant, since this is the period over which assets are depreciated on Eskom's balance sheet, and aligns with the plant lifetimes for new plants in the Integrated Resource Plan update (DoE 2013:68). However, Eskom also notes that it assumes that the technical lives of older plant (50 years, except the return to service stations) are equivalent to the useful economic lives of those power stations (2013:18). Thus, even though plant closure may not be a financial risk in terms of paying off the investment, retiring plant before the end of its planned life is still "stranding" that asset from Eskom's perspective, since they are foregoing earnings on a plant that could otherwise run for a further 20-30 years. In some cases, coal plants are not stranded when a 30-year life is assumed, though they are stranded if a 50-year life is assumed. The costs associated with an asset that is taken out of service or underutilised before the debt has been re-paid are of course much higher than the opportunity cost of underutilisation of an asset that has been paid off.

Secondly, delays in commissioning may affect whether new coal plants are stranded or not under an assumed shorter economic lifetime of 30 years. While we assume that Medupi and Kusile come online as was originally planned (i.e. between 2015 and 2020), Eskom CEO Brian Molefe has announced that the final commissioning date for Medupi is 2020 and for Kusile 2022 (Le Cordeur, 2015). Currently, projects under construction form part of Eskom's asset base in the tariff determination, but depreciation commences only once plants are fully commissioned (Das Nair, Montmasson-Clair, & Ryan, 2014; Eskom, 2012). Thus, closure before 2050 would, in reality, result in stranding of those assets.

A third aspect is that of stranded capacity (Johnson et al, 2013). This is defined as "the installed capacity that is not utilized when a plant is operating below the load factor for which it is designed". Load factors can be understood as the output of a plant "over a period of time relative to the potential maximum"; this depends on both running time (how often the plant is running throughout a given year) and average operating load (output of a unit/plant versus full-load design) (IEA, 2010).

In competitive electricity markets (e.g. the UK), coal plants are already facing early retirement due to low load factors rendering the cost of electricity produced by those plants uncompetitive in those markets. While the plant as a whole is not stranded, a portion of that useful asset is not being utilized optimally. The underutilization is a form of stranding, but is measured as that plant capacity that is not used. The economic costs would differ according to whether it is an existing (depreciated) plant or newer plant that has not been paid off. But the economic effect is to increase costs through sub-optimal utilization of coal-fired power plant assets.

Stranded capacity can be understood as a "transition cost". Rozenberg et al (2014) have pointed out this further aspect of the costs associated with stranded assets. The authors have argued that the costs of transition to a lower-carbon energy system has two parts: technical costs related to investment in new technology that may be more costly than conventional options, and the transition cost associated with the underutilization of assets to meet abatement targets under conditions of high levels of preexisting investment in high carbon infrastructure. Under very stringent carbon constraints, the significantly higher cost of electricity is caused by the need for rapid new investment to replace existing coal infrastructure, as well as meet growing demand (technical cost), while at the same time existing assets are not utilized fully because they emit higher levels of carbon dioxide and the investment therefore cannot be recouped while emission limits are met (transition cost).

In the scenarios discussed below, the fleet of coal plants run at lower average annual load factors to meet electricity demand while also meeting the carbon constraints imposed under different scenarios. This provides flexibility to the system in cases where the electricity sector is especially emission constrained (10Gt and 10Gt SAS scenarios in particular), and where wholesale closure of the plant would require expensive new infrastructure to be built or where demand cannot otherwise be met (for example, because of the lead times of new power plants). Because the model aims to have the least-cost system, it will utilize any carbon space available to it if the outcome is lower cost than another option. In some of the scenarios, however, the average annual load factors for the fleet are very low (often below 40% and in some cases below 10% load factor). The plant capacity in SATIM is aggregated, however, and the very low average annual load factors do not necessarily mean that the entire coal fleet is consistently running at technically or economically infeasible levels. Rather, certain plants and units are available when required. The fleet is, however, ramping up and down significantly in different time slices, for example between weekdays and weekends (while capacity is being decommissioned over time as per the end of life of each plant). It may be necessary to add a lower bound on the coal fleet for future work, so that capacity is retired when it is running at very low load factors, instead of remaining available to meet demand, which may be underestimating the costs of stranding and the costs of investment in new capacity required to meet demand.

The economic effects of stranded sets and capacity are therefore three-fold. While new capacity is required to meet demand in all scenarios, significantly more new capacity is required to fill in the gap between growing demand and a supply side system filled with older coal plants that must be run less so as to meet the mitigation target. This is exacerbated in situations where new coal capacity (not yet paid off and therefore producing electricity at higher cost) is run at lower load factors. Firstly because the costs of electricity from those plants is therefore higher; and secondly, because the investments may not be paid off at all if the assets are retired before the end of their lives. The replacement of coal infrastructure with new investments may be costly, but further investment in coal-fired power that becomes stranded adds unnecessarily to the costs of mitigation.

4.1 The Power Sector

Whilst the technology mix of electrical generating capacity remains similar in 2050 in all scenarios, renewable energy and nuclear are introduced far earlier as emissions are more tightly constrained in the 12 and 10Gt scenarios. Figure 3 illustrates the shift in electricity production from coal to predominately concentrating solar power (CSP) with high storage (14 hours) and nuclear; but also gas, wind, imported hydro, and solar PV.[11]

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[11] A full set of assumptions around technology costs, learning rates, lead times and other inputs are outlined in Altieri et al (2015).

Table 2 Installed capacity of existing coal fleet (GW)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Existing Coal (GW)	36,0	37,0	36,5	32,1	22,7	17,3	8,4	3,8	0,0

In the discussion below, the existing coal fleet refers to the current installed coal capacity in the electricity sector. Table 2 shows the total installed existing coal capacity (assumed retirement dates from the IRP 2010) (DoE, 2011). In the discussion that follows, "new coal" includes Medupi and Kusile and any further coal capacity that is built.

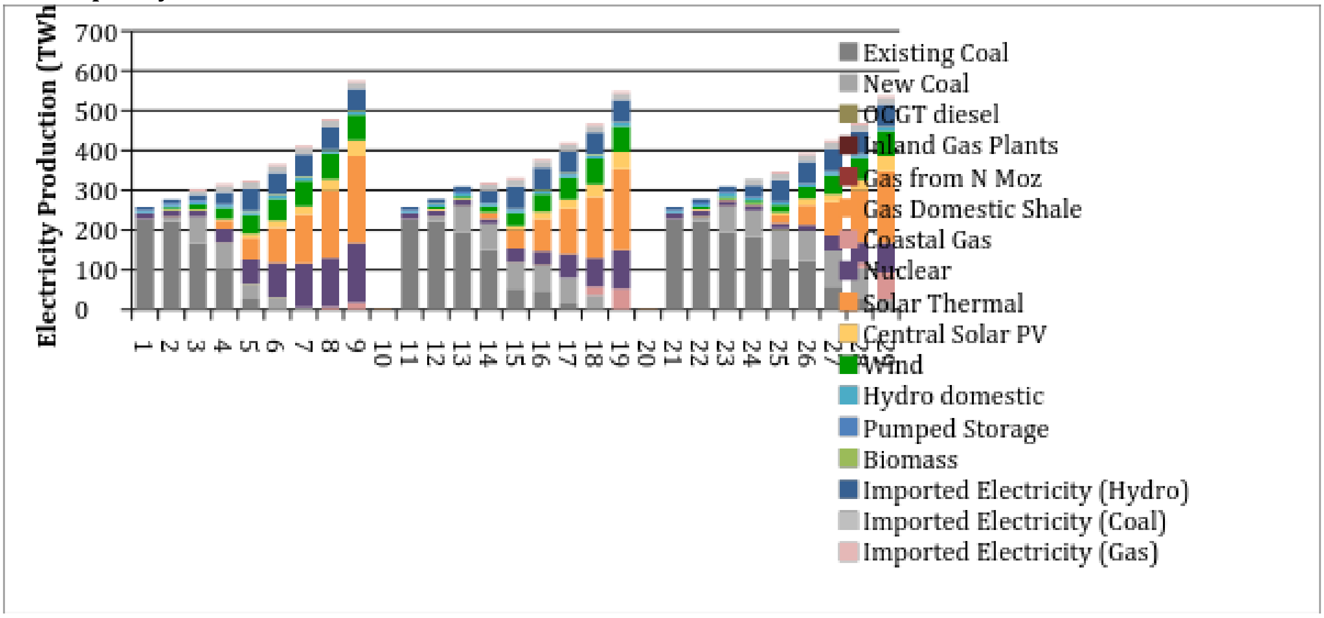

Figure 3 Electricity production under 14, 12 and 10Gt CO_2-eq constraints

Under the 14Gt constraint, new coal built over the period totals 11.9GW (net capacity). This includes Medupi and Kusile (8.7GW) and additional net capacity additions of 3.2 GW. By 2050 coal accounts for 24.5 TWhs of electricity produced (total production: 537 TWhs). Imported-LNG-fired turbines, nuclear and CSP supplement coal-fired electricity production. Decommissioning of existing coal plants proceeds according to the IRP 2010 schedule, with the last units of the existing fleet (i.e. Majuba) being decommissioned in 2048 and 2049. The existing fleet thus continues to run until the end of its planned life (50 years without life extension). Output from new coal peaks in 2040 and declines rapidly thereafter, with Medupi and Kusile coming offline by 2050. Installed coal capacity of 3.2GWs remains in 2050[12].

