UNITED NATIONS UNIVERSITY
UNU-WIDER

WIDER Working Paper 2017/39

Energy system and economy-wide implications of a rapid transition to decarbonized energy in South Africa

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February 2017

Abstract: Developed as well as developing countries will have to increase their ambition relative to their stated Nationally Determined Contributions to limit global temperature increases to 2°C above pre-industrial levels. South Africa's Nationally Determined Contribution, in line with national policy, is to follow a peak, plateau, and decline emissions trajectory to 2050, with the contribution post-2030 contingent on a fair contribution from other countries. Given the high levels of unemployment, poverty, and inequality in South Africa, there are concerns that a rapid transition to a low-carbon energy system would have severe socioeconomic consequences. This paper builds on initial work from the Deep Decarbonisation Pathways Project, and analyses the impacts on the energy system and the economy of an increase in ambition, in order to shed light on these concerns. The key policy recommendation from this analysis is that further investments in fossil fuel infrastructure in South Africa will have significant negative socioeconomic implications, and that further work should be done to reassess development pathways that could mitigate these negative impacts.

Keywords: energy, climate policy, welfare, economy-wide model, South Africa
JEL classification: Q43, Q54, I3, E13

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This study has been prepared within the UNU-WIDER project on 'Regional growth and development in Southern Africa'.

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ISSN 1798-7237 ISBN 978-92-9256-263-2

Typescript prepared by Joseph Laredo.

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UNU-WIDER acknowledges specific programme contribution from the National Treasury of South Africa to its project 'Regional growth and development in Southern Africa' and core financial support to its work programme from the governments of Denmark, Finland, Sweden, and the United Kingdom.

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1 Introduction

The Paris Agreement has gone some way to indicate what the gap is between the extent to which countries are willing to contribute to emissions reduction and the amount by which countries would be required to reduce emissions to keep temperature increases well below 2°C above pre-industrial levels. It is clear that developed as well as developing countries will need to increase their ambition to bridge this gap.

South Africa currently produces approximately 7.7 tonnes of CO_2-eq emissions per capita per annum, whilst the global fair share of emissions space for a 2°C world is calculated to be 1.5 tonnes per capita (Altieri et al. 2015). This is but one of the many suggested methodologies for allocating emissions space to 2050. However, it is likely that South Africa will come under pressure to significantly decrease its overall emissions no matter which global methodology is used to 'cut the pie'. Given that South Africa is heavily dependent on coal and that non-energy emissions account for approximately 6 per cent of total emissions (excluding process emissions), this would involve a rapid decarbonization of the energy sector.

Results from South Africa's Deep Decarbonization Pathways (DDPP) report show that a significant reduction in emissions (14 Gt cumulative to 2050) is possible, although this reduction in emissions takes South Africa down to only 3.9 tonnes per capita in 2050. South Africa's DDPP focused on sustainable development and modelled emissions constraints in the light of alternative economic pathways. Therefore, these emissions reductions were achieved whilst also making great strides towards sustainable development. In order to analyse solely the implications of an increase in ambition, this paper assumes that South Africa's economic structure is as it is in the base. Given the results from the analysis conducted in the DDPP, it is likely that alternative development pathways could not only mitigate some of the negative impacts found in this paper, but also increase sustainable development in South Africa.

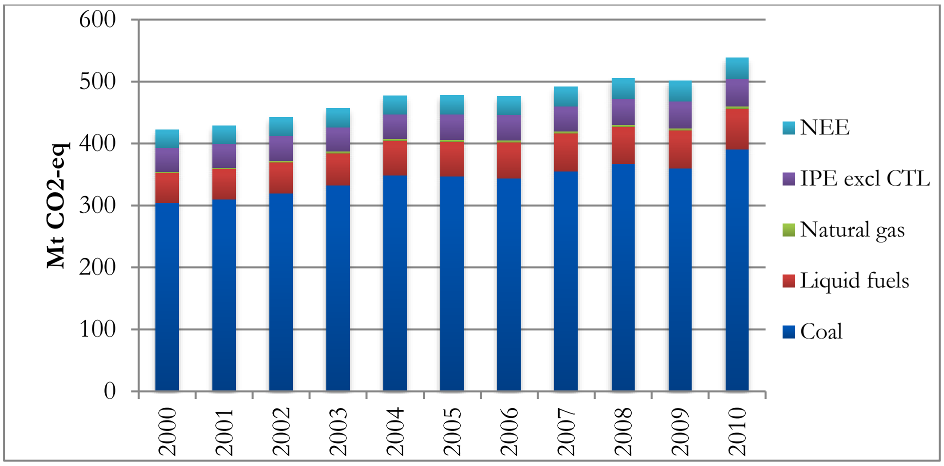
South Africa, as a developing country, is mindful that any transition to a low-carbon future must be undertaken in an equitable way. This paper addresses the critical question of what the socioeconomic implications of a rapid transition to decarbonization are for South Africa—a key question that should be addressed if the global target of temperature rise below 2°C is taken seriously. This paper uses a fully linked, bottom-up energy model and economic model to explore the socioeconomic implications of South Africa's undertaking a rapid transition to a decarbonized energy sector, with a focus on the impacts on the energy sector, potential sectoral winners and losers, employment impacts, and impacts on the welfare of households.

