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The Socioeconomic Implications of Renewable Energy and Low Carbon Trajectories in South Africa[1]

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Introduction

South Africa is highly coal dependent with a large variance between emissions per capita and levels of development. The current structure of the South African economy has resulted in sub-optimal outcomes: environmentally with high carbon intensity and socially with a Gini-coefficient of 0,63[2] 29.2 per cent of the population living on US$2.5 a day[3] and an official unemployment rate of 24.3 per cent.[4] High levels of poverty and inequality are likely to be exacerbated substantially by climate change impacts in the future.[5]

South Africa has committed to emissions reduction of 34 per cent by 2020 and 42 per cent by 2025 relative to a 'business-as-usual' baseline (RSA 2010). In order to reach these targets alternative energy options need to be explored. The country's Integrated Resource Plan (IRP) shows a move in the right direction with a decrease in the reliance on coal-fired plants and an increase in renewable energy generation capacity.

The current process of the IRP is influenced by a number of policy goals, including emissions reductions. These policy goals act as 'inputs' into the operational process. The intention of the IRP is to address these and propose an electricity supply plan that is aligned with these policy goals and ensures the supply of affordable and reliable electricity to the region. Three easily quantifiable indicators form the basis of decision making in the IRP; namely investment cost, emissions reduction and water usage. There are, however, a number of important economic and social policy goals that should also form an integral part of the decision making process, namely: (1) economic growth or GDP growth; (2) employment; (3) regional development; (4) localisation; (5) good terms of trade; and (6) low electricity price. The modelling approach used in the IRP is limiting in terms of analysing the plan's ability to address some of these policy goals. This is a major gap in the planning process, as these policy goals are important considerations for economic growth and development nationally as well as regionally. An interim attempt was made during the IRP process to quantify the possible effects of scenarios on these policy goals. The process followed a Multi-Criteria Decision Making[6] methodology informed by various stakeholder meetings. An important drawback of this method is that it is difficult to prove that there is solid theoretical backing for the results and that these results are not influenced by subjectivity. However, under time and budget constraints it was difficult to include a thorough economic analysis in the IRP process, and the need for this type of analysis was mentioned in the draft report for the IRP (DoE 2010).

This paper aims to fill this gap in the literature by using a highly disaggregated economy-wide model to analyse the potential socioeconomic implications of introducing renewable energy and implementing a carbon tax in South Africa. Furthermore, it seeks to use the model to address the impacts on two of the policy goals in the IRP, namely, economic growth and employment. The chosen methodology is appropriate for the analysis as it is theory-based and consistent with the current structure of the South African economy.[7]

There are a few existing studies that use similar methodologies to simulate mitigation actions in South Africa. Pauw (2007), Devarajan *et al.* (2011) and Alton *et al.* (2012) explore issues surrounding a carbon tax in South Africa. Devarajan *et al.* (2011) find that the implementation of a carbon tax in South Africa is likely to lead to a decrease in welfare but is, however, more efficient than other tax instruments in curbing energy use and emissions. An important limitation of this study, highlighted in Alton *et al.* (2012), is that there is no differentiation between energy technologies or inclusion of the country's long-term electricity investment plan. Pauw (2007), on the other-hand, distinguishes between different types of energy technologies and uses a partial-equilibrium energy model[8] to derive an optimal electricity investment schedule. This study finds smaller welfare reductions from the introduction of a carbon tax in comparison to Devarajan *et al.* (2011). Alton *et al.* (2012) follow Pauw (2007) by including detailed energy technologies and deriving electricity investment paths from an energy sector model. Secondly, they address a number of limitations of the aforementioned studies: the use of a dynamic CGE to overcome the lack of time dimension; industries are allowed to invest in less energy-intensive activities in response to higher energy prices; labour and capital market rigidities are captured; a number of tax recycling options are simulated. A carbon tax of R12 per ton of CO2 is introduced in 2012 and projected to rise linearly to a value of

R210 per ton in 2022; sufficient to meet the national emissions reduction target. This study highlights the importance of both the design of the carbon tax as well as the method of revenue recycling. In comparison, the use of tax revenues to fund corporate tax reductions is favourable for economic growth and high-income households but results in decreased welfare for the majority of the population. An alternative option of expanding social transfers, intuitively, improves welfare for low-income households but results in less economic growth.

The methodology used in this paper follows on from that used in Alton *et al.* (2012). The model design is extended to include a highly disaggregated renewable energy sector. Three scenarios, based on scenarios derived from a partial equilibrium energy sector model[9] used in the IRP process are simulated in this paper. The scenarios depict different levels of renewable energy investment and, since they are derived from an energy model, are consistent with South Africa's electricity system requirements. The results will include a comparison between potential impacts of these scenarios on economic growth, inequality, employment and emissions reduction.

Electricity Generation Options in South Africa

Description of the Model Scenarios

The Integrated Resource Plan (IRP) broadly describes the process of modelling and decision making for the future of South Africa's electricity generation. The main objectives are to, first, estimate the long-term future demand for electricity and, second, to identify possible scenarios of generation capacity that are able to meet this demand (DoE 2011). The long lead times and high investment costs associated with electricity generation capacity provide obvious motivation for the importance of integrated resource planning. A number of other concerns accompany these in the case of South Africa; economic uncertainty due to the long time horizon, pending emissions reduction targets, and security of supply concerns due to the country's dominant reliance on coal, to name but a few (DoE 2011).