[12] The modeling horizon extends only as far as 2050 and we therefore do not include later years. Since the constraint is modeled as a cumulative constrain on emissions, we would require some certainty on how mitigation policy would unfold after 2050 to model that; currently South Africa's policy extends only to 2050. If emissions were required to reduce further, then the remaining coal assets would be stranded. Since the Paris Agreement includes commitments to net negative

Existing and new coal plants are run at higher load factors than in more constrained scenarios, although there are slightly lower load factors for the existing fleet in the 2020s to absorb the output of new coal plants coming online. Table 3 below shows the average annual load factors of existing and new coal from 2010-2050 under a 14Gt constraint. As can be seen, new coal plants run until 2050 (the end of the modeling horizon), at expected load factors. Assuming a 30-year lifetime, neither Medupi nor Kusile would be stranded if they were commissioned on time. If commissioned later, the plant may be retired before being fully depreciated. If Eskom's assumption of plant lifetime (i.e. 50 years) is assumed, Medupi, Kusile and the additional replacement coal capacity will become stranded assets.

Eskom's assumption that plants have a 50-year lifetime means that both plants would be stranded from Eskom's perspective, as would the remaining 3.2GW installed coal capacity depending on the post-2050 climate policy and constraint.

Table 3 Average annual load factors for the fleet of existing and new coal plants with a 14Gt CO_2-eq constraint

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Existing Coal	0,72	0,69	0,61	0,65	0,63	0,80	0,80	0,79	0,00
New Coal	0,00	0,85	0,85	0,85	0,85	0,85	0,85	0,85	0,85

Under the 12Gt constraint, the electricity sector no longer includes domestic coal-fired electricity by 2050, although the sector does not fully decarbonize and continues to use gas and imported coal fired electricity. In this scenario, no additional coal plants are built after Medupi and Kusile, unlike the previous scenario. Medupi and Kusile are both retired (i.e. stranded) by 2050 when assuming either a 30-year lifetime (with delayed commissioning) or a 50-year lifetime. Capacity of 1.5 GW is retired by 2045 with the full 8.7 GW retired by 2050. Existing coal plants are not fully retired with the addition of new capacity; however, they are run at much lower load factors (see Table 3). On aggregate the entire coal fleet is significantly underutilized (i.e. run at lower load factors) by 2045.[13]

Table 4 illustrates how older plant in the fleet is run less to accommodate newer

emissions in the second half of the century, and Johnson et al (2013) found that coal-fired power would need to be phased out by 2050 to limit warming to below 2^0C, it is likely that the post-2050 climate change policy framework would require emissions reductions from all countries, including South Africa.

[13] The stranded capacity is essentially retired; however, the plants are not retired in the model and are viewed as available by the model if it requires them, and fixed O&M costs therefore continue. In reality, if those plants were no longer economic to run (for example because of very low load factors increasing the cost of the electricity produced), they would be retired fully and decommissioned. Currently, plants that are run at very low load factors in the model contribute to system reliability. Again, in reality, these could be non-viable assets, and the costs of transition (and stranding) are therefore likely underestimated.

(more efficient) coal plants while still meeting the carbon constraint (though both older plants and new coal (Medupi and Kusile) are run at lower load factors). The existing fleet is run at lower load factors from 2020 when Kusile is fully online, declining sharply from 2025. New plant is run at low load factors only towards the end of the period. By 2045, new coal plants are running at only 57% load factor, and by 2050 new coal capacity is not being run at all.

Table 4 Average annual load factors for the fleet of existing and new coal plants with a 12Gt constraint

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Existing Coal	0,72	0,69	0,61	0,53	0,26	0,31	0,21	0,02	0,00
New Coal	0,00	0,85	0,85	0,85	0,85	0,85	0,85	0,57	0,00

Under the 10Gt constraint (Table 5) all domestic coal plants are mothballed by 2040, and only a small quantity of electricity is produced from gas. Both existing and new coal fired plants are run at significantly lower load factors. Load factors for existing coal reduce to 52% by 2020 to account for new capacity. This is further reduced to 13% by 2030 before being retired by 2035. New coal, which is designed to run at a load factor of 89%, is run at only 49% by 2030 and 5% by 2040 before being decommissioned by 2045. The existing fleet is therefore stranded according to a 50-year lifetime for the existing plant; new coal is stranded assuming either a 30 or 50-year lifetime. There is substantial stranded capacity for the entire fleet of coal plants.

Table 5 Average annual load factors for the fleet of existing and new coal plants under a 10Gt constraint

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Existing Coal	0,72	0,68	0,52	0,36	0,13	0,00	0,00	0,00	0,00
New Coal	0,00	0,85	0,85	0,85	0,49	0,40	0,05	0,00	0,00

The results confirm that the risk of stranded assets increases as carbon budgets become more stringent. As can be seen, the risk of underutilized capacity of both older and newer plants increases as the carbon space allocated to the electricity sector is decreased; once a 12Gt constraint on the energy sector is imposed, coal-based electricity infrastructure becomes stranded. New coal (Medupi and Kusile) is run at lower load factors and retired before the end of their lives. Older plant becomes "stranded capacity" that is significantly underutilized. A more stringent constraint of 10Gt for the energy sector results in further stranding: of the capacity of the older fleet, which is underutilized, through the under-utilization of Medupi and Kusile, and through the early retirement of Medupi and Kusile.

4.2 Liquid Fuels Supply

Although the electricity sector provides most of the lowest cost options for mitigation, as we constrain the cumulative emissions further other sectors must also decarbonize. In this study we assume that the CTL plant will be closed as of 2040 based on a 60-year CTL lifetime assumption - the first half of the CTL plant was commissioned in 1980 and the second half in 1984. This differs from Sasol, who considers the end of the useful life of the CTL plant to be 2050, based on the development of new coal mines and other investments (Sasol, 2015). Future work will need to consider extending the life of the Secunda plant in the model to account for this difference. We note that if Sasol's assumption of a 70-year lifespan were assumed, different least-cost options for constraining emissions may arise.

In their study, Altieri et al (2015) found that under a 14Gt constraint, the CTL plant ran until 2040 (as per the assumed economic life of the plant). The disaggregated coal supply options in our modeling altered this finding, with the CTL plant reducing output from 2025 onwards before shutting down in 2040 (and with further coal plant being built in the electricity sector). In the 12Gt and 10Gt scenarios, however, the CTL plant is retired even earlier as the energy system meets the carbon constraint at the lowest cost. Under a 12Gt constraint, the output from the CTL reduces to 22% of full capacity by 2025 before output reduces to zero by 2030. Under a 10Gt constraint, the plant is no longer producing by 2025. The reduction in output from the CTL is replaced through growth in crude oil imports, investment in new crude refinery capacity and imports of refined product.[14]

4.3 Electricity sector with output of CTL fixed

One rationale for the following analysis (imposing carbon constraints while fixing the CTL output to 2040) is to understand the trade-offs that exist between different mitigation options. Currently, Sasol opposes the implementation of any climate change mitigation policy, in particular the carbon tax (Baker, Burton, Godinho, & Trollip, 2015). However, the economic effect of not implementing mitigation policy that covers all sectors is not well understood. We have therefore included the comparative scenarios to provide indicative results on the effect of increasing the mitigation burden for the electricity or other sectors, noting that once non-electricity sectors are linked that would provide a fuller understanding of the economic effects of mitigation in different sectors.

