DECARBONISATION AND THE TRANSPORT SECTOR: A SOCIO-ECONOMIC ANALYSIS OF TRANSPORT SECTOR FUTURES IN SOUTH AFRICA

That this is a final draft and the submission to JESA is still "embargoed", i.e. subject to final editorial review and the content may change slightly from how it looks now. It should not be distributed widely: it would be better to wait for it to appear in JESA before doing so.

Abstract

In South Africa, the focus of mitigation research has been on decarbonising the electricity sector, given that the sector was responsible for 61% of total greenhouse gas emissions in 2010, due to approximately 94% of electricity being generated by coal-fired power stations. Transport, the second-highest contributing sector, emitted a somewhat lower share of 15% in 2010, including refining emissions, but is expected to grow in relative contribution. Globally, governments are investigating transport solutions that not only reduce their national emissions but also decrease their reliance on energy imports and increase clean air in cities and towns. Given these priorities, a transition in the transport sector is seemingly inevitable. This paper outlines some key socio-economic implications of a transition in South Africa's transport system, building on work previously done. The focus is on a rapid decarbonisation of the South African economy and the potential impacts of implementing efficiency improvements in the transport sector, including mode switching. The overall finding is that a more ambitious decarbonisation target would have marginal impact on the economy relative to South Africa's nationally determined contribution. It was further found that the implementation of efficiency improvements and changes in behaviour (decreased mileage, increased occupancy, increased rail use and increased use of public transport) could significantly reduce the burden on the economy of a higher GHG emission reduction target.

Keywords:

Computable general equilibrium (CGE), transport, mitigation, electric vehicles, efficiency

1. Introduction

In South Africa, the focus of mitigation research has been on decarbonising the electricity sector, given that the sector was responsible for 62.5% of energy sector greenhouse gas (GHG) emissions in 2010 (RSA, 2013b), due to approximately 94% of electricity being generated by coal-fired power stations. Transport, the second highest GHG contributing sector, emitted a somewhat lower share, of 11%, in 2010, excluding refinery and process emissions (RSA, 2013b), but is expected to grow in relative contribution.

Given the urgent and growing need for countries to ramp up their ambition when it comes to their climate change response, efforts need to be made to reduce, if not eradicate, the use of carbon-intensive fossil fuels (coal, petroleum products, crude oil). With transport accounting for 34% of national energy demand (RSA, 2016b) and currently dominated by these fuels, interventions in this sector are key, and their greater impacts need to be well understood. This paper therefore aims to analyse the potential socio-economic impacts of decarbonisation with a focus on this sector.

Globally, governments are investigating in transport solutions that not only reduce their national emissions, but also decrease their reliance on energy imports and increase clean air in cities and towns (UK, 2017). Given these priorities, a transition in the transport sector is seemingly inevitable.

This paper builds on work done in Ahjum et al. (2017)'s study on the energy sector implications of South Africa's potential transport futures. Given South Africa's pressing development imperatives, this study goes a step further, to discuss the potential socio-economic implications of these energy futures. Its focus is on analysing the potential socio-economic implications of a more ambitious GHG reduction target and, further, the impacts if energy efficiency and mode switching were introduced in parallel.

The first section provides some background to work that has been done on decarbonisation in the South African context. This is followed by a brief overview of the transport future that will be analysed in this study. The third section details the linked energy and economic model approach that is used. Section four presents the key results from this analysis, followed by a discussion of the results, areas for future work and, finally, the conclusion.

2. Decarbonisation in the South African context

Altieri et al. (2016) examined the implications of meeting a cumulative carbon constraint between 2015 and 2050 of 14Gt CO_2-eq, in scenarios considering different economic development pathways for South Africa.The emissions constraint was met by a rapid decarbonisation of electricity supply and a move away from emissions intensive gas-to-liquids and coal-to-liquids (Altieri et al., 2016). A main finding of Altieri et al. was that the rapid and relatively lower cost decarbonisation of the electricity system encourages demand sectors to increase their dependence on electricity. In the transport sector, this provides an opportunity for a large-scale switch to electro-mobility technologies including battery electric (BEV), hydrogen fuel cell and hybrid vehicles. Such a transition would address one of the main concerns about plug-in vehicles: that the carbon emissions simply move from the vehicle's exhaust to the power station (IMF, 2015).

In a follow-up paper, Caetano et al. (2017) analysed an even more rapid transition to decarbonised energy in South Africa, and assumed a more stringent constraint of 10 GT from 2015 to 2050. To meet this carbon constraint, the electricity sector undergoes a rapid transition that leads to higher electricity prices between 2020 and 2040. The electricity price increases as a result of the increase in electricity sector investment requirements, which has a slightly negative impact on the economy. The cumulative impact of the transition is just over 4% of total GDP in 2040. The economy remains in the black, however, with a growth rate of 2.7% per annum on average over the period.