2 Background

2.1 Energy sector

South Africa has significant coal resources and reserves, and is heavily dependent on the use of coal; the burning of coal is the largest contributor to emissions in South Africa, as shown in Figure 1. The biggest single contributor to emissions is the electricity sector, in which coal-fired electricity generation accounts for over 90 per cent of total electricity generation.

Figure 1: Emissions from 2000 to 2010



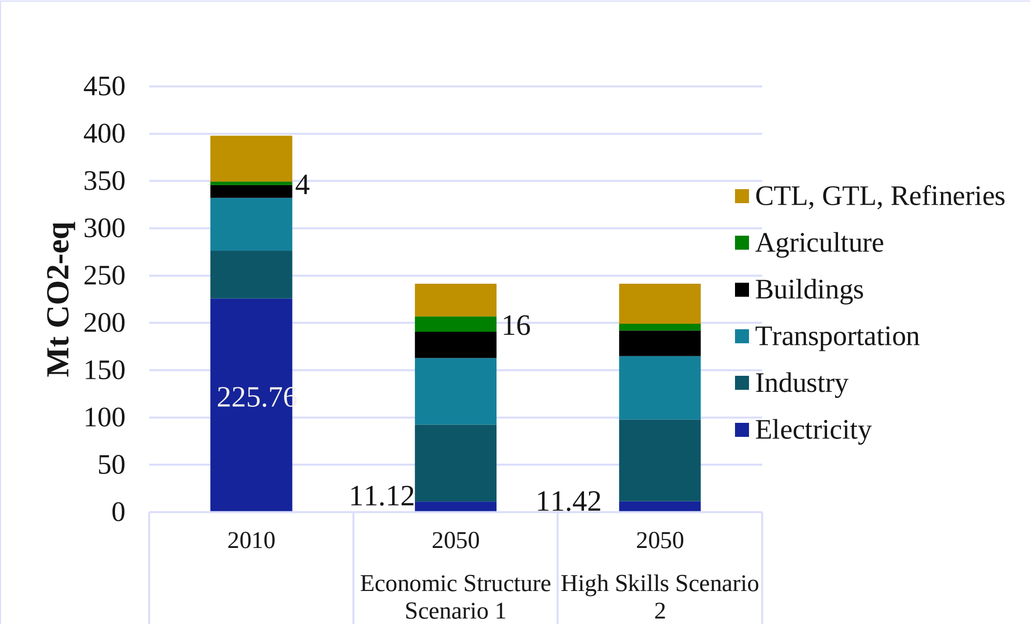
Source: DEA (2014).

In addition to existing infrastructure, there are two large-scale coal-fired plants currently under construction (Medupi and Kusile) as well as a commitment to two coal independent power producers (IPPs)—a total of 10,433 GW of total capacity, most of which is yet to come online.

Given this reliance on coal, a key part of a transition to a low-carbon energy system would be a reduction in the use of coal, notably in the electricity sector and coal-to-liquids (CTL) plants. As was found in the DDPP, there would be no stranded coal-fired plants in this scenario, as they are assumed to adhere to their retirement schedules. The electricity sector is also almost fully decarbonized by 2050, with annual emissions of around 11 Mt CO_2-eq in 2050 compared with annual emissions of just over 225 Mt CO_2-eq in 2010, as shown in Figure 2.[1] Under a 10 Gt scenario, the electricity sector would be forced to decarbonize much earlier, which would raise the risk of stranding fossil fuel assets. This would also increase the risk of 'mis-investment' as South Africa continues to invest in fossil fuel infrastructure expansion.

[1] This is assuming that no life-extensions are given to any of the coal-fired plants, although under the true technical definition of 'stranding' these assets would not be stranded if they had reached the end of their economic lives.

Figure 2: Energy-related CO_2 emissions



Source: Altieri et al. (2015).

2.2 Rethinking development

South Africa's current domestic policy system is one of lock-in and path dependency. It is clear that South Africa's current development pathway has failed to enable sufficient development. This was the starting point for South Africa's DDPP team, which considered positive policy steps for achieving development in a low-carbon world.

Sustainable development in South Africa is possible with sustained and decent employment. For a country with an unemployment rate of 27.1 per cent (StatsSA 2016), not including discouraged workers, job creation is of the highest priority.

There are two possible economic pathways:

- Economic structure
  This scenario presents a structural shift in the economy towards growth in sectors that are both low-carbon and employment-intensive. The main driver for growth is the agriculture sector, which is increasingly exploiting regional trade opportunities.
- High skills
  South Africa is constrained by the number of skilled workers in its labour force. This scenario presents an optimistic view of improvements in South Africa's education and therefore the number of skilled workers that will enter the labour force up to 2050.

In terms of development, both the economic structure and the high skills scenarios make great strides towards full employment and development in South Africa to 2050. However, unemployment remains high at 12 per cent and 18 per cent of the total labour force, respectively, in 2050. Growth is moderate, with an average annual growth rate of 2.8 per cent for the economic structure, although this growth is driven mostly by developments in agriculture. For the high skills scenario, growth in high-skills-intensive sectors drives overall GDP growth.

Both scenarios have a positive impact on income equality, with around 11 per cent of households in the lower income bracket (<R19,200 in 2007 Rand) by 2050, compared with nearly 50 per cent in the base year, 2010.