The scenarios where CTL output is maintained places increased pressure on South Africa's electricity sector to decarbonise. Decarbonisation of the electricity sector takes place considerably more quickly, in each case around 5 years earlier than it does in scenarios where the carbon constraint can be met through

[14] Because refineries are not yet linked in the energy and economy model, we are not yet able to analyze the economic impacts of such a switch, which would likely be significant, especially for South Africa's balance of payments and for the production of downstream chemical products. There would also be regional effects, since Sasol is strategically located inland near the primary demand centre in Gauteng, with most other refineries located in Durban with limited pipeline capacity to move refined product inland.

reducing output of non-electricity sectors such as CTL.

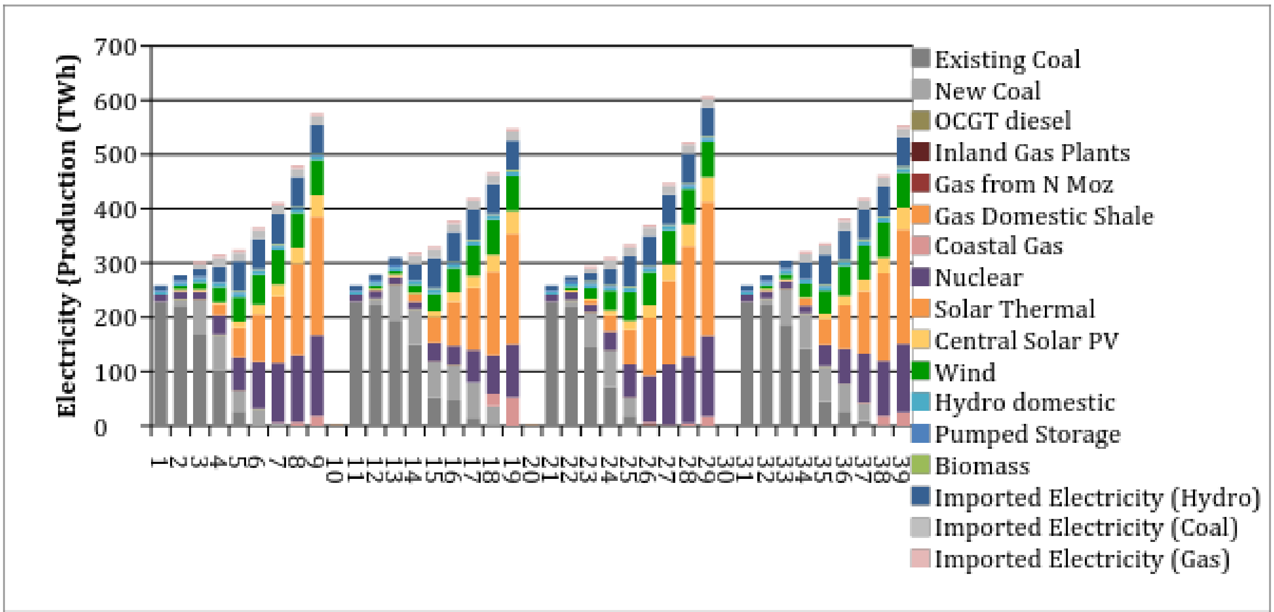

Figure 4 Electricity production in TWhs for 10 and 12 Gt constraints, compared with CTL output fixed to 2040 (SAS scenarios)

Figure 4 compares the 10 and 12Gt scenarios where CTL output is reduced to meet the constraint against scenarios with the same cumulative carbon constraint but where the CTL output is fixed to 2040.

Table 6 Average annual load factors for the fleet of existing and new coal plants in scenario 4 with a 12Gt constraint and CTL output fixed to 2040

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Existing Coal	0,72	0,68	0,58	0,50	0,22	0,17	0,12	0,00	0,00
New Coal	0,00	0,85	0,85	0,85	0,85	0,65	0,43	0,02	0,00

In the scenario with a 12Gt carbon constraint imposed and CTL output maintained to 2040, the effects on the coal fleet are substantial (see Table 6). Medupi and Kusile - which are likely to only be fully commissioned by the early 2020s – run at their designed load factors to 2030 before being run at lower average annual load factors from 2035 (of 65%), reducing to 43% by 2040 and 2% by 2045, before being retired by 2050.

Not only will those plant investments be stranded in terms of a 30-year life but they are also stranded capacity from 2030 onwards. This underutilisation of plant capacity would likely result in difficulties meeting the financial obligations attached to the investments. The existing coal fleet is run at continuously lower average load factors from 2015 onwards, declining from a 50% load factor in 2025 to 12% by 2040 before being retired by 2045. The existing coal fleet therefore becomes stranded capacity and stranded assets as the lifetime of some of these plants extend to 2049 (assuming a 50-year lifetime as per the IRP). More capacity has to be built to accommodate the underutilisation of the existing and new coal fleet. This is illustrated in Table 7 where installed capacity increases markedly from 2025-2045 to produce relatively similar levels of electricity as in the 12 Gt scenario.

Table 7 Total installed capacity (2010-2050) for 12Gt and 12Gt SAS scenarios (GW)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
12Gt	44,5	52,9	61,0	69,2	87,6	99,2	108,6	127,9	146,7
12 SAS	44,5	52,9	62,3	73,9	92,9	108,8	117,9	134,5	147,3

The 10Gt scenario with CTL fixed to 2040 results in higher levels of stranded capacity and assets (see Table 8). The average annual load factors of the existing fleet decline from 2015 onwards, reaching load factors of 9% by 2030 and retiring by 2035. The existing coal fleet is thus stranded capacity and, assuming a 50-year lifetime for existing plant, also stranded assets. Medupi and Kusile, fully commissioned only between 2020 and 2022, would run at their designed load factors until 2025, decline to an average annual load factor of 43% by 2030, and would be no longer run from 2035 onwards. Not only do those plants constitute stranded capacity from 2025-2035, but they would also be stranded assets 15 years before they are fully depreciated on Eskom's balance sheet.

Table 8 Average annual load factors for existing and new coal plants with a 10Gt constraint and CTL output fixed to 2040

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Existing Coal	0,72	0,67	0,45	0,26	0,09	0,00	0,00	0,00	0,00
New Coal	0,00	0,85	0,85	0,85	0,43	0,00	0,00	0,00	0,00

The difference in utilisation of the coal fleet when CTL output is maintained to 2040 is considerable. Not only is substantially more capacity required to meet demand when coal capacity is underutilised, but new coal investments would be stranded, adding to the total costs of electricity produced. Even when electricity demand is similar (as in 12 and 12 SAS), the capacity requirements are much higher as the existing fleet cannot be run at higher average annual load factors if the carbon constraint is to be met. The scenario where a 10Gt constraint is imposed and CTL output remains constant to 2040 is an extreme case, showing the substantial effects of stringent energy sector mitigation targets not being cascaded down to sub-sectors on a least-cost basis.

4.4 Demand sectors

Demand sectors must also decarbonise more quickly to account for the emissions space utilised in the production of liquids from coal. In industry, the result is considerably higher levels of natural gas use and lower direct coal use in the more stringent carbon scenarios. In commerce, demand growth is met entirely from increased use of natural gas and significantly higher electricity use. Commercial sector coal use grows in all scenarios except 10 SAS, though at lower rates than total energy demand growth. In transport, demand growth is similarly met from growing use of natural gas (see APPENDIX for detailed graphs of demand sector responses).

4.5 Shortcomings of the partially linked model

The energy model is only partially linked to the economic model through the electricity sector. The full sector constraint is therefore translated into an electricity sector constraint that is passed through into the CGE model. This means that the full cost of decarbonising supply and demand sectors is not fully represented in the economic model. For example, as industry switches to natural gas instead of coal, the cost associated with the switch would not be seen in the growth rates of sectors that are switching. Only the effects of higher electricity prices are passed into the economic model.

The structure of the CGE and SATIM differ in key ways; this results in slightly different electricity demand outcomes. By using a model linked only through the electricity sector, it is likely that we are under estimating electricity demand that would result from demand sectors fuel switching to electricity in response to the carbon constraint. Thus the results reported above for demand sectors (industry, commerce and transport above) are not fully reflected in the CGE electricity investment plan. The investment levels in the CGE therefore may under count the investment required in electricity and thus underestimate the effect on the economy. On the other hand, the electricity intensity of growth (that is, the electricity demand driven by GDP growth) in the CGE is higher than in SATIM, which offsets the under investment to some extent. A fully linked model would not face this problem and this remains an important area for future work.