The focus of these studies was mainly on the rapid transition in the electricity sector as a response mechanism. The potential opportunities that a decarbonised electricity sector could provide for the transport sector has yet to be unpacked. Given the significance of transport in total final energy demand in South Africa, and that globally electro- mobility is gaining traction, these opportunities need to be explored.

3. Methodology

This section provides a brief description of the models – linked energy (SATIM)[1] and economic (e-SAGE)[2] – that are used to unpack these opportunities for transport in South Africa. The motivation for using this approach is given below.

[1]Detailed model documentation for SATIM can be found at: http://www.erc.uct.ac.za/Research/esystems-group-satim.htm.

[2] A detailed explanation of the e-SAGE model can be found in the Alton et al. (2014) paper where the e-SAGE model is used to analysis carbon taxes in South Africa.

3.1 SATIM

SATIM is a full-sector TIMES model that includes both the supply and demand sides 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 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 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. SATIM 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).

Long-term modelling requires a credible storyline with a consistent set of assumptions. SATIM relies on a scenario-based approach for long-term modelling. Unlike forecasts, these scenarios do not pre-suppose knowledge of the main drivers of demand; instead, a coherent set of assumptions form the basis for the changes in these drivers as they evolve in a consistent system (Merven et al., 2014). This is difficult to achieve without the use of an economic model.

In addition, SATIM does not endogenously account for the feedback from the economy as sectors and consumers respond to changes in energy prices, and as the economy responds to energy investment requirements. By not accounting for this feedback, it is likely that SATIM will over- or under-estimate energy demand when used independent of an economic model.

3.2 E-SAGE

E-SAGE was developed by the United Nations University World Institute for Development Economics Research (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. 2011). The government, enterprises, 14 household groups based on their per capita expenditure, and interactions with the rest of the world[3] are all represented. The behaviour of industries and households is governed by rational expectations (Thurlow 2004, 2008). Industries and producers aim to maximise profits, while households aim to maximise 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 that 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:

- **Savings and investment:** Previous studies have found that the savings-driven investment closure is most appropriate for South Africa.[4]

- **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.[5]

3 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.

4 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 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.

5 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.

- **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.[6] 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.

A key feature of the e-SAGE model is that energy is considered an intermediate input and the interaction between intermediates and factors is governed by a Leontief production function (Merven et al., 2017).

Although e-SAGE has come some way to including more detail on the energy sectors, the model is not designed to optimise the supply of energy, which is needed to efficiently allocate investment to energy sectors. This requires a detailed representation of technologies that exist and that are available to the energy sector, as well as detailed energy demand profiles, such as those that exist in the SATIM model (Merven et al., 2017).

3.3 Linked model

The linked SATIM and e-SAGE model brings together a bottom up engineering model of South Africa's energy system (SATIM), and a top down economic model (e-SAGE), which is a computable general equilibrium model. In the linked model (see Figure 1), alternate runs of SATIM and e-SAGE are performed from 2006 to 2050, and information is passed between models after each instance. In each iterative loop SATIM uses the sectoral GDP and household income from e-SAGE to compute an electricity investment plan, electricity price projection, the energy component of all activities' production function, and the energy component of households' consumption functions.[7]

The use of a linked model allows a detailed analysis of both the resultant technology mix and the key socio-economic indicators.

6 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.