In terms of emissions, the 14 Gt emissions constraint is met in both scenarios, mainly from almost completely decarbonizing South Africa's electricity sector by 2050.

2.3 Climate policy

In 2009, South Africa made a pledge to reduce emissions by 34 per cent in 2020 and 42 per cent in 2025, in relation to its BAU baseline. This reduction below BAU has since been formalized in the National Climate Change Response White Paper as the 'peak, plateau and decline' (PPD) trajectory (DEA 2011), and communicated in South Africa's Nationally Determined Contribution (DEA 2015).

The emissions trajectory 'range'[2] is an implicit carbon budget (Winkler and Marquard 2012); annual emissions outlined by the Department of Environmental Affairs (DEA 2011) add up to a total budget of 15 (lower PPD) to 23 (upper PPD) Gt CO_2-eq from 2010 to 2050. We assume that emissions have been around 3 Gt from 2010 to 2015 (though this estimate is uncertain until a new GHG Inventory is produced). That would leave a budget of 12–20 Gt CO_2-eq for the period 2016–2050 (Caetano and Burton 2015). Therefore, the 14 Gt constraint on energy emissions that was assumed in South Africa's DDPP can be seen as the mid-point between upper and lower PPD.

Although this may be within the bounds of South Africa's climate policy, it may not be within the range of South Africa's fair share of contributions to a global effort to keep temperature rise below 2°C.[3]

3 Methodology

3.1 Modelling approach

The study is based on modelling that uses the fully linked inter-temporal bottom-up optimization energy model of South Africa (SATIM-F) and a dynamic recursive computable general equilibrium model (e-SAGE), as described in Merven et al. (forthcoming).

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-F 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,

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[2] A 'benchmark emissions range' exists with an upper and lower bound; this range developed in response to uncertainties in the business-as-usual projection, and the choice of upper, mid, or lower PPD for implementation has become a key site of conflict between different stakeholders.

[3] This is explained further in Section 3.2.

lighting, and process heat). Final energy demand is then calculated endogenously on the basis of 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, and 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. The demand sectors are industry, agriculture, residential, commercial, and transport, and the supply sectors are electricity and liquid fuels.[4] In DDPP, the full energy model (SATIM-F) was not yet linked to the CGE model (e-SAGE); only the electricity component of the energy model (refered to as SATIM-E) was linked to e-SAGE. Therefore, the impact of a decarbonized energy sector on the economy was probably underestimated, as the pass-through from other sectors was not accounted for.

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 and four labour groups disaggregated according to level of education, and there is a distinction between energy and non-energy capital (Arndt et al. 2014). The government, enterprises, 14 household groups based on their per capita expenditure, and interactions with the rest of the world[5] 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 '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 on the basis of the new equilibrium during the between period, 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-F (Alton et al. 2014; Altieri et al. 2015).

CGE models are governed by a set of closure rules, which are used to ensure that macro-economic 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 to all of the e-SAGE model runs:

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

[5] 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.

- **Savings and investment:** Previous studies have found that the savings-driven investment closure is most appropriate for South Africa.[6]
- **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 payments to and from other countries.[7]
- **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.[8] Skilled 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 that 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 to less energy-intensive capital and technologies, the ease of which is specified exogenously (Alton et al. 2014).[9]

Linking the energy (SATIM-F) and economic (e-SAGE) models

The linked model draws on features of both models to improve the modelling outcome. The energy model is able to capture the demand for energy (including time-of-use) as well as detailed supply-side investment options in a wide range of technologies, under carbon constraints. On the other hand, e-SAGE 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-F and e-SAGE are performed from 2006 to 2050, and information is passed between the models after each instance, as shown in Figure 3. In each iterative loop SATIM-F uses the sectoral GDP and household income from e-SAGE to compute an electricity investment plan, electricity price projection, and the energy component of all activities' production function, as well as the energy component of households' consumption

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[6] The relationship between savings and investment continues to be a highly debated and controversial topic in macroeconomics (Nell 2003). Neoclassical 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 the light of this, the e-SAGE model assumes a savings-driven closure (Arndt at al. 2011). This implies, amongst other things, that the deficit (foreign debt) is kept constant.