5. Economy-wide impacts

This section examines the economy-wide effects of the electricity build plans for the scenarios discussed above. We describe the effect on the electricity price, investment required in the electricity sector, and sectoral growth.

5.1 Electricity prices and electricity investment

This section examines the effect of varying levels of decarbonisation in the electricity sector on the electricity price and the portion of national investment (measured as gross fixed capital formation) allocated to the electricity sector, i.e. we unpack the investment required to meet increasingly stringent carbon constraints given current installed coal-fired generation capacity. This allows us to describe the effect on electricity prices of under-utilising existing coal plants and replacing them with lower carbon supply options; it also highlights the electricity price effects of national mitigation policy that does not address energy supply sectors such as liquid fuels production in a carbon-constrained future. Figure 5 highlights the effect on the final electricity price for different scenarios.

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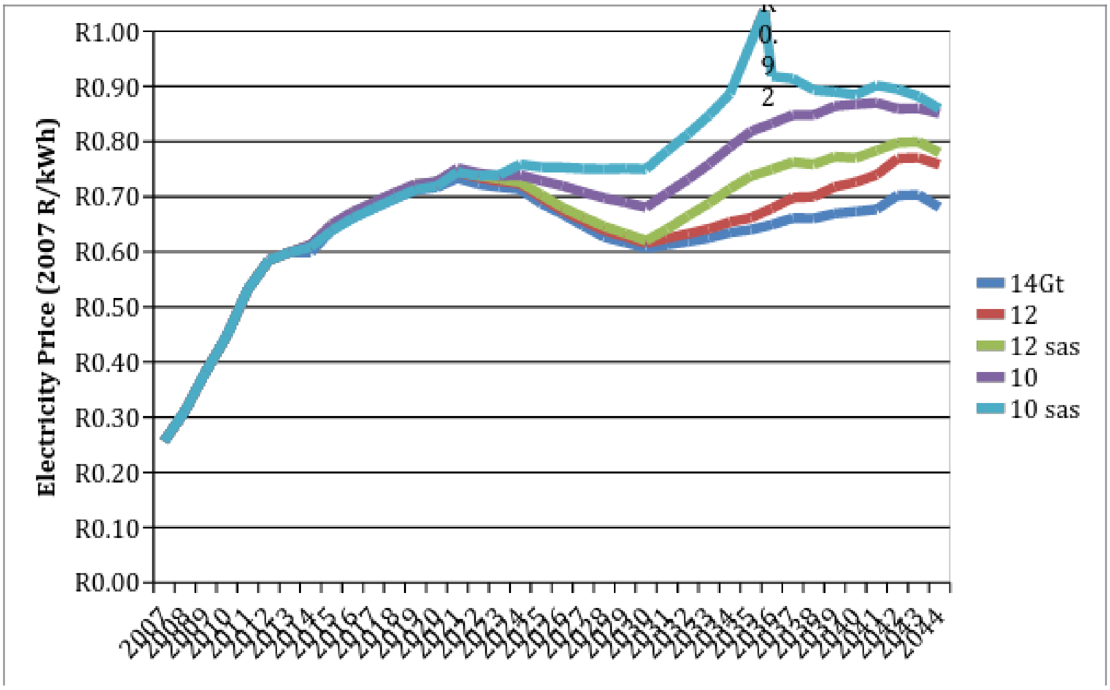

Figure 5 Electricity price under different decarbonisation scenarios, 2007-2045, in 2007 R/kWh)

As can be seen, the price trajectory is fairly similar in the 14Gt, 12Gt and 12 Gt SAS scenarios until 2030, after which the price trajectories begin to diverge.

In the 14Gt scenario, the electricity price increases from 2030 onwards as new investments are made to meet growth in electricity demand, i.e. the price increases as new capacity is built to replace coal plants retiring as per the decommissioning schedule and to meet demand growth (primarily through new coal, nuclear, and CSP). As described above, under a 14Gt constraint the fleet of old coal and new coal are run at normal load factors, and the electricity sector does not need to replace underutilised capacity with new investments.

Under the 12Gt scenario, the electricity price increase from 2030 is also partly caused by replacing retiring coal capacity (of older plant), which is decommissioned in line with the IRP. But there is a further need for replacement capacity to compensate for the stranded capacity of the older fleet, which is run at lower load factors, especially from 2030 onwards. Because Medupi and Kusile are run at normal load factors until 2040, before being reduced to a load factor of 57% in 2045 and retired by 2050, much of the investment in new coal can be recouped, suppressing price increases compared to more stringent scenarios or scenarios where CTL continues to run and forces the underutilisation of new coal plants to accommodate the emissions from the production of liquid fuels.

Thus, in the 12Gt scenario with CTL output fixed, prices are significantly higher

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[15] We report the prices to 2045 only; from 2045 onwards 'end effects' skew the results, because the model is no longer investing to meet demand in the post-2050 period.

than in the scenario with a 12Gt constraint and reduced CTL output. New coal assets are run at lower load factors from 2035 onwards, preventing those investments from being paid off; the plants (Medupi and Kusile) are essentially mothballed by 2045, running at 2% annual average load factor. Again, because of the aggregation of time slices in the model, it is not possible to disaggregate the output in detail, so while one unit may be online (in the extreme case mentioned above), most of the capacity of the plant is standing idle. It is likely that at such low levels of utilization, those plants could be mothballed; since such low levels of utilisation is likely not economically viable). Running the new coal plants below their designed load factors also reduces the likelihood of recouping the investment made in those plants or results in higher cost electricity from those plants. Replacement capacity is required to fill in the demand gap created from running the coal plants (old and new) at lower load factors to allow the electricity sector to decarbonise more quickly and meet the constraint while the CTL plants output (and emissions) remain flat to 2040.

In 10Gt and 10 SAS, the extremely stringent carbon constraint (in the latter, with increased pressure placed on the electricity sector by continued CTL output) mean that not only is significant new coal capacity stranded, but also there is a requirement to fill the gaps in supply left by the stranded capacity of the older plant and the underutilised new coal capacity with replacement generation infrastructure.

In the 10Gt scenario, there is significant investment required to fill the demand gap left by stranded capacity of the older fleet, with existing coal no longer running by 2035. New coal is run at 5% load factor by 2040 and no longer run at all by 2045, resulting in stranded assets that must still be paid off as well as the need for new capacity to meet demand. The stringency of the carbon constraint is amplified in scenario 5 (10Gt SAS) to accommodate the emissions from the CTL plant. Here, with Medupi and Kusile stranded assets by 2035, not only are those investments not paid off but new capacity is required to meet demand, over and above that required in scenarios without any stranded assets or underutilised capacity. Furthermore, demand for electricity increases in 10 SAS as sectors switch away from other fuels to electricity as the electricity sector rapidly decarbonises, exacerbating the costs of stranding capacity and assets.

As is to be expected, as assets or capacity are stranded, the investment costs in the electricity sector rise.

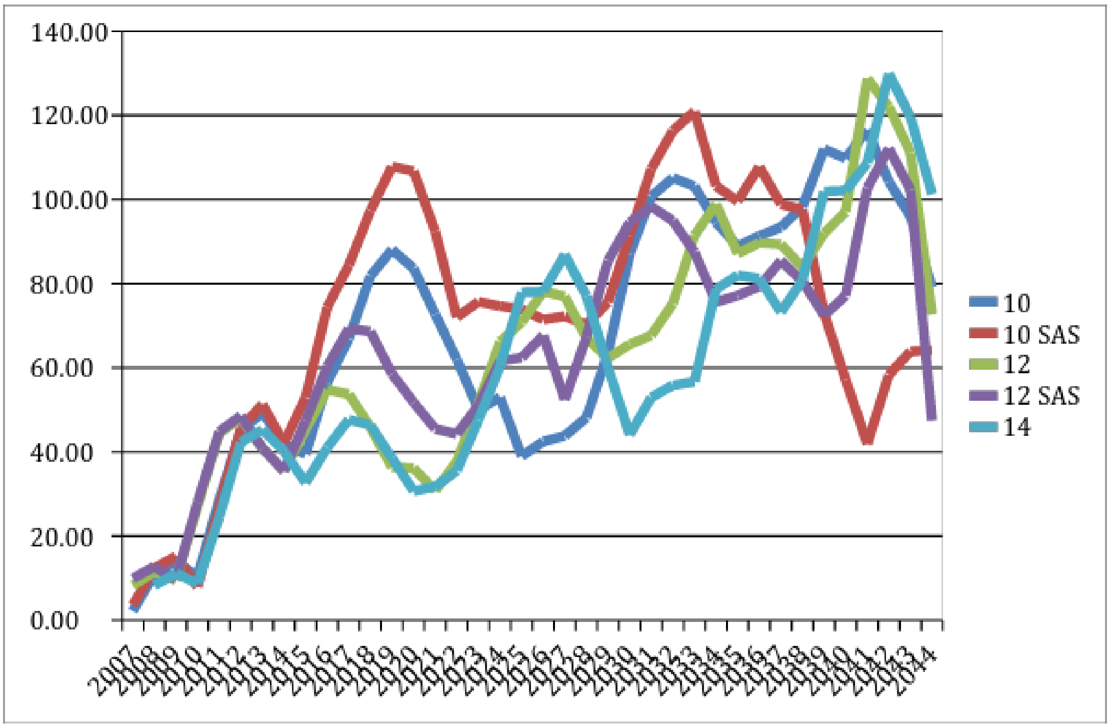

Figure 6 Annual investment costs for electricity sector for all scenarios (2007 billion Rand)