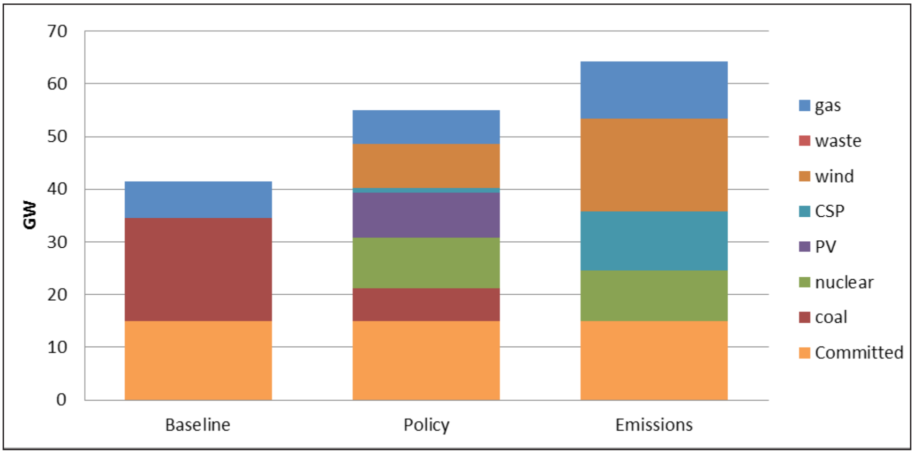
The scope of the IRP spans over the total demand and supply for electricity in South Africa, and includes Eskom as well as non-Eskom sources of generation capacity. The foundation of the plan is built on a number of policy recommendations, such as cost-minimisation, emissions constraints, regional development and localisation potential.

The initial stage of the IRP requires the generation of a base case, or reference scenario. This base case represents the least cost option and is considered the optimal option in terms of meeting capacity needs when the only limitation is the cost factor (DoE 2011). There are a number of other scenarios that are then compiled in the light of explicit policy and the consideration of risk adjustments that eventually lead to the determination of a proposed electricity build plan for South Africa.

A number of policy requirements govern the IRP. These form the foundation on which the IRP is built. Three particular elements of policy are crucial to the determination of the plan. Firstly, the Energy White Paper (DME 1998) specified a preference for the movement away from reliance on coal and towards a more diverse electricity generation mix with the inclusion of nuclear, natural gas and renewable options. Secondly, in light of potential future international climate change obligations, the IRP is considerate of South Africa's climate change policy. With regard to this, the importance of accounting for the environmental impacts of electricity generation technologies is noted and should be accounted for in the IRP. Thirdly, much political pressure is applied to ensure that electricity provision remains at the least possible cost to the consumer. In light of this, the purpose of the IRP is to provide a capacity build plan to meet the expected demand growth at the minimum social cost. The cost should include the costs associated with the impact of externalities.

The ultimate goal of the IRP process is to present a build plan that is acceptable to the Ministry as the most optimal scenario depicting a number of constraints and policy interests. The plan is not 'set in stone' and should be revised every two years in an attempt to mitigate the effects of uncertainty and allow the plan to evolve to meet revised demand growth and include any technological developments that may occur over the period. The current scenario is the policy-adjusted plan; considered to be a compromise between the least cost scenario (base case) and the scenario with the strictest emissions target. But it is also the most costly, being the emissions 3 scenario. The use of these three scenarios in this paper allows an appropriate contrast between employment projections under a low carbon trajectory and under a 'business-as-usual trajectory', where there is no need to reduce emissions. Figure 1 provides a graphical representation of the total new capacity builds under these scenarios over the period of analysis, 2010 to 2030.

Figure 1.1: The Planned Capacity Builds for all Three Scenarios (GW)

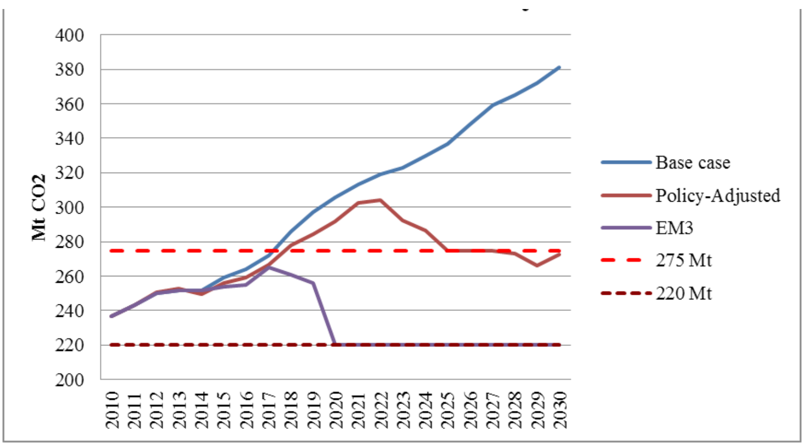


Source: Own calculations based on the IRP (2011)

The least-cost technology option in South Africa is coal, with coal-fired plants supplying over 90 per cent of South Africa's electricity. This is apparent in the baseline scenario where capacity for coal-fired electricity generation almost doubles over the period to 2030. There are a number of capacity build plans that are considered 'firm commitments' and are either in the process of being built or in the final stages of planning. Two large coal-fired plants, Medupi and Kusile, make up the bulk of the committed builds and are planned to add 8,760 MW of capacity by 2020 (dependent on delays). A number of small renewable electricity generation plants are also considered 'committed', however their contribution is minor in comparison, with an estimated 2,400 MW by 2030.