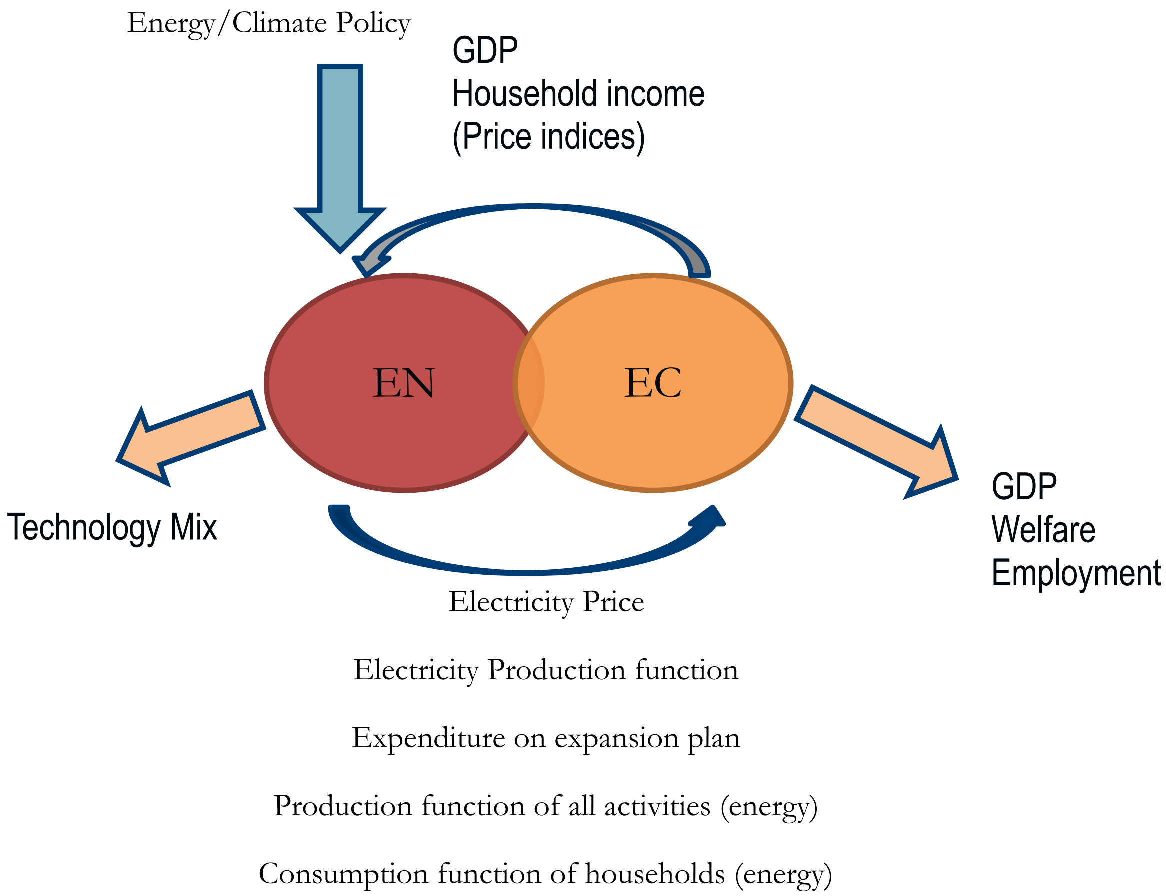
[7] The IMF projections show South Africa maintaining a current account deficit similar to the current deficit to 2020, in line with the assumptions made in the model.

[8] 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 low-skilled unemployment is structural.

[9] 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.

functions.[10] The use of a linked model allows a detailed analysis of both the resultant technology mix and the key socioeconomic indicators.

Figure 3: Links between the energy and economic models



Source: Merven et al. (forthcoming).

3.2 Scenario development

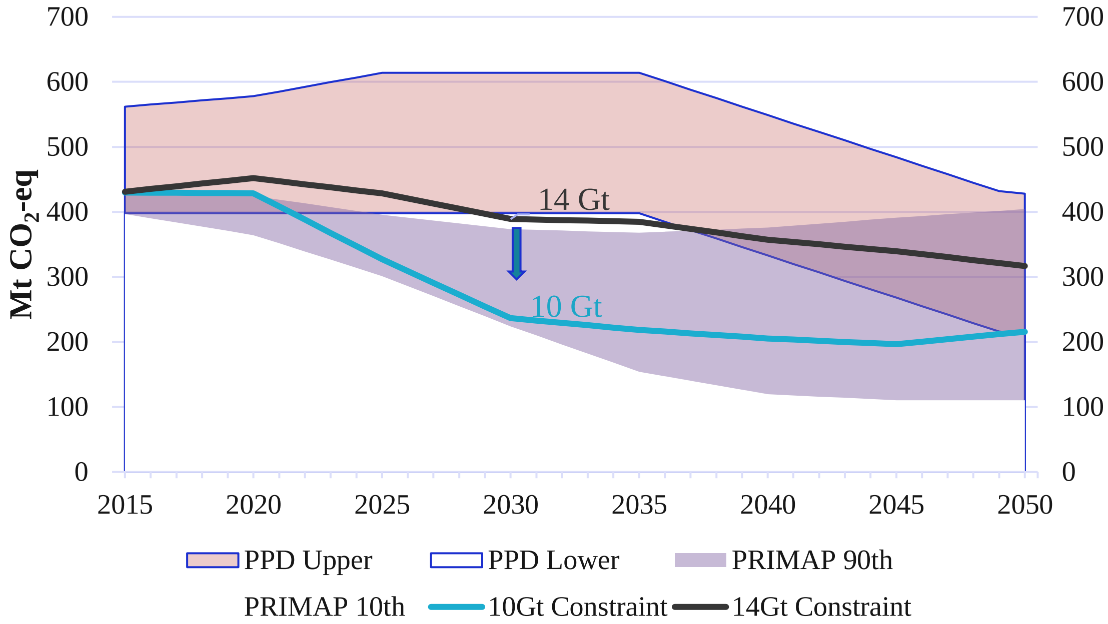
As previously mentioned, although a 14 Gt carbon constraint is within South Africa's PPD trajectory, South Africa's fair share of the remaining global carbon budget is usually, although not always, lower (Winkler and Marquard 2012). Rocha et al. (2015), using random weightings of different assumptions (including historical responsibility, capability, ability to mitigate, base years, and probabilities of temperature rise), have proposed an allocation range for South Africa (2016–2050) of 7.6–13.7 Gt CO_2 for a 50 per cent probability and 6.7–13 Gt CO_2 for a 66 per cent probability of limiting temperature rise to 2°C above pre-industrial levels (Caetano and Bruno 2015).