The investment required echoes the price trajectories. As can be seen, the 14Gt and 12 Gt scenarios are fairly similar to 2030; 12 SAS has higher investment levels as electricity supply is decarbonised more quickly and older plant underutilised. The 10Gt and 10 SAS scenarios are considerably higher. Table 8 highlights the cumulative investment required for each scenario for the period 2007-2044.

Table 9 Cumulative investment (2007-2044) for all scenarios (in 2007 billion Rand)

	10	12	12 SAS	10	10 SAS
2007 Rand billion	2241,70	2411,57	2411,66	2574,04	2708,67
% change between each scenario		7,6	0,0	6,7	5,2
% change compared to 14Gt scenario		7,6	7,6	14,8	20,8

As can be seen, the cumulative investment required under a 10 SAS scenario is substantially higher than the other scenarios (20.8% higher than the 14Gt scenario), while the 10Gt scenario requires almost 15% more investment over the period compared to the 14Gt scenario. The cumulative investment of the 12 Gt scenario is 7,6% higher than the 14Gt, but the 12 SAS scenario is the same as the 12Gt scenario (though the electricity price is higher in 12 SAS than 12 over the period 2030-2045, by 2050 the installed capacity is the same). This is an interesting finding; the cumulative investment required to 2044 is the same whether CTL output is fixed and decarbonisation happens in the electricity sector rather than liquid fuels, but the build plans differ, resulting in higher electricity prices earlier in the period in 12 SAS. The effect on electricity users is therefore greater in the 12 SAS scenario against the 12Gt scenario, with the difference in costs affecting different users of energy, even though total investment levels over the period are the same.

5.2 Effects on Gross Domestic Product and Sectoral Growth Rates

Finally, we highlight the effect of the electricity price increases and higher levels of investment required on selected sectors. We report results for the 14Gt, 12Gt, and 10Gt scenarios, excluding the 12 SAS and 10 SAS scenarios. Because the model is linked only through the electricity sector, we are not able to see many of the economic effects of extensive fuel switching under the latter scenarios. As seen above, the effect on the electricity price is significant. But the expected effects on the demand side, for example on the coal sector (where output would reduce dramatically) or petroleum products are not currently captured in the linked model.

Figure 7 shows the average annual growth rates for the major sectors under different carbon constraints. Since the economic modelling simulates a structural change in the economy (through higher growth in agriculture, which is a non-energy intensive sector), the effect on overall GDP of the increasingly stringent mitigation scenarios is not substantial. The results echo the findings in Altieri et al (2015; 2016), who found that a different development pathway for South Africa could allow continued growth of the economy while South Africa also meets climate change mitigation targets. Without a structural change in the economy, however, the effects of considerably higher electricity prices on energy-intensive sectors would not be offset by higher growth in the agricultural sector.

In the 14Gt scenario average annual growth rates are 3,04%. By comparison, the 12 and 10Gt scenarios are 3,03% and 3,01% respectively. Importantly, this is because the electricity price increases impact on energy-intensive industry in particular, which comprise a relatively small portion of GDP. Thus, at a sectoral level, non-ferrous metals is impacted significantly by the electricity price increases. Under a 12Gt scenario the sector stagnates (declining by an average 0,01% per year), but it contracts significantly under the 10Gt scenario, declining by an average 0,71% per year. Less marked but still significant declines in growth rates can also be seen in iron and steel and the metals sectors, as well as a small decrease in mining overall. Iron and steel, which grows at 1,11% in the 14Gt scenario, grows much more slowly in the more constrained scenario: 0,99% in 12Gt and 0,75 in 10Gt.

The increased openness to trade allows for higher levels of growth in the agriculture sector, which offsets the lower growth in energy-intensive sectors. Without this structural change in the economy, the effects on growth and employment would be much greater.

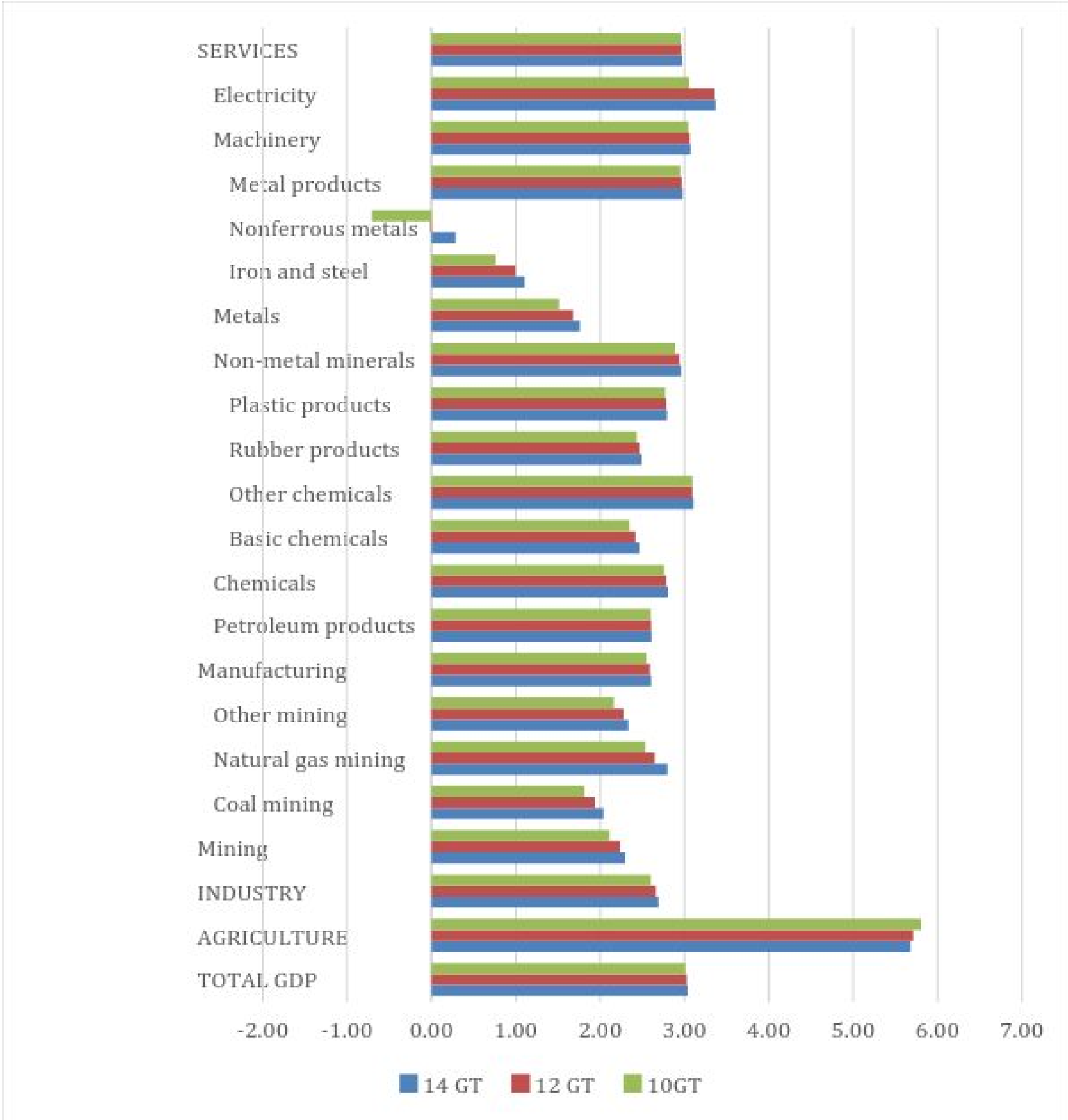

Figure 7 Average annual growth rates (2015-2044) for selected sectors under different carbon constraints

6. Discussion

As the results presented above have highlighted, stranding power sector assets can result in substantial electricity price increases and larger cumulative investment must be allocated to the power sector to provide the infrastructure required to meet demand. This investment (and cost to users) comes over and above the cost of meeting a 14Gt cumulative constraint in which no stranding of assets took place (assuming a 30 year life for new coal and on time commissioning of plants).