7 For a more detailed explanation of the linked model, see Merven et al. (2017).

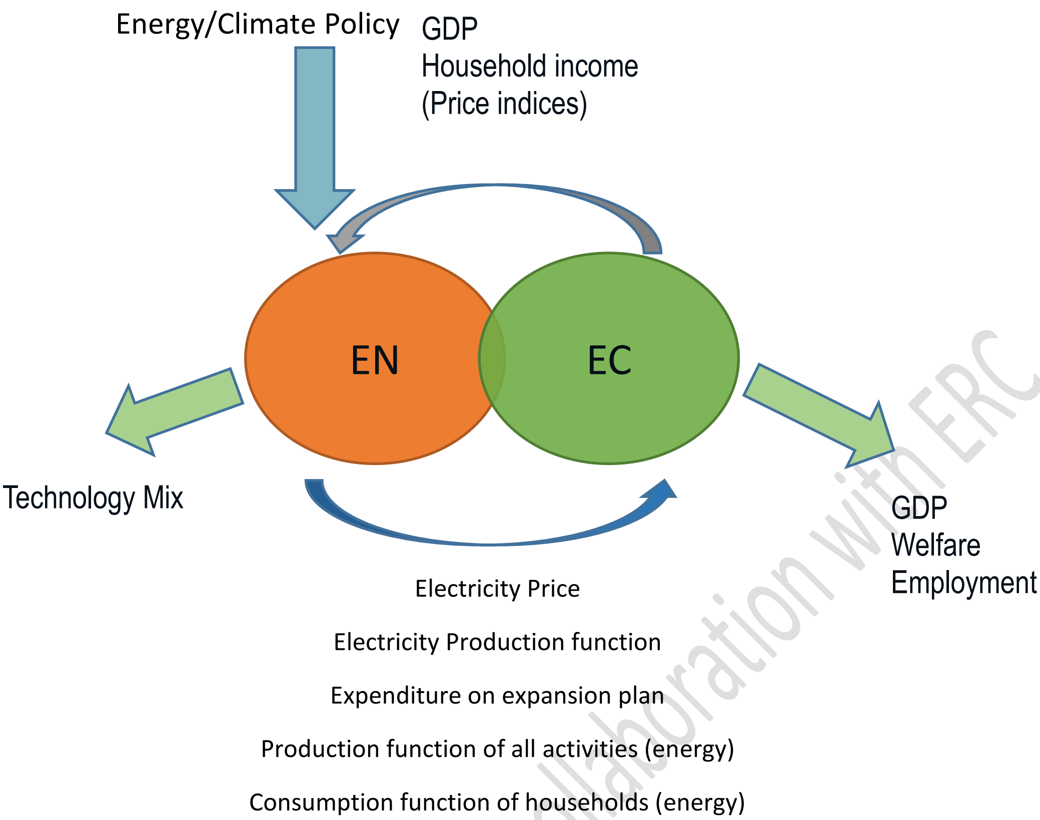

Figure 1: Summary of the link between SATIM and e-SAGE (Merven et al. 2017).

4. Transport sector futures

The transport sector, especially the energy infrastructure (refineries, pipelines, etc.) that supports it, requires a long-term planning horizon. The associated infrastructure investments are bound by long lead times, large sunk costs, and impact on society and the environment. The SATIM model was used to analyse the evolution of road transport in South Africa to 2050, given uncertainty in technology costs, technology options and fuel prices in Ahjum et al. (2017). These scenarios provide a valuable research base for long-term planning. The preference for alternative fuels, the extent of electric vehicle adoption, and the implications of a decrease in reliance on petroleum products are explored. Three scenarios were chosen for the purpose of this paper, firstly to show the impact of a more stringent carbon constraint, and secondly to show the impact of implementing efficiency improvements in the transport sector, including mode switching.

The baseline scenario includes a carbon cap of 14 Gt CO_2-eq cumulative from 2015 to 2050. This is in range with the emissions trajectory presented in South Africa's international obligation and its long terms climate mitigation goal that underpin its nationally determined contribution (NDC) (Altieri et al., 2016), hence the baseline scenario is referred to as the NDC scenario in this paper. In this scenario, it is assumed that private vehicle ownership is strongly linked to income (Dargay, 2001). The NDC scenario also assumes that there are no exogenous behavioural changes (annual mileage and occupancy are kept constant at 2006 levels for passenger transport). For freight transport, mode share between road and rail are also kept constant at that calibrated for the base year, 2006.

The second scenario, 'Increased ambition', is, as the name suggests, a scenario where South Africa increases its ambition in climate change mitigation and carbon emissions are constrained to 10 GT CO_2-eq cumulative from 2015 to 2050. This emissions constraint is loosely aligned with the lower PPD that underpin South Africa's long term mitigation goal. The assumptions for the demand projections are the same as in the baseline scenario.

The third scenario is 'Increased ambition EMS', which is the same as the second scenario in terms of carbon constraint, but also includes exogenous technology-based efficiency improvements and exogenous mode switching in the transport sector – for example, more efficient private vehicles and car-sharing. The demand projection for freight transport assumes that road-to-rail freight is promoted and the share of rail corridor transport increases, in line with Transnet's road-to-rail strategy (RSA, 2016). For passenger transport, behavioural changes are simulated, such as a decrease in private vehicle ownership and decrease in annual mileage, and an increase in occupancy. There is also an increase in the demand for passenger-kilometres (pkm) that are met by public transport over the period to 2050, in accordance with the White Paper on National Transport Policy (RSA, 1996) and the Moving South Africa Action Agenda (RSA, 1999). The efficiency of conventional internal combustion engine vehicles improves annually, as described in Ahjum et al. (2017). These scenarios are summarised in Table 1.

Table 1: Scenario summary.

	NDC[8]	Increased ambition[9]	Increased ambition EMS[10]
Carbon constraint	14 GT	10 GT	10 GT
Efficiency	No	No	Yes
Mode switching	No	No	Yes

[8] Referred to as 'Reference' in Ahjum et al., (2017).
[9] Referred to as 'Ref10GT' in Ahjum et al., (2017).
[10] Referred to as 'eMode10' in Ahjum et al., (2017).