Figure 4 compares the ranges from Rocha et al. (2015) (bottom shading) with the PPD mitigation range put forward by South Africa (top shading). As can be seen, only the lower end of PPD range overlaps with the ranges proposed by Rocha et al. (2015). We have overlaid the PPD and the estimates of South Africa's allocation with the emissions trajectories of the scenarios used in this

[10] For a more detailed explanation of the linked model, see Merven et al. (forthcoming).

analysis for comparison (these cover the energy sector only, so are merely indicative, since emissions from the rest of the economy would increase the carbon budgets).

Figure 4: South Africa's climate policy versus PRIMAP estimates[11]



Source: Caetano and Burton (2015).

4 Results

4.1 Electricity sector

Electricity supply

As expected, the electricity sector experiences rapid decarbonization under a 10 Gt carbon constraint, as shown in Figure 5. The electricity sector is completely decarbonized by 2040, whereas under the 14 Gt scenario it is almost decarbonized by 2050. The coal-fired plants do not follow the expected retirement schedules and come off line rapidly between 2020 and 2040. This would mean that some units of Kusile would come online and have to be switched off to meet the carbon constraint—illustrating a high risk of stranding power sector assets.[12]

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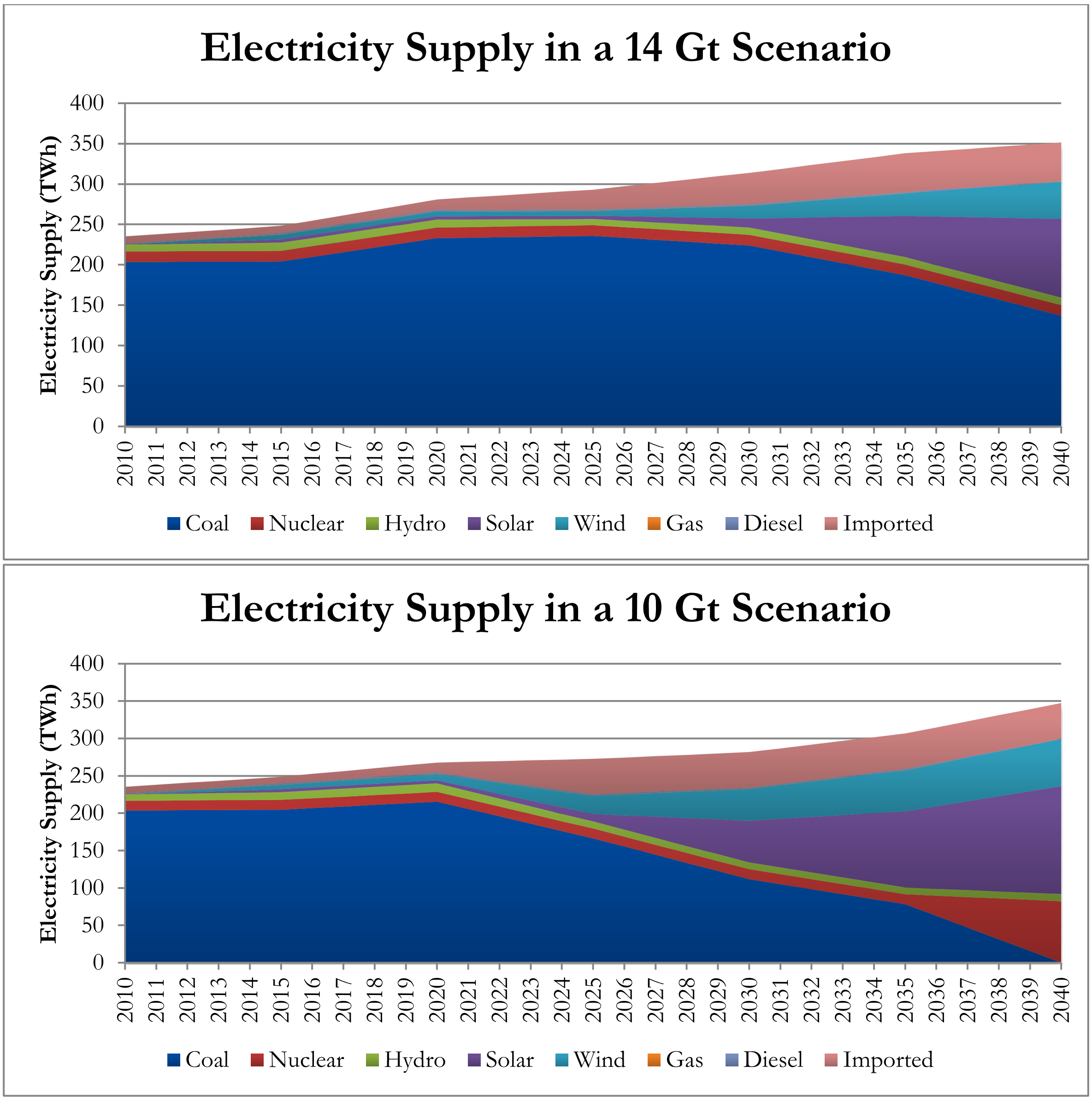
[11] As can be seen, only the lower end of the PPD range overlaps with the PRIMAP (Potsdam Real-time Integrated Model for probabilistic Assessment of emissions Paths) ranges proposed by Roche et al. (2015).