The policy-adjusted scenario displays a more diversified electricity build plan, with the inclusion of 9600MW of nuclear power, and 8400 MW each of wind and solar photovoltaic (PV). There is also an increase in peaking capacity, open-cycle gas turbines (OCGT) and closed-cycle gas turbines (CCGT), with 6280 MW of capacity in total. The emissions 3 scenario relies heavily on the use of renewable energy, contributing to approximately 60 per cent of total electricity capacity by 2030. As in the policy-adjusted scenario, 9600MW of nuclear power is planned to come online during the period with no additional base-load capacity from coal-fired plants. The emissions reductions in this scenario, although substantial with an annual emissions limit of 220MT CO2-eq, still won't get South Africa to the targeted emissions reduction of 42 per cent from baseline by 2025. Alton *et al.* (2012) estimate that, given domestic demand forecasts and production quotas, at least an additional R0.46 trillion of investment would be needed for South Africa to reach its emissions reduction target. The emissions pathways for the three scenarios are given below:

Figure 1.2: Emissions Pathways for the Base Case, Policy-adjusted and Emissions 3 Scenarios



Source: Based on IRP calculations

In order to ensure that the scenarios are comparable, we simulate the same total electricity supply in GWh for all scenarios. Renewable options for electricity generation currently have low capacity factors, in comparison to nuclear power and coal-fired plants. The rest of this section will expand on the technology options available in the IRP.

Technology Options for Electricity Generation

There are some alternative electricity generation options outlined in the IRP. Each option producing the same good, electricity, but with different technology coefficients – i.e., they have different factor and intermediate inputs. Table 1 provides a summary of the technology options in terms of cost, demand for intermediates and factor demand.

Table 1.1: Intermediate and Factor Estimates for Electricity Generation Technologies

	Coal	Nuclear	Hydro	PV	CSP	Wind	Waste	Gas	Diesel
Base Year 2007									
Electricity Supply (GWh)	229 571	11 317	5 845	213	319	32	204	1	86
Gross Operating Surplus10 (R mil)	55 749	2 480	1 369	140	103	8	76	0	16
Total Employment (people)	33 014	2 071	2 063	64	96	7	56	0	12
High Skilled (people)	15 054	795	990	32	48	3	26	0	6
Assumptions[11]									
Build cost (Rmil/GWh)	17 785	26 575	9 464	37 225	37 425	14 445	9 464	4 868	4 868
Levelised Cost12 of Plant (Rmil/GWh)	0,40	0,74	0,13	1,43	1,42	0,70	0,54	0,96	2,25
O&M (jobs/GWh)	0,14	0,18	0,35	0,30	0,30	0,22	0,27	0,14	0,14
Construction/ Installation (Job years/MW)	10,40	10,80	19,40	52,30	10,80	4,50	6,90	6,20	6,20
Manufacturing (Job years/MW)	1,50	1,20	0,90	16,80	7,20	22,50	0,80	0,07	0,07
Imported Content (%)	35	35	35	70	50	70	50	35	35
Value[13] (R/GWh)	6 225	9 301	3 312	26 058	18 713	10 112	4 732	1 704	1 704
Fuel (Rmil/GWh)	0,08	0,07	0,00	0,00	0,00	0,00	0,00	0,60	2,39

Source: Own calculations based on EPRI (2010)[14]

Measuring Economy-wide Impacts

Structure of South African Economy and Labour Markets

Table 2 outlines the structure of the South African economy and labour market in 2007. South Africa has a dominantly services-based economy, with services accounting for over 66 per cent of gross domestic product (GDP) and approximately two-thirds of employment. The electricity sector is a relatively small sector, with a contribution of around 1.8 per cent of GDP and 0.3 per cent of employment. Historically cheap electricity prices coupled with a mineral-rich country has aided the development of energy-intensive sectors in the economy. For this reason, we believe that the importance of the electricity sector is understated when looking at the direct contribution to GDP; the indirect effects of changes in the electricity sector are more pronounced given the forward linkages associated with the sector.

Table 1.2: Structure of South Africa's Economy and Labour Market (in percentage)

	Share of Total				Exports/ Output	Imports/ Output
	GDP	Employment	Exports	Imports		
Total GDP	100,00	100,00	100,00	100,00	11,21	15,28
Agriculture	3,11	3,74	2,64	0,95	11,14	5,65
Industry	30,77	29,08	83,73	84,22	21,49	27,53
Mining	8,83	8,79	33,41	10,47	65,07	40,75
Coal Mining	1,59	1,61	4,49	0,21	43,82	4,31
Manufacturing	16,83	15,88	48,75	72,47	16,55	30,04
Petroleum	1,15	0,20	2,17	3,67	8,41	21,84
Electricity	1,81	0,31	1,57	1,29	15,22	14,43
Coal-fired	1,63	0,28	-	-	-	-
Nuclear	0,15	0,02	-	-	-	-
Hydro	0,02	0,01	-	-	-	-
Construction	2,70	3,93	-	-	-	-
Services	66,12	67,18	13,63	14,83	3,11	3,91

Source: South Africa 2007 social accounting matrix (own calculations)

Eskom is the state utility and runs a monopoly in the electricity sector, generating approximately 95 per cent of the electricity used in South Africa and an estimated 45 per cent of the electricity used in Africa (Eskom 2011). Electricity generation is highly reliant on the use of coal, which remains the cheapest generation option given that South Africa is a coal-rich country. There was not much diversity in terms of electricity generation in 2007, with approximately 93 per cent of electricity generated by coal-fired plant; 1.8GW (5 per cent) generated by Koeberg, Africa's first nuclear power station; and the remainder generated mainly from hydropower (Eskom 2011).