5. Results

5.1 Introduction

This section contains results from the linked energy and economic model for the three scenarios, the NDC scenario with a 14 GT constraint, the Increased ambition scenario with a 10 GT constraint, and the Increased ambition EMS scenario which combines a 10 GT emissions constraint with exogenous energy efficiency and mode switching in the transport sector. A number of indicators will be reported on, including a brief explanation of the energy sector results (energy mix and effects on the electricity sector), and socio-economic results that include trade effects, GDP, sectoral GDP, employment, and income and welfare. In brief, results show that, under certain assumptions, BEVs could play a significant role in providing a private transport solution that is also low in carbon. Secondly, consumption of gas and electricity (especially distributed electricity) in the transport sector could surpass that of diesel and petrol by 2045. Lastly, efforts made to increase efficiency and mode switching in the transport sector could significantly reduce negative economic impacts that could result from stringent emissions constraint.

5.2 Energy mix and the electricity sector

In comparison to the scenarios with more stringent carbon constraints, the NDC scenario has marginally higher aggregate fuel consumption for road transport in 2045, namely 285 PJ as opposed to 278 PJ for the Increased ambition scenario and 274 PJ for the Increased ambition EMS scenario. Figure 2 shows the fuel consumed by the transport sector under all three scenarios in 2045. In the NDC scenario, demand is met through liquid fuels, low penetration of biofuels used mostly for public transport, a significant amount of hydrogen (41 PJ) used primarily for freight transport, natural gas (both imported and local), and electricity (both utility and distributed), which is the dominant energy source for the transport sector in 2045. An important result is that in 2045 the transport sector is more reliant on electricity and natural gas than diesel and petrol, which is a significant transition from the sector's current fuel demand.

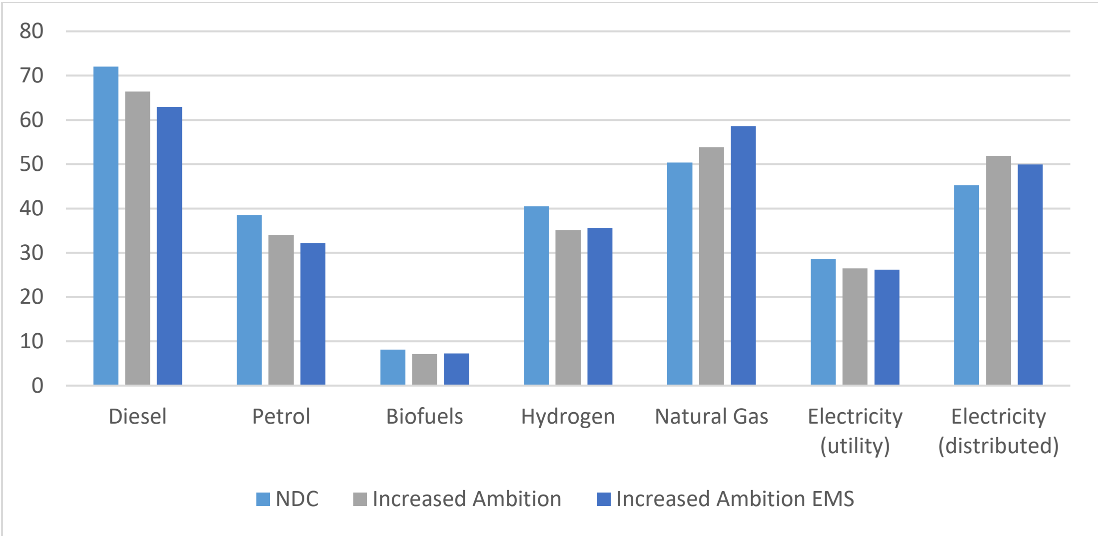

Figure 2: Fuel consumption in 2045 (PJ).

In the Increased ambition scenario there is notably less diesel and petrol used in the transport sector, compared to the NDC scenario. This is mainly for public transport and for freight. Less hydrogen is consumed in the more carbon-constrained scenarios, because hydrogen production relies on the natural gas reformation process, which in itself not carbon-neutral. The increased stringency of carbon emissions also results in more demand for natural gas and electricity (especially distributed electricity for charging private vehicles).

For private road transport, there is a high reliance on distributed electricity to fuel BEVs in all three scenarios in 2045. In all scenarios, it is assumed that the cost premium on BEVs declines to meet parity with internal combustion engine vehicles in 2030 and that there is potential for distributed generation of renewable energy by households and commercial buildings. Under these assumptions, BEVs could play a significant role in providing a private transport solution that is also low-carbon.

As the stringency of the carbon constraint increases from 14 GT to 10 GT and the model responds by rapidly decarbonising the electricity system, the transport sector's demand for distributed electricity increases above the NDC scenario in 2045 for both Increased ambition scenarios (see Figure 2). The increase in demand for distributed electricity is a result of the increase in private BEVs on the road. All energy demand sectors in the SATIM model follow the same trend and switch to decarbonised electricity as a least-cost mitigation option.