[12] In reality, these plants might not be built if there is a high risk of stranding these assets further down the line. However, the initial investments have already been made, construction has started and there are no signs that these investments will be abandoned prior to completion.

Figure 5: Electricity supply in 14 Gt and 10 Gt scenarios



Source: Authors' calculations.

Electricity price and investment requirement

The electricity price increases significantly in the 10 Gt scenario, relative to the already increasing electricity price in the 14 Gt scenario, shown in Table 1. It is important to note that it is not just that the electricity price increases; the electricity price is significantly higher for a sustained period. If this were the case, there would significant repercussions for both households and electricity-intensive users in South Africa. Households that can afford to will move off grid[13] and industries will do the same; alternatively, operations may cease (dependent on whether or not they would still be competitive).

[13] A move off grid refers to the users not purchasing from the utility (Eskom) or the municipalities, but rather building their own infrastructure to meet their energy demand. With current electricity prices this is already starting to happen in South Africa.

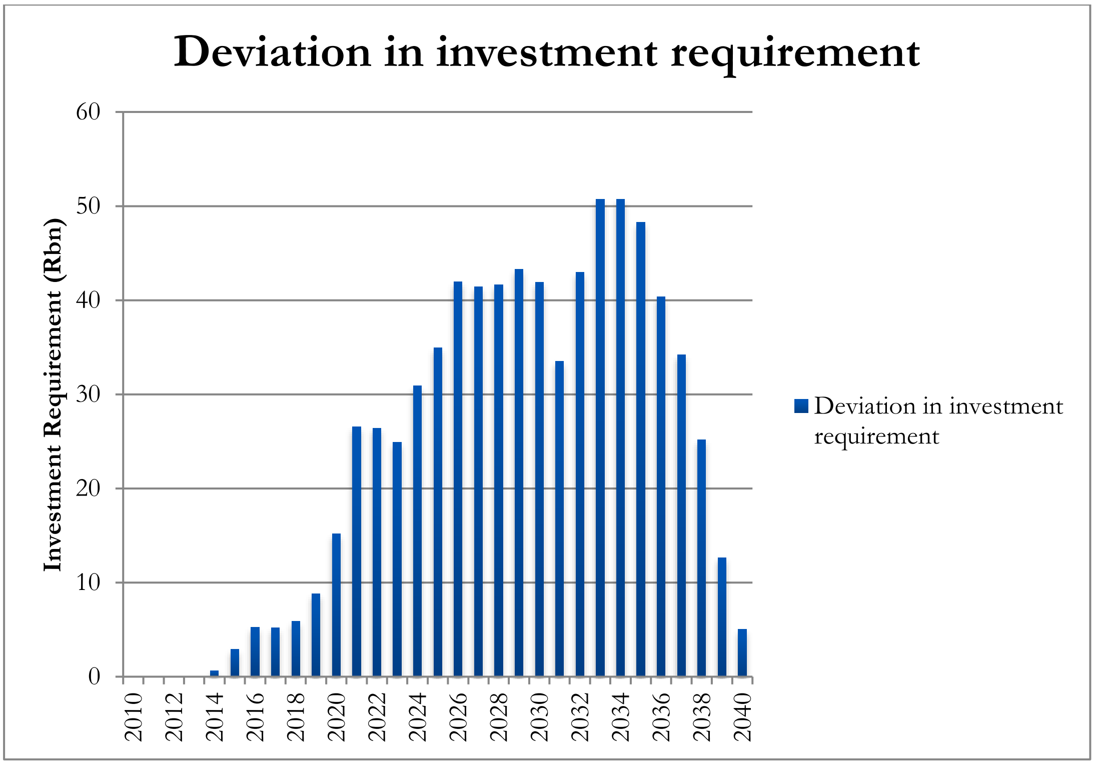
Table 1: Electricity prices

	14 Gt	10 Gt	Deviation
2010	45	45	0%
2015	62	62	0%
2020	66	70	5.4%
2025	77	81	5.5%
2030	96	103	7.7%
2035	91	96	5.2%
2040	86	103	19.0%

Source: Authors' calculations.

Rapid decarbonization in the electricity sector and the resultant stranding of coal-fired plants would increase the investment requirement by R742bn (2007 Rand). Figure 6 shows the annual investment requirement as a deviation from the already costly 14 Gt constrained energy sector. A 10 Gt constrained energy system would require investment immediately, as the coal-fired plants would be decommissioned earlier than they need to be (starting from as early as 2020).

Figure 6: Deviation in investment requirement (14 Gt scenario)



Source: Authors' calculations.