Description of the Static E-SAGE Model

A number of CGE models have contributed to the local policy making process in areas including trade strategy, income distribution, and structural change in low-income countries. There are several features of this class of models that make them suitable for this type of analysis (Arndt, Davies, & Thurlow 2011). Firstly, the structure of CGE models ensures that all economy-wide constraints are respected and provide a theoretically consistent framework for welfare and distributional analysis (Arndt, Davies, & Thurlow 2011). Secondly, CGE models simulate the functioning of a market economy, and provide a platform for analysis on how different economic conditions affect markets and prices (Arndt, Davies, & Thurlow 2011). One of the drawbacks of this type of modelling, however, is that the credibility of the results is highly dependent on the accuracy of the data and assumptions made when calibrating the model. It is possible to mitigate this limitation through transparency and disclosing the assumptions made and data used in building the economy-wide model.

The South African General Equilibrium (SAGE) model used in this analysis is derived from neoclassical tradition originally presented in the seminal work by Dervis, de Melo, & Robinson (1982). A number of extensions and adaptations have been made to this framework including the ability for producers to produce more than one commodity and the explicit treatment of transaction costs (Lofgren, Harris, & Robinson 2001). The dynamic-recursive energy extension to the SAGE model, developed by Channing Arndt, Rob Davies and James Thurlow (2011) is used in this paper. The SAGE model was extended to reflect the detailed structure and workings of South Africa's energy sector. In addition, the model was developed further to capture a detailed factor demand for the electricity sector. The SAGE model is a dynamic recursive model; in simple terms a sequence of static model runs that are solved to simulate the passing of time. The static model is solved 'within-the-period' with the use of non-linear equations that are solved simultaneously to capture linkages that exist in the real economy. This is followed by a 'between-period' run where a number of parameters are updated according to exogenous behavioural changes over time as well as the results from the previous static run. The E-SAGE model simulates the period between 2010 and 2030 and each static run represents one year.

There are 46 productive sectors, or *activities*, identified within the model; as well as six factors of production including, capital, crop land and labour. Labour is disaggregated further into four factors by level of education – primary, middle, secondary, tertiary.

The production schedule for a sole producer is provided for simplicity, although, in reality, the SAGE model contains 46 sectors, each of which are assigned a representative producer. The behaviour of the representative producer is such that they will maximise profits subject to a given set of input and output prices (Thurlow 2004). The model follows neoclassical theory, and assumes constant returns to scale and, hence, a constant elasticity of substitution (CES) function is used to determine production (Arndt, Davies, & Thurlow 2011):

$$QA_i = \alpha_i^p \left(\sum_f \delta_{if}^p \cdot QF_{if}^{-p_i^p} \right)^{-1/p_i^p} \tag{1}$$

where QA is the output quantity of sector i, α^p is the shift parameter reflecting total factor productivity (TFP), QF is the quantity demanded of each factor f (i.e., labour and capital) and δ^p is a share parameter of factor f employed in the production of good i. The elasticity of substitution between factors σ is a transformation of ρ^p.

The use of a CES function allows producers to respond to changes in relative factor returns by smoothly substituting between available factors to derive a final value-added composite (Thurlow 2004).

Profits π in each sector i are defined as the difference between revenues and total factor payments (Arndt, Davies, & Thurlow 2011):

$$\pi_i = PV_i \cdot QA_i - \sum_f (WF_f \cdot QF_{if}) \tag{2}$$

where PV is the value-added component of the producer price, and WF is factor prices (e.g., labour wages and returns on capital). Profit maximisation implies that factors will receive an income where marginal revenue is equal to marginal cost, based on endogenous relative prices (Thurlow 2004). Maximising sectoral profits subject to Equation 6, and rearranging the resulting first order condition provides the system of factor demand equations used in the model (Arndt, Davies, & Thurlow 2011):

$$QF_{if} = \propto_i^{p^{\frac{p_i^p}{1+p_i^p}}} \cdot QA_i \left(\delta_{if}^p \cdot \frac{PV_i}{WF_f} \right)^{1/(1+p_i^p)} \tag{3}$$

According to Arndt *et al.* (2011), the SAGE model assumes a Leontief specification for technology when calculating the intermediate demands of individual goods as well as when merging aggregate factor and intermediate inputs. This use of fixed shares is due to the belief that technology, and not the decision making of producers, determines the mixture of intermediates per unit of output, and the ratio of intermediates to value-added (Thurlow 2004). In light of this the complete producer price PA is (Arndt, Davies, & Thurlow 2011):

$$PA_i = PV_i + \sum_j (PQ_j \cdot io_{ij}) \tag{4}$$

Where io_{ij} represents the fixed input-output coefficient used in the demand for intermediates, which defines the quantity of good j used in the production of one unit of good i (Arndt, Davies, & Thurlow 2011).

The SAGE model represents an open-economy and hence the model recognises the two-way trade that exists between countries for similar goods (Arndt, Davies, & Thurlow 2011). Substitution possibilities, governed by a CET function, exist between the production for domestic and for foreign markets, (Thurlow 2004). A CET function is used to allow the distinction between domestic and imported goods in terms of differences in time and/or quality that may exist between them (Thurlow 2004).

Producers are driven by profit maximisation and therefore choose to sell in the market that offers the highest returns (Thurlow 2004). Exported commodities are disaggregated further using a CES according to the specific region under a CES specification (Thurlow 2004). The assumption that the substitution between regions is governed by a CES specification is fair as one would expect that producers would react to changes in relative prices across regions. This would therefore change the geographical composition of their exports accordingly (Thurlow 2004).

The import market is treated in the same regard. Substitution possibilities exist between imported and domestic goods under a CES Armington specification (Armington 1969). This is true in the use of both final and intermediate goods (Arndt, Davies, & Thurlow 2011).

The SAGE model distinguishes between different institutions that exist in the South African economy; namely, households, government and enterprises. Households are disaggregated according to income deciles, except for the top decile, which is divided into five income categories (Thurlow 2004).