The investment requirement for the new electricity sector generation infrastructure is passed to the e-SAGE model. Figure 3 illustrates how much higher the investment requirement is when the carbon constraint moves from 14 GT to 10 GT. The Increased ambition scenarios would require 61% (without

EMS) to 64% (with EMS) more investment over the period before 2045, compared to the NDC scenario. A significant amount, given that the NDC scenario calls for ZAR 2.6 trillion (2015 rand) over the period, especially in the later years as sectors switch to decarbonised electricity in order to meet the more stringent carbon constraint.

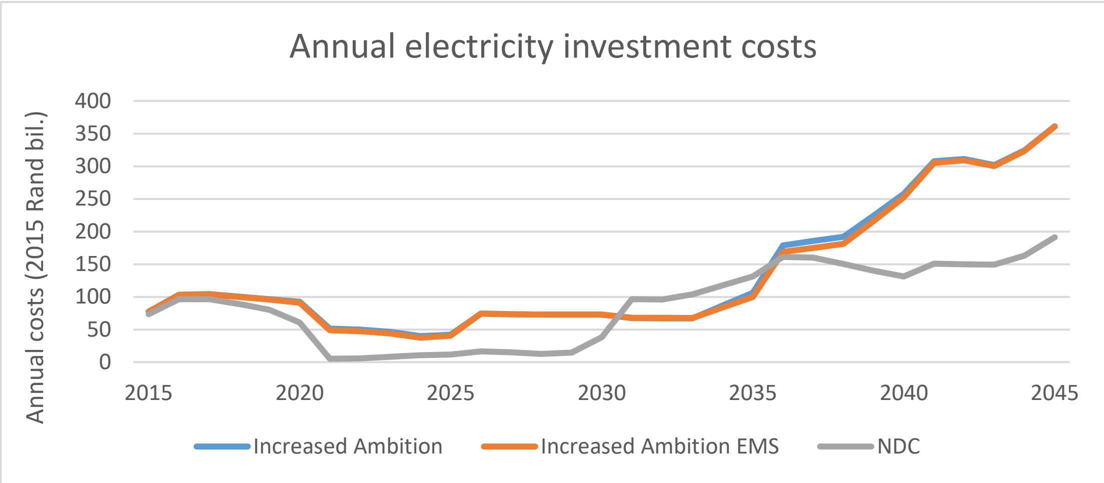

Figure 3: Annual electricity sector investment requirement.

In the e-SAGE model, it is assumed that all investment is taken from the savings pool and therefore an increase in investment allocated to the electricity sector means that there is less investment available for other sectors in the economy. This is explored in more detail in the section that follows. Sectors are impacted by this transition mechanism, as well as by the electricity price effects.

Table 2: Electricity prices as a deviation from the NDC scenario.

2015 cents/kWh	NDC	Increased ambition	Increased ambition EMS
2015	101.8	0%	0%
2025	128.0	24%	24%
2035	136.4	12%	12%
2045	166.7	16%	16%

Table 2 shows the electricity price growth path for the NDC scenario from 2015 to 2045, as well as the increase in the electricity price for both 10 GT scenarios over the period. The higher investment requirement in the 10 GT scenarios has a sustained impact on the electricity price, with an electricity price ~24% higher than the NDC scenario in 2025. The sustained increase in electricity price has a negative impact on sectors that have a high demand for electricity as their cost of production increases and this negatively affects their profitability, and thus slows down their growth. In the 2020s the higher electricity price in the Increased ambition scenarios, relative to the NDC scenario, is driven by the stranding of old coal-fired plants that do not run to the end of their lives, as was found in Burton et al. (2016).

5.3 Imports and the exchange rate

The 10 GT scenarios (Increased ambition with and without EMS) both rely heavily on imported fossil fuels, even more so than the NDC scenario (16%), at 21% and 20% of total import value respectively. This is mostly due to high amounts of gas imports (shown in Table 3) that are used in electricity generation, hydrogen generation and for freight transport, and the imported crude oil for the production of diesel. There is a large reduction in the imports of crude and liquid fuel, but these are offset by natural gas imports. Total fossil fuel imports as a portion of total imports are similar in all scenarios until 2035 when there is large uptake of gas, not only in transport but other sectors of the economy too. This would change significantly if a more optimistic view of domestic gas production, particularly shale gas, were assumed in the scenarios.

Table 3: Fossil fuel import breakdown for scenarios.

(R billions)	2015	2045 NDC	2045 Increased ambition	2045 Increased ambition EMS
Gas	0	183	210	212
Crude	53	23	32	27
Petroleum	36	16	19	17

The exchange rate is assumed to be flexible, and adjusts to maintain a budget deficit for South Africa to 2045. On average, the exchange rate appreciates slightly for both scenarios, compared to the NDC.

This has a negative impact on export-sectors of the economy. The trade narrative is explained further below.