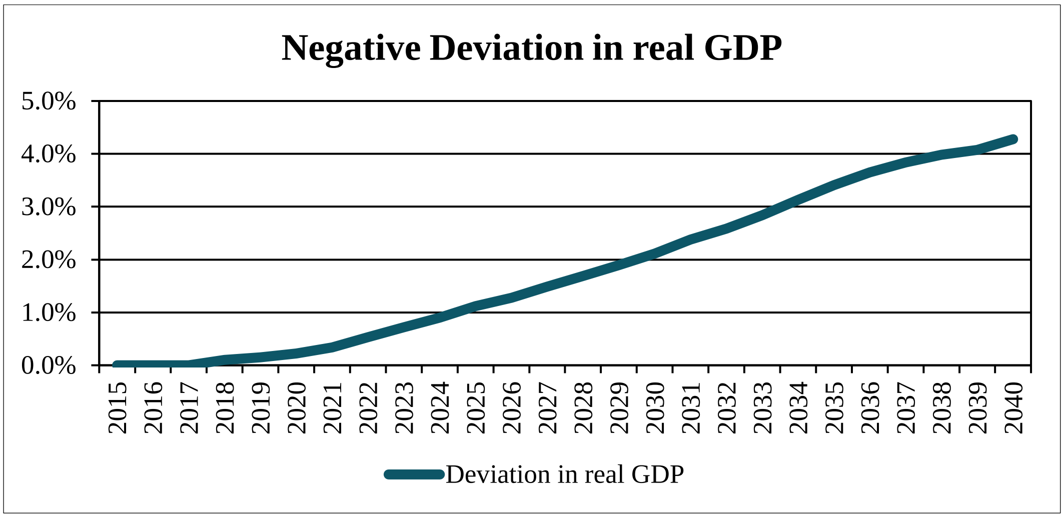
As previously mentioned, the investment requirement increases significantly to replace the new coal infrastructure (Medupi, Kusile, and the coal IPPs), which illustrates the risk that is posed by investing in further fossil fuel infrastructure and increasing South Africa's carbon lock-in.

4.2 Economy-wide

Overall GDP

The economy-wide impacts of a rapid transition to decarbonized energy are significant. The two main transmission mechanisms are the changing energy prices and the increased investment requirements that would decrease the investment available to other (more profitable) sectors of the economy. There is a cumulative impact on GDP as the economy contracts relative to the 14 Gt scenario with a resultant negative deviation in real GDP of just over 4 per cent in 2040, shown in Figure 7. The economy is still growing at a rate of 2.71 per cent per annum on average over the period, but there is added pressure, which would filter through to various macroeconomic impacts as government, private, and household consumption is constrained.

Figure 7: Negative deviation in real GDP (14 Gt scenario)



Source: Authors' calculations.

Sectoral GDP

When the impacts on overall GDP are broken down into sectoral impacts, it is evident that there is a general contraction in the economy, relative to the 14 Gt scenario, with all sectors except electricity and natural gas experiencing slightly less growth (see Table 2). The petroleum and coal-mining sectors, however are in structural decline in both the 14 Gt and the 10 Gt scenarios as domestic use as well as exports fall in these sectors. The electricity sector grows, as more investment in this sector is exogenous and allocated according to the investment that is required to decarbonize. The natural gas sector grows in the 14 Gt scenario and more so in the 10 Gt scenario as industry and transport demand for gas increases over the period.

Table 2: Implications for sectoral GDP

Impact on sectoral GDP (%)	14 Gt	10 Gt	Deviation from 14 Gt
TOTAL GDP	2.85	2.71	-0.14
AGRICULTURE	3.25	3.08	-0.16
INDUSTRY	2.65	2.53	-0.11
Mining	2.76	2.59	-0.16
Coal mining	-1.14	-2.13	-0.99
Natural gas mining	4.42	4.47	0.05
Manufacturing	2.50	2.31	-0.19
Petroleum products	-0.61	-0.80	-0.18
Other industry	2.91	3.11	0.20
Electricity	2.59	3.57	0.97
SERVICES	2.93	2.77	-0.16

Source: Authors' calculations.

Employment

The factor closure assumption is that there is unemployment for unskilled workers, but skilled labour are fully employed over the period. Given this assumption, there are 460,000 job losses in the 10 Gt scenario relative to the 14 Gt scenario. For skilled labour, factor returns grow less than in the 14 Gt scenario, from the decrease in demand for skilled labour. The sectors that experience the highest share of jobs lost are coal mining, basic chemicals, iron and steel, and nonferrous metals. Employment in the electricity sector increases by approximately 9,000 jobs, which is expected given that the sector grows significantly more in the 10 Gt scenario. Interestingly, in the natural gas sector employment decreases relative to the 14 Gt scenario, as the sector increases in capital intensity. Table 3 shows the overall levels of employment for each labour type as well as the resultant deviation between scenarios.