The factor income generated from production forms the primary source of income for households and enterprises (Thurlow 2004). In addition, due to the model representing an open economy, household incomes consist of transfers from the government, other domestic institutions as well as from the rest of the world. Factor returns in South Africa have been found to differ across both occupations and sectors. In this light, the SAGE model uses a fixed activity-specific wage-distortion term combined with the economy-wide wage to generate activity-specific wages that are paid by each activity (Thurlow 2004). There are a number of assumptions governing the factor market. Firstly, the supply of capital is fixed over a specific time-period, i.e. fully employed, but is considered immobile across sectors (Thurlow 2004). Energy capital, however, is treated as fully employed and activity-specific. There is assumed to be unemployment for the unskilled workers, however, the other three labour categories are assumed to be fully employed and mobile. Remittances are also received by factors from the rest of the world and therefore also contribute to factor incomes (Thurlow 2004).

The SAGE model follows general equilibrium theory in that households within a certain income category are assumed to share identical preferences, and are therefore modelled as 'representative consumers' (Thurlow 2004). According to this theory, equilibrium is reached when the representative household maximises their utility subject to a budget constraint. In the model, each representative household has its own utility function, in which QH is the level of consumption is income-independent and constrained by the households' marginal budget share (Arndt, Davies, & Thurlow 2011). Utility is maximised for the consumer subject to a budget constraint, in which PQ is the market price of each good, YH is total household income, and sh and th are marginal savings and direct income tax rates, respectively (Arndt, Davies, & Thurlow 2011). By maximising the above utility function subject to a household budget constraint, a linear expenditure system (LES) of demand is derived (Arndt, Davies, & Thurlow 2011).

The LES of demand represents the consumer preferences captured in the model, given prices and incomes. These demand functions define households' real consumption of each commodity (Thurlow 2004). The LES specification is used in the model as it allows the identification of excess household income and therefore ensures a minimum level of consumption (Thurlow 2004).

The government is considered to be a separate agent with income and expenditure, although it isn't considered to have any behavioural functions (Arndt, Davies, & Thurlow 2011). Most of the income earned by the government is from direct and indirect taxes and its expenditure is assumed to be on consumption and household transfers (i.e., grants) (Thurlow 2004).

Household and enterprise savings are collected into a 'savings pool' from which investment in the economy is financed (Thurlow 2004). It is assumed in the model that government borrowing can diminish this supply of loanable funds and that capital inflows from the rest of the world are able to increase it (Thurlow 2004). There is no specified behavioural function governing the level of investment demand in the model, although the model assumes that the total value of investment spending must equate the total amount of investible funds TI in the economy (Arndt, Davies, & Thurlow 2011).

The SAGE model assumes full employment and factor mobility across sectors. Thus the following factor market equilibrium holds (Arndt, Davies, & Thurlow 2011):

$$\sum_i QF_{if} = QFS_f \tag{5}$$

where QFS is fixed total factor supply. Assuming all factors are owned by households, household income YH is determined by (Arndt, Davies, & Thurlow 2011):

$$YH_h = \sum_{if} \omega_{hf}(1 - tf_f) \cdot WF_f \cdot QF_{if} \tag{6}$$

where $\omega\omega$ is a coefficient matrix determining the distribution of factor earnings to individual households, and tf is the direct tax on factor earnings (e.g., corporate taxes imposed on capital profits).

The model is set up with a number of closures that govern macro adjustments. The selection of appropriate closures should ensure that the model reacts to shocks in a way that is representative of the real economy under investigation. There are considered to be three broad macroeconomic accounts in the SAGE model: the current account, the government balance and the savings and investment account (Thurlow 2004). The macroeconomic balance in the SAGE model is governed by a number of closure rules, which provide a mechanism through which adjustments are made to maintain this balance, or equilibrium (Arndt, Davies, & Thurlow 2011).

According to Arndt, *et al.* (2011), the current account is considered to be the most important of these macro accounts. A substantial amount of research pours into this topic, although in this case due to the single-country open economy CGE model it is considered an exogenous variable (Arndt, Davies, & Thurlow 2011). It is assumed that a flexible exchange rate adjusts in order to maintain a fixed level of foreign borrowing for the current account macro closure rule (Thurlow 2004). South Africa's firm commitment to a flexible exchange rate system and idea that foreign borrowing is unlimited ensure that the chosen closure rule is realistic (Thurlow 2004).

The second closure rule concerns the government balance. The government consumption spending in the SAGE model is considered to be exogenous. In response to this the fiscal balance, or government savings are flexible and adjust accordingly (Arndt, Davies, & Thurlow 2011).

The third closure rule, perhaps the least obvious, involves the choice of a savings-investment closure (Thurlow 2004). 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. The SAGE model assumes a balanced savings-driven closure where government and investment expenditure are fixed shares of absorption, determined by a scaled marginal propensity to save (mps).

Along with these three macroeconomic accounts, a factor market closure exists in the model. The various factors in the economy require specification in terms of how they are to be treated in the model. The SAGE model assumes full employment for high-skilled labour and unemployment amongst low-skilled labour with labour being mobile across sectors – a suitable closure for the South African context (Pauw 2007). Capital stock is assumed to be fully employed and activity-specific for the electricity sector, as the simulations impose a structural shift on production capacity. Land is assumed to be fixed and immobile as it is generally treated.

The consumer price index is assumed to be the numeraire in the SAGE model (Arndt, Davies, & Thurlow 2011). In other words, all prices are considered relative to the weighted unit price of household's initial consumption bundle (Arndt, Davies, & Thurlow 2011).