5.4 Aggregate and sectoral GDP

Overall there is a slight negative impact on GDP in the Increased ambition scenario, compared to the NDC scenario. An advantage of using a dynamic model is that it is possible to analyse the results as the economy transitions over the period. As shown in Table 4, there is a negative impact on GDP in both scenarios compared to the NDC scenario, but the results suggest that, if efficiency improvements in the transport sector are implemented – including changes in behaviour (decreased mileage, increased occupancy, increased rail use and increased use of public transport), the potential negative impacts on GDP of more stringent carbon constraints will be dampened significantly. This implies that mitigation policy must take into account energy efficiency improvements and behavioural change in conjunction with national carbon budget if it is to reduce costs of mitigation.

Table 4: Total GDP as a deviation from NDC.

	Deviation from NDC	
	Increased ambition	Increased ambition EMS
2025	-1.0%	-0.8%
2035	-1.2%	-0.8%
2045	-2.4%	-1.5%

The trade and exchange rate effects as well as the energy infrastructure requirements both have an impact on sectoral GDP. To understand how these narratives play out, the impacts on sectoral GDP need to be analysed. At a sector level, the electricity sector is positively impacted by the increase in investment flows to fund the expansion in generation capacity. This is shown below in Table 5 by the 38% and 29% increase in other industry contribution to GDP for Increased ambition and Increased ambition EMS, relative to the NDC scenario.

Table 5: Sector contribution to increase in total GDP.

		Deviation from NDC	
	NDC	Increased Ambition	Increased Ambition EMS
Agriculture	3.89	-1%	-2%
Mining	9.25	-5%	-7%
Manufacturing	13.13	-7%	-5%
Other industry[11]	10.54	38%	29%
Services	63.20	-4%	-3%

There is an increase in the mining sector's contribution to GDP for both scenarios relative to the NDC. This is driven by growth in the natural gas mining sector, which is offset by the contraction of the coal mining sector, with a decline in annual sectoral growth of approximately 5% on average, relative to the NDC scenario. The domestic use of coal declines significantly in the 10 GT scenarios with the stranding of coal assets (mines, power sector and coal-to-liquids). This is consistent with previous work that has examined the potential for stranding assets in South Africa in more detail (Burton et al., 2016). Coal exports also decrease in both Increased ambition scenarios, which also contribute to the contraction of the sector, shown in Table 6.

Table 6: Average annual sectoral GDP growth.

		Deviation from NDC	
	NDC	Increased Ambition	Increased Ambition EMS
Agriculture	**3.25**	**-0.13**	**-0.11**
Industry	**3.00**	**0.02**	**0.03**
Coal mining	0.15	-1.72	-1.86

[11] Other industry includes the electricity sector, water distribution and construction. All the growth shown in this sector is from growth in the electricity sector, compared to the NDC scenario.

Natural gas mining	6.39	-0.63	-0.91
Manufacturing	2.48	-0.21	-0.14
Petroleum products	-1.99	-0.42	-0.62
Metals	2.64	-0.44	-0.32
Other industry	3.16	-0.20	-0.10
Electricity	3.83	-0.25	0.09
Construction	2.58	-0.24	-0.17
Services	**4.33**	**0.57**	**0.47**

The increase in investment requirement from the increased stringency of the carbon constraint has the overall impact of decreasing the investment available to other sectors of the economy, hence the negative impact on GDP overall as well as at a sector level. This is true for all sectors other than the natural gas mining sector and the electricity sector. As previously mentioned, however, efficiency improvements and behavioural change in the transport sector are key interventions that would dampen the negative impacts on GDP, and also in this case the impact on sectoral growth.

5.5 Employment

In terms of employment effects there are significant negative impacts on the employment of unskilled labour when the carbon constraint is changed from 14 GT to 10 GT, although, when efficiency improvements and behavioural change in the transport sector are introduced at the same time, these negative effects are dampened considerably. These impacts are shown in Table 7.

Table 7: Employment metrics

		2045	Deviation from NDC	
Number of workers (Full-time equivalent)	2010	NDC	Increased ambition	Increased ambition EMS

Labour	12 182 104	19 083 411	-925 127	-611 926
Unskilled labour	5 703 840	11 497 006	-925 127	-611 926
Primary	1 932 654	3 858 755	-302 910	-200 931
Middle	3 771 186	7 638 251	-622 217	-410 995
Skilled labour	6 478 264	7 586 404	-	-
Secondary	3 541 282	4 262 654	-	-
Tertiary	2 936 982	3 323 750	-	-

The decrease in the employment of unskilled workers in the Increased ambition scenario, relative to the NDC scenario is driven by the relative decline in growth in almost all sectors, but notably in sectors that rely on unskilled labour because of higher prices, namely, the coal mining sector and the agricultural sectors (agriculture crops, forestry and fisheries). The employment gains that are seen in the EMS scenario, relative to the Increased ambition scenario, are from slightly less employment losses overall, and notably from an increase in employment in the agriculture crops sector relative to the NDC scenario.[12]

The electricity sector, given the positive impact on growth in both Increased ambition scenarios, increases employment by around 134 770 and 108 423 employees, respectively. There is also an increase in the employment in transport services, mainly driven by increases in freight and public transport that are captured in this sector. Freight and public transport are currently combined in the Transport services sector in e-SAGE, so the links between models are currently weak and possibly underestimate the extra expenditure required by the state on public transport, and rail infrastructure for freight.