In extreme cases, average annual load factors for the fleet of less than 10% were seen. This might approximate utilisation of a single unit at a large plant. Frequently starting up and shutting down plant reduces efficiency, as does running units at lower than designed average operating loads (IEA, 2010). This level of detail is not seen in SATIM, which aggregates the capacity of the fleet. In short, however, the key message is that stranding of assets may be necessary in a carbon-constrained world. And stranded assets result in higher electricity prices. Building new coal plants will only add to this risk.

The economic effects of higher electricity prices results in slower growth in energy-intensive sectors overall, negatively affecting non-ferrous metals in particular. However, average annual GDP growth rates for the economy as a whole remain similar under more stringent carbon constraints. This is possible provided the economy shifts way from energy-intensive sectors, especially iron and steel and non-ferrous metals (and of course the coal sector, which remains un-linked in the model; the effects are therefore underestimated). Without this structural change, the challenge of growing the economy to address high levels of unemployment and poverty would increase substantially if stringent mitigation targets were required in the electricity sector.

The Department of Environmental Affairs is not currently allocating South Africa's carbon budget (i.e. its long-term climate mitigation commitments) between different sectors. The country may also have to reduce its emissions further in the long-term, as the world moves towards emission reductions consistent with 2°C and net negative carbon emissions after 2050. A scenario with a 14Gt constraint is broadly consistent with the mid-PPD of SA's climate policy, but since global country contributions are not yet consistent with limiting warming to below 2^0C, many countries, South Africa included, may need to reduce emissions further.

Having examined more stringent scenarios, we highlight two major risks currently facing South Africa. Firstly, that electricity planning will assume a higher share of the national carbon budget for the sector to 2050 and will invest in fossil power accordingly; in later years, this capacity will either have to be stranded wholesale and retired prematurely, or become stranded capacity with plants run at low average load factors. As in Johnson et al, we find that less stringent near-term climate policy results in longer-term stranded capacity. This risk was highlighted in the IRP update (DoE, 2013: 25); the study was extended to 2050 partly to overcome the risk, because "by excluding the period after 2030 there is a risk of building coal-fired generation in the period leading up to 2030 on the assumption that the carbon emission caps would continue at the same level, but this would lead to a constraint in reducing the emissions or under-utilisation of generation capacity if the cap needed to be reduced over time as indicated by the government's peak-plateau-decline (PPD) objective." Given that the electricity sector is a lower-cost option for decarbonisation, we argue that the IRP 2010 emissions constraints (which allow for new coal-fired capacity to be built), should be revisited

Under the scenarios outlined above, the rate of retirement required to meet the emission constraints exceeded the rate at which the fleet is scheduled to retire, especially when new coal plants are brought on line. Continued investment in coal plants after Medupi and Kusile need to be carefully considered by energy planners since these are the investments most likely to be stranded assets in future years; Medupi and Kusile will also run the risk of becoming stranded capacity if emissions constraints for the country or the electricity sector are tightened.

Figure 8 shows how the constraint we have imposed differ markedly from the emissions constraints in the IRP update. The IRP update assumed that the electricity sector would retain a proportional share of national emissions space to 2050; however, this may not be the least cost mitigation option.

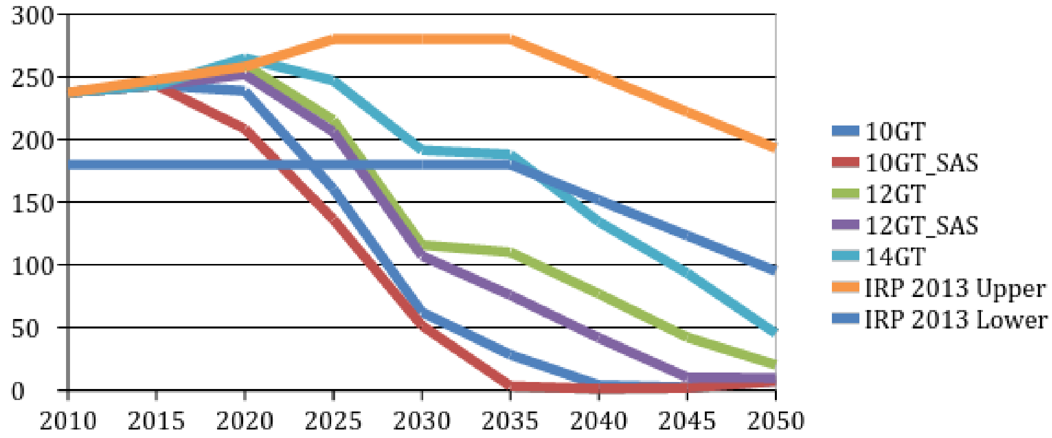

Figure 8 Comparison of carbon constraints in the Integrated Resource Plan update and those applied in the current study

Secondly, South Africa's climate policy does not adequately account for the emissions associated with liquid fuels production. If South Africa is to continue to rely on CTL for liquid fuels supply to 2050, then higher levels of decarbonisation in other sector will have to take place. If a least-cost mitigation plan is to be adopted for the county, then the Department of Environmental Affairs and National Treasury must (as the implementers of mitigation policy) understand the political and economic trade-offs between these sectors better. While the effects on total investment in the electricity sector (e.g. the 12 and 12 SAS scenarios) may be similar, the electricity price increases earlier when more coal-based electricity capacity is stranded to meet the emissions constraint. In essence, this means that electricity-intensive industry must endure higher electricity prices for Sasol to avoid the stranding of its coal-to-liquids asset and the mines that support it. Alternatively, mitigation in other sectors must be deepened. Continued reliance on emission-intensive industry is risky, both to South Africa's standing as a global citizen committed to emission reductions but also directly to the economy. Not only will international pressure increase in future years as implementation of the Paris Agreement unfolds internationally, but the coal sector globally is now viewed as being in structural decline. At the same time, industrial policy continues to favour energy- and carbon- intensive industry (DTI, 2015).

Finally, the use of a linked model is able to highlight the potential effects of mitigation on electricity prices and thus output from demand sectors. The effects on energy-intensive industry, especially non-ferrous metals is negative as increasingly stringent carbon emission targets result in stranded assets and stranded capacity (and thus increase the costs of mitigation). However, this can be offset with a structural change in the economy. South Africa's industrial policy, historically premised on energy intensive mining and minerals beneficiation (these sectors remain important in the DTI's *Industrial Policy Action Plan*), runs a risk of creating a stranded economy. While these sectors may be important to the current economy, it is incompatible to depend on them for industrial development in a situation of potentially much higher energy prices in the future.

7. Future Work

This paper has used a partially linked energy and economic model to unpack the economic effects of mitigation and the impact of stranding assets on the South African economy. There are key areas of future work that remain. These include:

- Further linking of the energy and economic models, including refineries and CTL, coal mining and demand sectors.
- Running a "no new coal" scenario to understand how South Africa can balance the infrastructure it has already invested in with the emissions commitments it has made to avoid stranding assets and contribute its fair share to limiting average global temperature rise.
- Examining the coal resource implications of these scenarios, i.e. stranded resources and unburnable reserves and resources.
- Examining the inclusion of the coal baseload independent power producers programme under different future mitigation targets to understand the costs and risks of stranding new coal assets.