The Energy Sector and Carbon Tax Simulations

Electricity is defined as a single commodity in the SAGE model comprised of each electricity subsector's (i.e. nuclear, hydropower, etc.) separate supply onto the national grid. The model assumes that each of these subsectors has its own distinctive production technology, based on estimates from an earlier study by Pauw (2007). It is also assumed that each subsector requires a different mix of factor inputs (Arndt, Davies, & Thurlow 2011). Hence, there are different electricity 'activities' but a sole electricity commodity. This is a realistic assumption as consumers in South Africa are not able to demand certain 'types' of electricity as it all comes from the national grid; electricity subsectors have very different supply processes and costs.

A number of adjustments had to be made to allow multiple energy subsectors produce the same commodity. The updated production functions are adapted to:

$$QAS_{is} = \alpha^p_{is}\left(\sum_f \delta^p_{isf} \cdot QF_{isf}^{-p^p_{is}}\right)^{-1/p^p_{is}} \tag{7}$$

$$QF_{isf} = {\alpha^p_{is}}^{\frac{p^p_{is}}{1+p^p_{is}}} \cdot QAS_{is}\left(\delta^p_{isf} \cdot \frac{PV_{is}}{WD_{isf} \cdot WF_f}\right)^{1/\left(1+p^p_{is}\right)} \tag{8}$$

$$PAS_{is} = PV_{is} + \sum_j PQ_j io_{ijs} \tag{9}$$

where QAS is the output of subsector s within aggregate sector i, PAS is the subsector producer price, and io reflects each subsector's unique production technology. Factor demands QF are also defined at sector level.

A high elasticity of substitution is assumed to exist between energy subsectors in order to replicate their product homogeneity (Arndt, Davies, & Thurlow 2011). However, switching between different energy subsectors is constrained by the fixed installed capital in each subsector, due to the immobility of this capital (Arndt, Davies, & Thurlow 2011). The speed at which South Africa can exchange between energy sources is determined by new capital investment as installed capital is assumed to depreciate at a fixed rate (Arndt, Davies, & Thurlow 2011). In the current extension to the SAGE model, new investment in each subsector is determined exogenously and follows the Integrated Resource Plan (IRP) (Arndt, Davies, & Thurlow 2011).

Energy is treated as an intermediate input in the E-SAGE model; aggregated with other intermediates using a Leontief production function. Producers are, however, able to respond to energy price changes by the use of a 'response' elasticity (ρ). The energy product input coefficient (ioij) falls either when energy prices rise (provided there is some new investment) or when the new investment share (sj) is positive (provided the price rises). This relationship is illustrated below:

$$io \downarrow ij,t+1/io \downarrow ijt = 1-(1-P \downarrow jt/P \downarrow j,t-1 \uparrow -\rho) \cdot s \downarrow i$$

The carbon tax simulations were applied domestically; similar to an ad valorem tax placed only on fossil fuels burned within the South African borders. We assumed that there was a uniform reduction in indirect sales tax rates to have a less severe, distribution neutral simulation. An important next step would be to model tax recycling options, especially in light of the findings from Alton *et al.* (2012) that show that the choice of revenue recycling is a main driver of the economic impact of a carbon tax in South Africa. The modelling of alternative recycling options was not conducted in this paper due to time constraints; however, based on the results from Alton *et al.* (2012) mention will be made of the potential impacts of these alternative options on our results.

The carbon tax design proposed by the National Treasury for South Africa is highly complex (RSA 2013). At first glance, the proposed R120 per ton of CO2 seems to be a significant tax allocation, although it is only half of the carbon tax value estimated by Alton *et al.* (2012), if South Africa is to reach emissions reduction targets. The Treasury proposed an initial phasing-in period from 2015 to 2019 with the rate increasing at 10 per cent annually until the end of 2019. The rate of increase for the second period, 2020 to 2025, will be announced in February 2019. All sectors will benefit from a 'basic tax-free threshold' of 60 per cent of emissions as well as a number of complex exemptions for energy-intensive users. The electricity sector will benefit from an additional 5 per cent to 10 per cent exemption whilst the petroleum sector will be exempt from an additional 15 per cent to 20 per cent for being a trade-exposed sector. Energy intensive sectors such as chemicals, glass, cement, iron and steel, ceramics and fugitive emissions from coal mining will benefit from exemptions of up to 85 per cent (RSA 2013). The effective tax rate is therefore much lower at between R12 and R48 per ton of CO2, likely to be too little to transform South Africa's emissions pathway.

The carbon tax simulated in this analysis is designed in a more simplistic manner. The carbon tax is also assumed to phase in between 2015 and 2019, increasing linearly over the period until a total of R120 per ton of CO2 is levied on all sectoral emissions. Given that the effective tax rate is significantly lower than this, the scenarios will overestimate the proposed carbon tax. The decision not to include the exemptions is, firstly, to simplify this initial analysis and, secondly, because existing literature suggests that an effective tax rate of between R12 to R48 per ton is not enough to have a significant impact on South Africa's emissions trajectory.

Results and Discussion

The simulations were run under two conditions: one without a carbon tax and a second with a simplified carbon tax. The next step would be to model the exact tax design proposed by the Treasury and compare the socioeconomic implication with this simplified version of the tax; an interesting modelling exercise for the future. As previously noted, alternative revenue recycling options not modelled in this paper is on the agenda for future work.