5.6 Income and welfare

There is a negative impact on income and consumption in both the Increased ambition and Increased ambition EMS scenarios, and households earn ~11% less over the period in comparison to the NDC scenario. The poor households (bottom 50% of income earners) are worse off with earnings of ~12% less over the period, compared to non-poor households that earn ~10.9% less. The decline in welfare

[12] The value chain for biofuels is not accurately represented in this version of the model. Therefore, the growth and employment effects of biofuel production are not well captured and are underestimated in the results.

of all households, relative to the NDC scenario, is predominately caused by the negative employment effects and the overall decline in growth in the economy. The slight appreciation of the rand in both 10 GT scenarios dampens the negative impacts due to the increased affordability of imported goods and services.

6. Caveats and future work

There are a number of interesting areas for future work, and it is recommended that, given the increase in electromobility globally, that these transport sector transitions are investigated further.

This analysis has been made possible by using a sophisticated linked energy and economic model that contains both a detailed energy system for South Africa, as well as all the macroeconomic linkages in the economy. Although this modelling approach is well suited to the research questions posed in this paper, there are some important caveats and areas for future work.

- The model is built on a 2007 SAM, and needs to be updated to the latest available SAM for South Africa, namely 2012, to have a more recent description of the economy as the starting point for the analysis.
- The growth in gas portion of the mining sector assumes that gas extraction takes place domestically. It would be important to also further explore scenarios where no such discoveries are made and all the natural gas is imported.
- The value chains for transport sector fuels, namely hydrogen and biofuels, are not yet captured in the linked model. Therefore, it is likely that the results underestimate the knock-on effects of increased reliance on these fuels, in particular the employment impacts and increased demand for domestically produced products.
- The transport sector in the computable general equilibrium model currently aggregates freight and public transport into one sector and to improve the characterisation of the scenarios presented here, it would be important to make this disaggregation, to better track the subsidy burden of public transport on the fiscus.
- The vehicle ownership information from SATIM is not yet passed through to the eSAGE model, therefore the vehicle fleets in each model are not yet consistent. There are, however, increases in the demand for vehicles that occur endogenously in the eSAGE model. For instance, as household income increases there in an increase in vehicle demand that filters through to the vehicles manufacturing sector.

- Infrastructure requirements for electric vehicles, the cost of this infrastructure, and the potential benefits for localisation are not yet captured in the eSAGE model. It would be interesting to expand this analysis to include a specific case study on investing in electric vehicles in South Africa, given the global trends towards increased electric (battery electric, plug-in hybrid, and fuel-cell electric) car ownership (IEA 2016).
- It is also important to explore the implementation of policies for electric vehicle penetration as well as incentives that could be used to enable this. It is likely that with the right policies in place, a rapid transition to electric vehicles could happen organically and without a hard carbon constraint. For instance the cost of electric vehicles could be subsidised, special parking bays or allowances could be introduced, or the import tariff on electric vehicles could be reduced, currently at 43% of the vehicle price (Venter, 2017).

7. Conclusions

This paper outlined some of the key socio-economic implications of a transition in South Africa's transport system, building on work done by Ahjum et al. (2017). The focus was on a rapid decarbonisation of the South African economy and the potential impacts of implementing efficiency improvements in the transport sector including mode switching. The findings show that under certain assumptions BEVs could play a significant role in providing a private transport solution that is also low carbon. Overall the results suggest that a rapid decarbonisation of the South African economy would have a slightly negative impact on the economy relative to a less ambitious decarbonisation target. Further, it was found that the implementation of efficiency improvements in the transport sector and changes in behaviour (decreased mileage, increased occupancy, increased rail use and increased use of public transport) could significantly reduce the burden on the economy of stringent emissions reductions. This implies that mitigation policy must take into account energy efficiency improvements and behavioural change in conjunction with national carbon budget if it is to reduce costs of mitigation.

References

Ahjum, F., Merven, B., Stone, A. and Caetano, T. (Forthcoming 2017). An analysis of road transport vehicles in South Africa towards 2050: Factors influencing technology choice and implications for fuel supply. Energy Research Centre, University of Cape Town, Cape Town, South Africa.

Altieri, K.E., Trollip, H., Caetano, T., Hughes, A., Merven, B. and Winkler, H. 2016. Achieving development and mitigation objectives through a decarbonization development pathway in

South Africa. *Climate Policy* 16(sup1): S78–91.