8. Conclusion

This paper has outlined the potential impacts of stranded power sector assets in South Africa, using a partially linked energy and economic model to examine the effect of increased mitigation targets for the risks of stranded assets and therefore the effects on electricity prices and investment. We found that as mitigation trajectories for the electricity sector are lowered, the risk of stranding assets increases; from a 14Gt constraint without stranding, to a 12Gt scenario where older plant is stranded capacity and new coal is run below its designed load factors, and yet further to a 10Gt constant where assets are stranded and capacity is stranded. As is to be expected, stranding assets results in higher investment in the sector to meet demand, with higher electricity prices as a result of that. We argue that give the potential increase in global pressures to reduce emissions, that further investment in coal-fired power carries with it the risk of stranded capacity, stranded assets and thus higher electricity prices. Using a linked model, we have shown that the effects of this on the South African economy can be offset by structural changes to the economy, but that impacts on energy-intensive sectors could be significant.

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10. APPENDIX

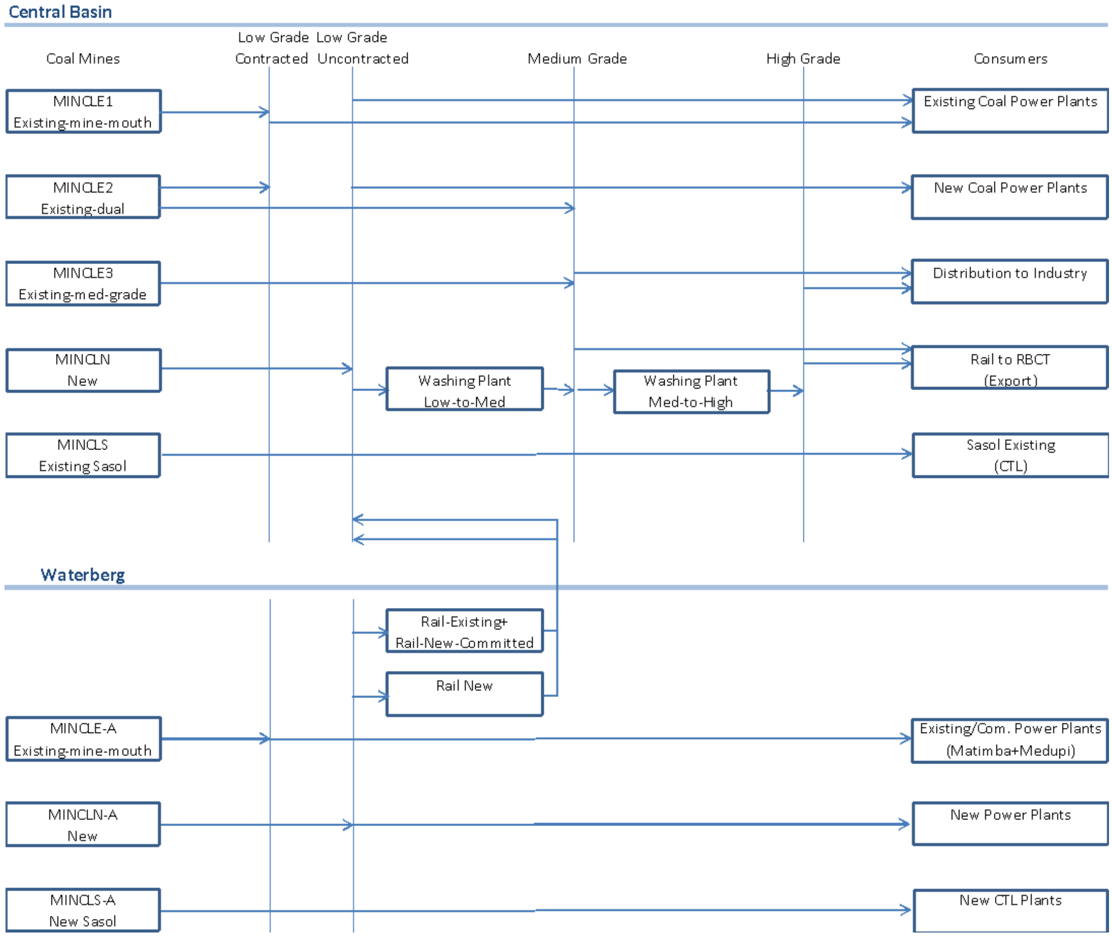

Figure 9 Diagram of coal supply options in SATIM (Merven & Durbach, 2015)

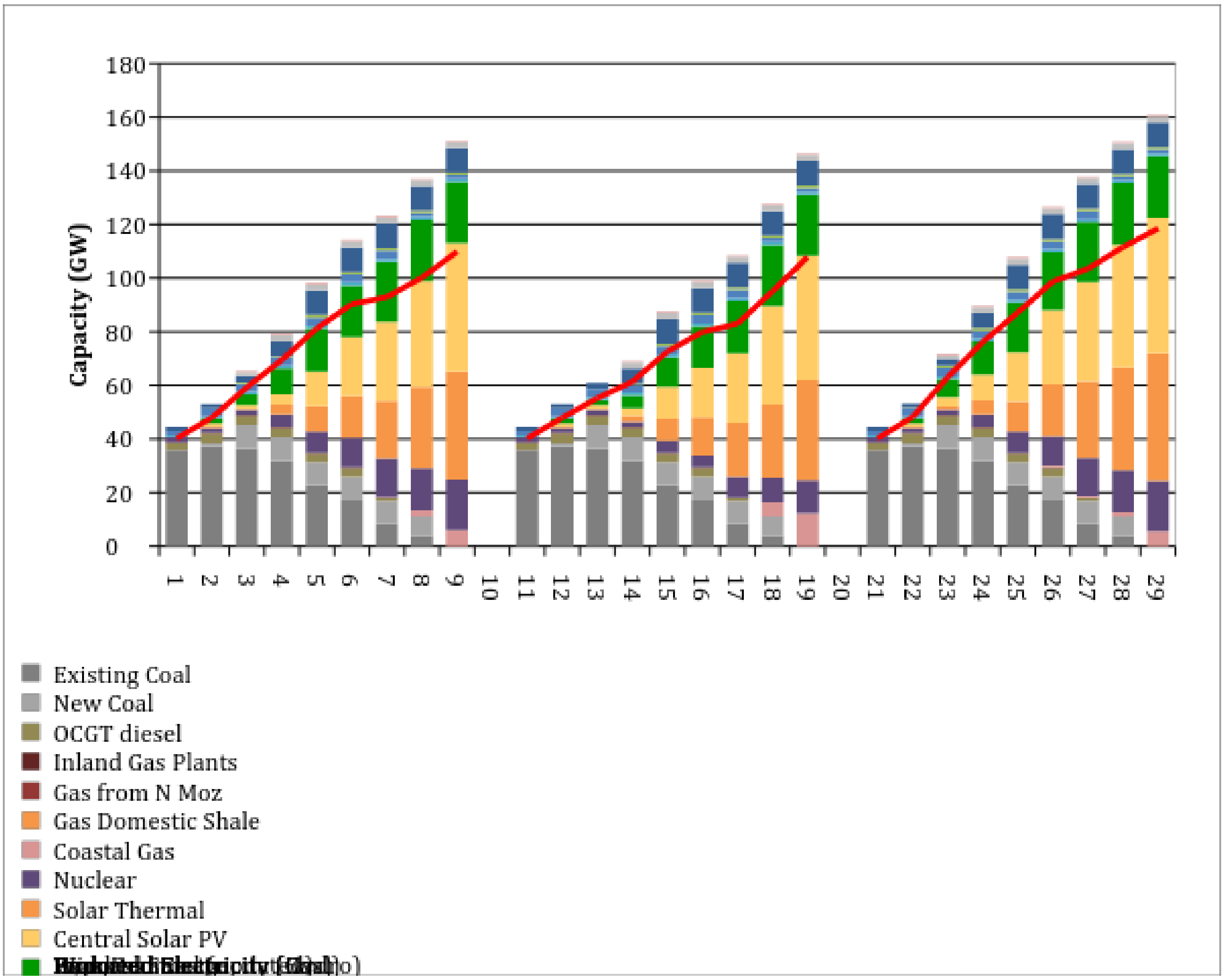

Figure 10 Installed capacity in different scenarios (GW)