Table 3: Implications for employment

Employment Impact (thousands of FTE[14] jobs)	2010	2050		
		14 Gt	10 Gt	Deviation
LABOUR	12,176	6,154	5,694	-460
Unskilled labour	5,698	5,216	4,756	-460
Primary	1,930	1,720	1,571	-150
Middle	3,768	3,496	3,185	-310
Skilled labour	6,478	938	938	-
Secondary	3,541	610	610	-
Tertiary	2,937	329	329	-
Electricity sector	35	11	21	9

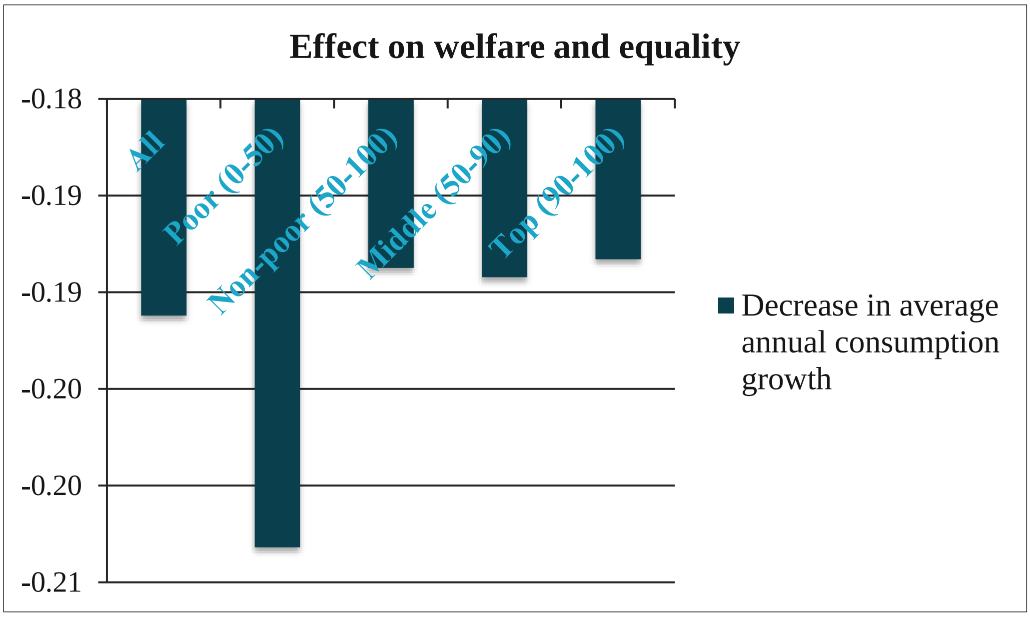
Source: Authors' calculations.

[14] FTE—Full-time equivalent.

Welfare

As a simple proxy for welfare, the changes in average annual consumption show that lower-income households are slightly worse off than higher-income households, as illustrated in Figure 8. This is expected for two reasons: first, because there are significant job losses for unskilled labour; and second, as energy commodities make up a larger share of lower-income households' consumption bundles, the impact of higher prices would be greater on these households.

Figure 8: Effect on welfare and equality



Source: Authors' calculations.

5 Discussion, caveats, and future work

The 10 Gt scenario presents a rapid transition in the energy sector, and requires immediate action in order to meet the emissions constraint. A rapid transition of this nature would have a negative socioeconomic impact on South Africa, given its significant carbon lock-in. It is clear that further investment in fossil fuel infrastructure would amplify this negative impact. The ability of the energy sector to make such a rapid transition needs to be assessed (especially in relation to the infrastructure and construction constraints, which may not be accounted for in this analysis, e.g. number of cranes, and supply of cement). In addition, available options to increase efficiency need to be explored at a more granular level.

Investing in low-carbon and employment-generating sectors could ease this transition and increase development, as was illustrated in the DDPP analysis. It would be interesting to analyse the impacts of rapid decarbonization on alternative economic pathways for South Africa.

The higher electricity prices caused by a rapid transition to decarbonized electricity could cause both commercial users and households to move off grid. This could pose a serious problem in terms of recouping investments in the electricity sector, as well as for the subsidization model that is currently in place to increase affordability for lower-income households. This dynamic is not yet captured in the model, and presents an interesting case for future work.

There is huge uncertainty in energy and economic modelling, especially when modelling so far into the future. Another interesting area for future work would be to extend this analysis to a Monte Carlo simulation approach in order to assess the potential impacts under uncertainty (Merven and Durbach 2015).

Last, the CGE model currently uses a 2007 SAM, and the analysis could be improved with a more recent SAM (the 2012 SAM, for instance). It would be interesting to see how the results differ when a more recent SAM is used.

6 Key messages and conclusions

It is clear that there is a gap between South Africa's NDC and South Africa's fair contribution if temperature rise is to remain below 2°C. It is likely that South Africa, like all developed and developing countries, will be required to increase its ambition if there is any hope of keeping temperature rise below this level.

The increase in ambition is modelled in this analysis by making the emission constraint for the energy sector more stringent—from 14 Gt used in DDPP to 10 Gt. In order to achieve a 10 Gt constraint, South Africa would have to act immediately by increasing investment in the electricity sector, which would need to be completely decarbonized by 2040. Coal-fired power plants would not follow their retirement schedules and would experience a more rapid decommissioning plan, some units of Kusile coming online only to be switched off almost immediately. In reality this would not happen, but it does call into question the need for further investment in new fossil fuel infrastructure—especially given that South Africa is not constrained by electricity supply for the foreseeable future and that alternative generation technology options exist.

A rapid transition to decarbonized energy in South Africa is likely to have negative impacts, especially on lower-income households. These households are affected by both rising electricity prices and job losses. It is possible that, should South Africa explore alternative economic pathways, these negative impacts would be mitigated, but this needs to be explored further in future work.

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