Table 3 presents the results for the simulations run without a carbon tax. All three scenarios fair quite favourably in terms of growth in South Africa, with a slightly lower average growth rate for the policy-adjusted scenario and more so for the emissions 3 scenario. It should be noted that the assumptions governing the financing of the electricity build plan might be resulting in an overly optimistic economic growth projection. It is assumed that the build plan is financed by a foreign loan, of which an annual interest payment of 5 per cent is made annually; none of the principal payment is made over the modelling period to 2030. This may be a contentious assumption; however, given that economy-wide models are not predictive but rather are a valuable tool for comparing possible futures, the relative burden on the economy should be sufficient for our analysis. It would be interesting to explore different financing options and analyse the potential impacts of these on the economy – a topic that should be noted for future work.

Table 1.3: Simulation Results without a Carbon Tax (in percentage)

	GDP Growth	Inequality	Emissions Reduction	Employment
Base	3,90	1,10	0	1,32
Policy	3,82	1,01	-11	1,31
Emissions 3	3,67	0,85	-18	1,29

Source: Author's calculations

The emissions 3 scenario requires significantly more investment in comparison to the base case and to a lesser extent the policy-adjusted scenario. This is shown in the slight contraction of the economy relative to the base case. Economic growth is still positive, but the higher investment cost results in a decrease in the investment funds available for other, more profitable sectors in the economy.

The second indicator is titled '*inequality*'; in this instance the values refer to the relative increase in income growth for poorest decile in comparison to the richest decile.[15] In the base case, the income of the poorest decile increases by 1,1 per cent over the simulation period, in relation to the richest decile; the income gap is narrowing slightly and therefore inequality is decreasing. The policy-adjusted and emissions 3 scenarios are less favourable for income distribution. There are a number of reasons for this. The first reason is related to a higher cost of investment, the relative decrease in growth of other sectors in the economy has an impact on employment and ultimately household income. There is a negative impact on the growth of all sectors, except the electricity sector (as one would expect) and natural gas mining; driven by the increase in demand for gas turbines in the two alternative scenarios (policy-adjusted and emissions 3). Coal mining, for instance, contracts by 1.14 per cent relative to the base; as a sector with a high employment multiplier, especially for low-skilled labour, this would detract from the gains in the electricity sector. The second reason is directly linked to the decrease in employment of the various labour groups over the period. Renewable energy options are more labour intensive, per GWh of electricity, in comparison to base load coal, although they do require a larger proportion of high-skilled labour. There is a slight decrease in overall employment from the investment in the alternative plans, relative to the base case; the decrease in employment for the low-skilled labour group is much lower than the average. Low-skilled labour employment decreases by 5 per cent compared to the base, compared to high-skilled (individuals with tertiary-level education) that had no unemployment over the period under the emissions 3 case. This, in-turn, has a negative impact on income distribution.

The reduction in emissions, as one would expect, is significantly higher for the emissions 3 scenario, with a reduction of 18 per cent compared to the base[16]. As previously mentioned, at least R0.46 trillion would be required for the electricity sector to reach its emissions plateau by 2025, in addition to the R1.3 trillion already estimated for the emissions 3 scenario. The relatively high allocation of renewables in the policy-adjusted scenario does make a dent in South Africa's emissions, however, with a reduction of 11 per cent compared to the base.

Table 1.4: Simulation Results With a Carbon Tax (in percentage)

	GDP Growth	Inequality	Emissions Reduction	Employment
Base	3,90	1,06	-29,26	1,31
Policy	3,79	0,97	-39,66	1,30
Emissions 3	3,64	0,81	-43,62	1,28

Source: Own calculations

The simulation results with a carbon tax are shown in Table 4 and indicate that the tax is likely to have a slightly contractionary effect on the economy, with some sectors actually becoming more profitable given the changes in relative prices that occur as a result of the tax. Biomass, for example, grows by 2.38 per cent relative to the base for the base case scenario with a carbon tax; 2.05 per cent for the policy-adjusted and 1.47 per cent for the emissions 3 scenario.[17] Given that the effective tax rate is overestimated in these simulations, a conclusion can be made that the tax may not have a detrimental effect on the economy and could incentivise growth in 'cleaner' sectors; highlighting the potential benefit of moving to a low carbon trajectory.

The reduction in emissions is significantly increased for all three cases, with approximately a 44 per cent reduction in emissions in the emissions 3 scenario by 2030, relative to the base. The tax is also very effective in reducing emissions in the base case, with a reduction of 30 per cent. The results echo that found in previous studies, that even at the full R120 per ton of CO2 and with a very costly electricity build plan based on a carbon limit for the sector, South Africa is unlikely to reach their target of a 42 per cent reduction in emissions by 2025, relative to a 'business-as-usual' baseline. One can conclude that the proposed tax level, even without the 'basic tax-free threshold' and complex exemptions for energy-intensive users, is still too low and needs to be revised if South Africa wants to reach its emissions targets.

The distributional impact of a carbon tax is not as favourable; however, the income gap is still narrowing. Employment also remains positive, albeit less than the employment growth rate without a carbon tax. The slight decrease is attributed to the marginal contraction of the economy due to increased energy prices.

There are a number of tax recycling mechanisms that are available to increase the distributional impact of the carbon tax; referring back to Alton *et al.* (2012) where it was found that the revenue recycling option is an important driver of the economic impact of a carbon tax. Given the findings of their study one would expect that the distributional impact of the carbon tax would be more favourable if the revenue was recycled to fund social grants and less favourable if it were coupled with a decrease in corporate tax. A complete analysis of potential revenue recycling options has been noted for future work.

Conclusion

In conclusion, the introduction of renewable energy and low carbon trajectories is likely to have a slightly negative impact on employment and a marginally contractionary impact on the economy. This is a key finding as it indicates that the implementation of these mitigation actions is not likely to cripple the economy and that there are benefits that South Africa should capitalise on.