Alton, T., Arndt, C., Davies, R., Hartley, F., Makrelov, K., Thurlow, J. and Ubogu, D. 2014. Introducing carbon taxes in South Africa'. *Applied Energy* 116(1): 344–54.

Analysis, Systems, and Planning Group (2013). Assumptions and methodologies in the South African TIMES (SATIM) Energy Model. Available at: http://www.erc.uct.ac.za/groups/esap (accessed February 2017).

Arndt, C., R. Davies, and J. Thurlow (2011). 'Energy Extension to the South Africa General Equilibrium (SAGE) Model (Version 2)'. Helsinki: United Nations University World Institute for Development Economics Research. Unpublished mimeo.

Arndt, C., Davies, R., Gabriel, S., Makrelov, K., Merven, B., Salie, F. and Thurlow, J. 2014. An integrated approach to modelling energy policy in South Africa: Evaluating carbon taxes and electricity import restrictions' UNU-WIDER Working Paper 2014/135. Helsinki: United Nations University World Institute for Development Economics Research.

Burton, J., Caetano, T., Hughes, A., Merven, B., Ahjum, F. and McCall, B. 2016. The impact of stranding power sector assets in South Africa: using a linked model to understand the economy-wide implications. Energy Research Centre, University of Cape Town, Cape Town, South Africa.

Dargay, J.M. 2001. The effect of income on car ownership: Evidence of asymmetry. *Transportation Research Part A: Policy and Practice* 35(9): 807-821.

Dervis, K. and S. Robinson 1982. *General equilibrium models for development policy*. Cambridge University Press.

Energy Research Centre [ERC] 2014. South African TIMES model. Available at: http://www.erc.uct.ac.za/groups/esap (accessed February 2017).

International Energy Agency [IEA]. 2016. Global EV outlook 2016: Beyond one million electric cars. International Energy Agency. Paris, France. April 2017. Available at: https://www.iea.org/publications/freepublications/publication/Global_EV_Outlook_2016.pdf.

International Monetary Fund [IMF]. 2015. *How Large Are Global Energy Subsidies?* International Monetary Fund Working Paper – WP/15/105. May 2015. Available at: https://www.imf.org/external/pubs/ft/wp/2015/wp15105.pdf.

Löfgren, H., Lee Harris, R. and Robinson, S. 2002. A standard computable general equilibrium CGE model in *GAMS*. Vol. 5. *Microcomputers in policy research*. International Food Policy Research Institute, Washington D.C. 2002.

Merven, B., Moyo, A., Stone, A., Dane, A. and Winkler, H. 2014. The socio-economic implications of mitigation in the power sector including carbon taxes in South Africa. Working paper for CDKN project on linking sectoral and economy-wide models. Energy Research Centre, University of Cape Town, Cape Town, South Africa.

Merven, B., Arndt, C. & Winkler, H. 2017. The development of a linked modelling framework for analysing the socioeconomic impacts of energy and climate policies in South Africa. WIDER Working Paper 2017/40. Helsinki: UNU-WIDER.

Nell, K., 2003, Long-run exogeneity between saving and investment: Evidence from South Africa. TIPS Working Paper 2-2003, Trade and Industrial Policy Strategies.

Thurlow, J., 2004. A Dynamic computable general equilibrium CGE model for South Africa: Extending the static IFPRI model. Trade and Industrial Policy Strategies, Pretoria, South Africa.

Thurlow, J. 2008. A recursive dynamic CGE model and microsimulation poverty module for South Africa. International Food Policy Research Institute, Washington, D.C., USA.

Republic of South Africa [RSA]. 1996. *White paper on national transport policy*. Department of Transport, South Africa.

Republic of South Africa [RSA]. 1999. *Moving South Africa action agenda.* Department of Transport, South Africa.

Republic of South Africa [RSA]. 2013. *Energy balance.* Department of Energy, South Africa.

Republic of South Africa [RSA]. 2013b. *GHG inventory for South Africa 2000–2010*. Department of Environmental Affairs, South Africa.

Republic of South Africa [RSA]. 2016. *National transport master plan NATMAP 2050.* Department of Transport, South Africa. 19 October 2016.

Republic of South Africa [RSA]. 2016b. *Draft integrated energy plan IEP report*. Department of Energy, South Africa. Pretoria.

United Kingdom [UK] 2017. *Driving the future today: A Strategy for ultra low emission vehicles in the UK*. Office for Low Emission Vehicles. UK Government. London. Available at: https://www.gov.uk/government/publications/driving-the-future-today-a-strategy-for-ultra-low-emission-vehicles-in-the-uk.

Venter, I. 2017. New body to tackle public perception, cost of electric vehicles. *Engineering News.* 25 January 2017. http://www.engineeringnews.co.za/article/new-body-to-tackle-public-perception-costs-of-electric-vehicles-2017-01-25

Winkler, H. 2007. Long-term mitigation scenarios. Project Report. Energy Research Centre, University of Cape Town, Cape Town, South Africa.