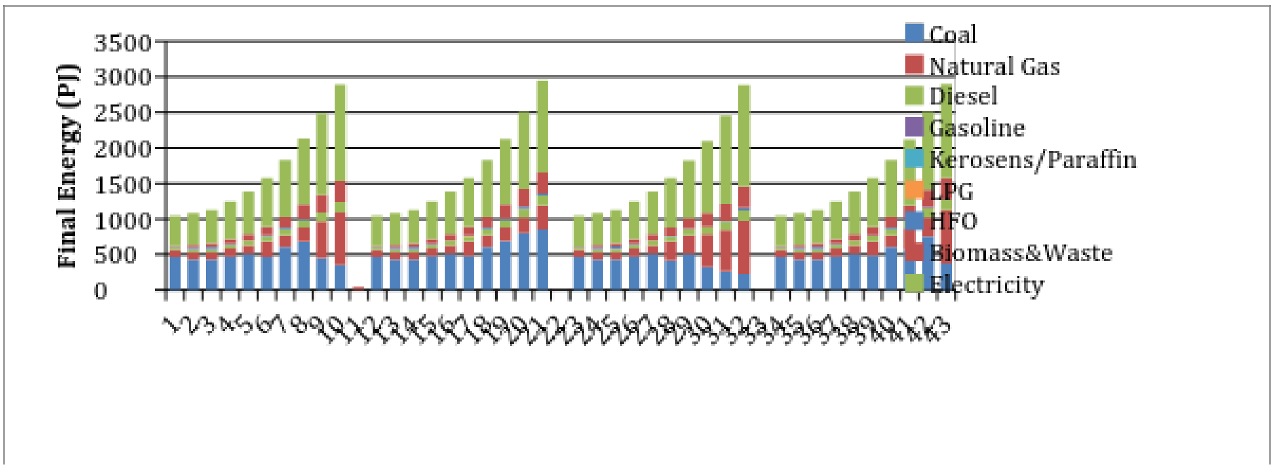

Figure 11 Industrial energy use

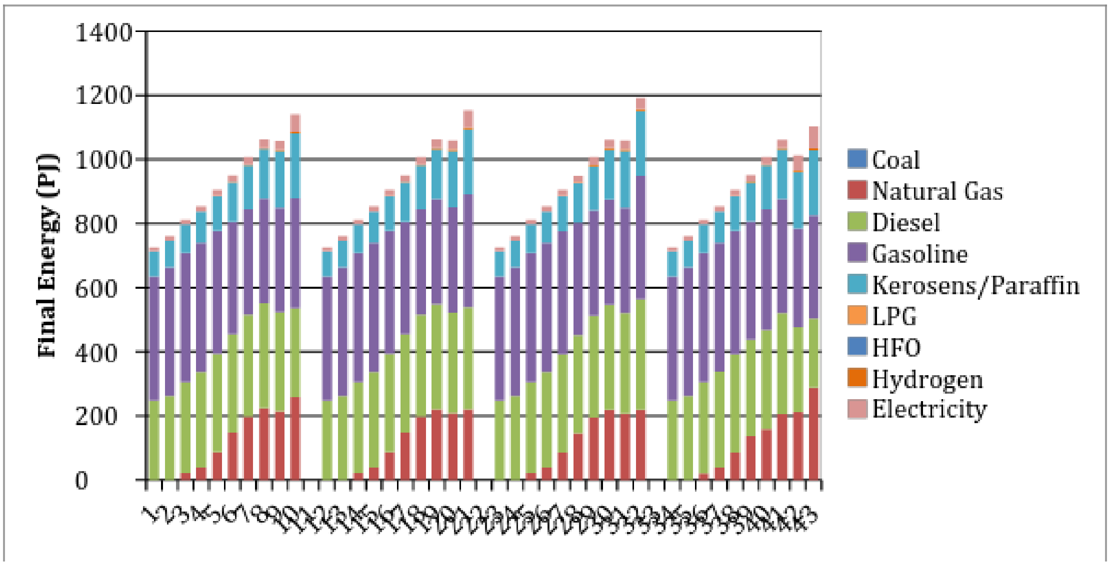

Figure 12 Transport energy use

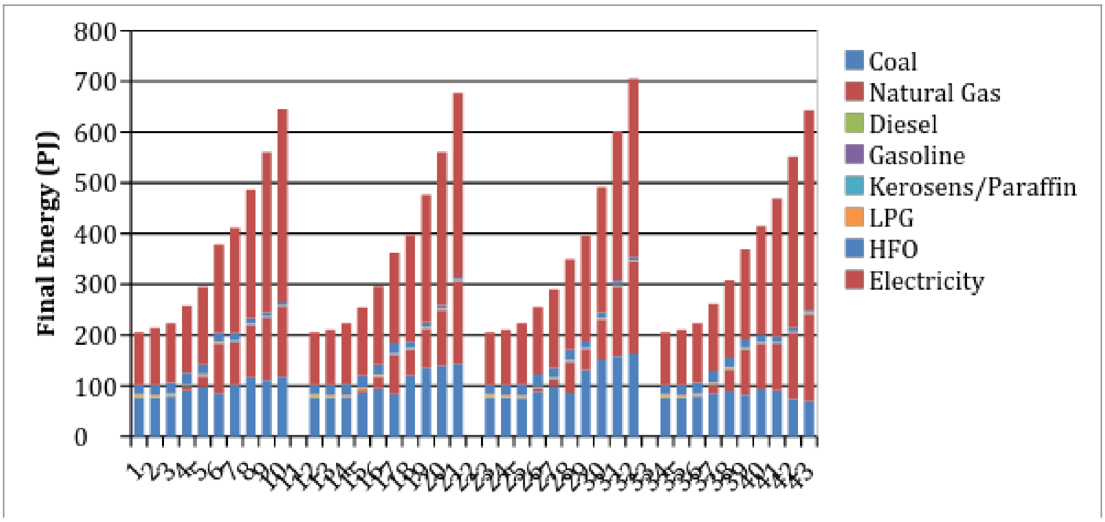

Figure 13 Commerce energy use

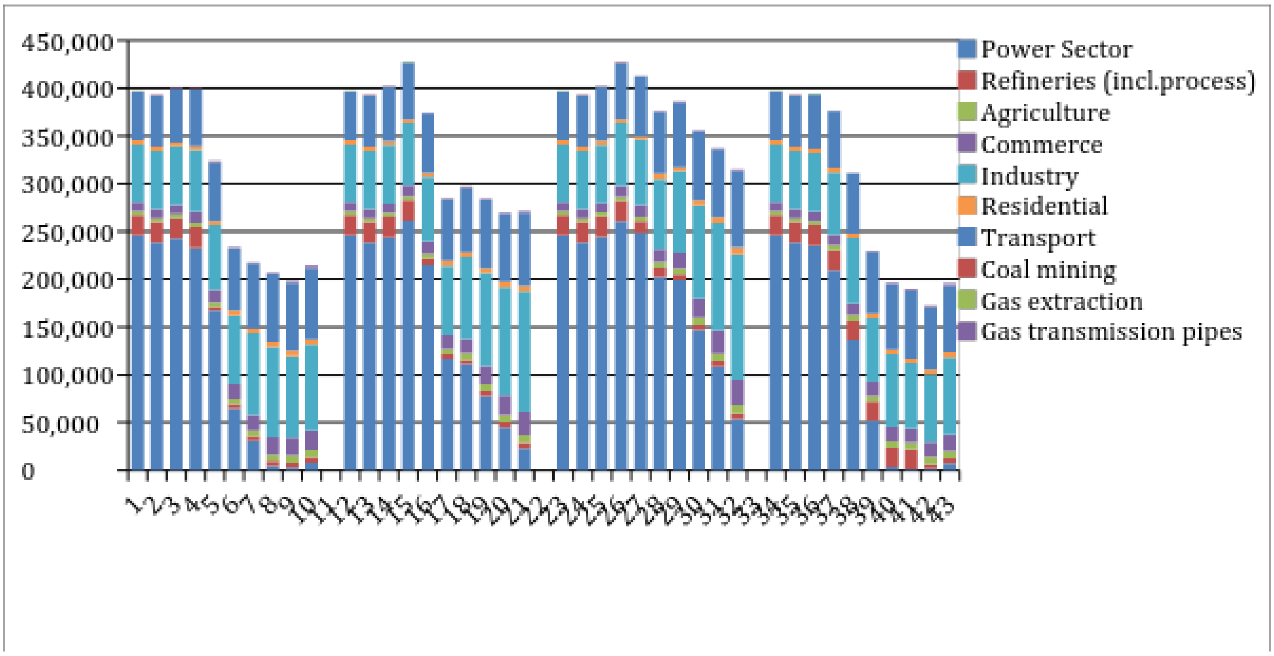

Figure 14 Annual emissions in CO_2-eq by sector under various scenarios