Renewable energy options, unfortunately, still have relatively high investment costs. These costs are the main driver for the results in this study. The higher cost of renewables causes a slightly contractionary effect on the economy from the decrease in the investment funds available to other more profitable sectors.

And regarding employment, even though some renewable energy options have higher job years per MW (approximately 52 job years/MW for PV compared to 10.8 for coal-fired plants), the positive impact on direct employment is drowned out by the negative impact on indirect employment. The loss of low-skilled jobs dominates this effect, which results in higher income inequality.

In terms of emissions reduction, one can conclude that the introduction of renewable energy, even to the extent proposed in the emissions three scenario, is not sufficient for South Africa to meet its emissions reduction target of 42 per cent against a 'business-as-usual' baseline by 2025.

The implementation of a carbon tax is likely to have less of a '*devastating*' impact than was previously thought. Higher energy prices might incentivise the development of 'cleaner' sectors such as the biomass industry. The addition of a carbon tax proves quite effective in terms of lowering total emissions; however, the tax level (even without the exemptions) is still too low and will not be enough to get emissions down to the target trajectory. Modelling a carbon tax of around R12 to R48 per ton of CO2, the effective tax rate taking all proposed exemptions into account, would have even less of an impact on the emissions. The argument that an increased tax level will cripple the economy seems unjustified and South Africa should capitalise on the growth of sectors that could become profitable with the introduction of a carbon tax.

The distributional impact of a carbon tax is not favourable in this case, albeit the income gap is still narrowing and employment is still positive. Revenue recycling options are a key driver of impact of a carbon tax on the economy. Designing the carbon tax with a revenue recycling option to fund social grants is likely to lead to more favourable welfare effects, but less economic growth.

In conclusion, this paper shows that current renewable energy plans and the proposed carbon tax level are not enough to allow South Africa reach its emissions reduction target of 42 per cent by 2025. Both of these mitigation actions are found to have a less 'devastating' impact on the economy than was previously thought. If South Africa is to meet the challenge of decreasing emissions as well as decreasing inequality and eradicating poverty a higher carbon tax should be introduced along with a revenue recycling mechanism that could increase the income allocation to lower income deciles and result in increased welfare.

Notes

1. The model development initially started during a research stay at UNU-WIDER in Helsinki, where Dr James Thurlow and I disaggregated the energy sector in the e-SAGE model to include more detail for renewable energy generation technologies. Further model developments and the analysis of the potential implications of a carbon tax were conducted during my time at the German Institute of Global and Area Studies (GIGA) in Hamburg under the supervision of Jun.-Prof. Dr Jann Lay and funded by the Volkswagen Foundation.

2. World Bank (2013). "World Development Indicators 2013." Washington, D.C.: World Bank. http://data.worldbank.org. Accessed July, 2014.
3. Stats SA (2013). "Millennium Development Goals, Country Report 2013". Pretoria: Statistics South Africa. http://www.statssa.gov.za/MDG/MDGR_2013.pdf. Accessed July, 2014.
4. This increases to 34,6% if you include discouraged workers. Source: Stats SA (2015). "Quarterly Labour Force Survey: Quarter 4, 2014". Pretoria: Statistics South Africa. http://www.statssa.gov.za/publications/P0211/P02114thQuarter2014.pdf. Accessed July, 2014.
5. For further reading on the potential impacts of climate change in South Africa and Africa in general, see Gbetibouo and Hassan (2005) and Bryan *et al.* (2009).
6. Multiple-criteria decision making or multiple-criteria decision analysis (MCDA) refers to a method of structuring and solving decision and planning problems that involve multiple criteria. In this case, the IRP engaged with stakeholders to assign a score for each scenario in terms of the aforementioned criteria. The scores were weighted, aggregated and the scenarios compared according to their overall scores.
7. The economy-wide model used in this study, e-SAGE, is a computable general equilibrium model and is calibrated using actual economic data for the South African economy. CGE models are widely used for policy analysis. For further reading, see Thurlow (2004).
8. The partial-equilibrium model used in Pauw (2007) was a MARKAL model for South Africa's energy sector. The MARKAL model is a long-term multi-period energy technology optimization model. Selected results such as changes in the energy supply mix, energy efficiency and investment requirements from the energy model were used to inform the CGE model.
9. The IRP scenarios were modeled using PLEXOS Integrated Energy Model, a mathematical optimization model for the energy sector.
10. Gross operating surplus is the portion of income that is earned by the capital factor from production by incorporated enterprises.
11. These assumptions are based on the lifetime of the plant and are based on EPRI (2010) and, for renewable energy options, REIPPPP announcements (DoE, 2013).
12. Levelized cost of plant is the unit cost of electricity generation over the life of the plant. It includes all the costs needed to build and operate a power plant over its lifetime, normalized over the total net electricity generated by the plant.
13. The portion of investment assumed to flow out the economy through imported content requirements during the build phase. Based on weighted averages for imported content over the first 2 bids (DoE, 2013).
14. The IRP has recently been criticized for being 'out-of-date', especially in terms of the demand forecasts and the cost assumptions for the technology options; the Renewable Energy IPP Procurement Programme provides more realistic employment, local content and cost data. The estimates given in the table will be updated to reflect these in the near future.
15. The use of this form of inequality measure may be criticized for being over-simplified and vulnerable to the effects of outliers. For the purpose of this paper it is sufficient and more complex inequality measures could be used in future modeling exercises.

16. These are economy-wide emissions, not only for the electricity sector.
17. This finding is supported by other research and existing policy that identify the potential for growth in South Africa's biomass sector; for further reading, see Winkler (2005), Dasappa (2011) and DME (2007).

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