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**The Development of A Linked Modelling
Framework For Analysing Socio-economic
Impacts Of Energy And Climate Policies in
South Africa**

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Abstract:

This paper presents some methodological improvements made to the linked SATIM-eSAGE energy-economy-environment modelling framework for analysing energy and climate policy in South Africa. The improvements include the linking of the other economic sectors and the households of the eSAGE economy wide model to the SATIM energy model. Two scenarios are used to illustrate the benefits of having the new links, which include an energy efficiency scenario and an ambitious climate mitigation scenario. The results show that there are significant socio-economic benefits of having a more energy efficient economy. For the chosen set of assumption around technology development, the newly linked model shows that an ambitious CO₂ mitigation can be achieved and would be much less onerous if technological change was allowed compared to the simplistic case, where energy technology remains stagnant. The work presented in the paper provides some solid foundations for further work on the energy-economy-environment policy arena for South Africa. Some of this further work includes the calibration of the two models to a more recent base year and perhaps align more closely the sectoral disaggregation of the two models, which would improve the robustness of the energy-economy insights that could be drawn from the models. The framework could also relatively easily be adapted to other countries where the standard IFPRI CGE model has been developed, and where some form of optimization energy model is available.

Keywords: CGE, TIMES, Energy Models, Economic Modelling, South Africa

JEL classification:

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1. Introduction

Energy-economic and environment (E3) models are simplified representations of the complex energy-economic and environment systems that we are part of. These models are useful in that they help to organise information about the system in a systematic way. They help decision makers and stakeholders better understand the system, both in terms of how different courses of action impact on the system and help meet objectives, and how the system responds to different uncertain and uncontrollable situations.

There are two wide-spread modelling approaches for the quantitative assessment of economic impacts induced by energy and climate policies: models focussing on the energy system and models of the broader economy. The two model classes differ mainly with respect to the emphasis placed on technological details of the energy system vis-à-vis the comprehensiveness of endogenous market adjustments (Böhringer and Rutherford 2008), (Hourcade et al. 2006). In some energy policy studies, the energy sector can be appropriately viewed in isolation from the remainder of the economy. In other situations, this may be inappropriate as there may be two-way interdependence between energy markets and the rest of the economy (Hogan, Manne, and others 1977). At the same time, economy-wide models represent sectoral economic activities and energy through aggregate production functions, which are not well suited to capture the temporal and discrete nature of technology choice, as well as ensuring basic energy conservation principles (Lanz and Rausch 2011).

The alternatives for addressing the limitations of the two modelling approaches are:

1. To embed a simplified energy model within an economy-wide model as done in (Crassous et al. 2006);
2. To embed a simplified economy-wide model in an energy model as done in (Remme and Blesl 2006);
3. To keep both models as they are but link them by passing variables between them (as described below).

Initial work has been undertaken at the Energy Research Centre in collaboration with UNU-WIDER on using the third (iterative) approach, focusing on the power sector (Arndt et al. 2014), where the energy sector is represented by the existing South African TIMES Model (SATIM) (Analysis and Group 2013) and eSAGE (Arndt, Davies, and Thurlow 2011) is the economy-wide model. However, in order to more adequately analyse energy and climate policies that go beyond the power sector, it is important to also link the other sectors. Other limitations of the current approach is that changes other than the demand (e.g. labour, capital costs and exchange rates) that occur in the economic model are not currently passed back to the energy model.

2. Objective of Paper

The objective of the paper is to describe the methodology of further coupling the two models and show some illustrative results showing the impacts of the improved methodology:

- What are the socio-economic benefits of improving the efficiency of energy utilisation in the South African economy
- What are the socio-economic implications of committing to an ambitious CO₂ reduction target for South Africa

3. What has been done until now?

3.1 Work done at ERC in collaboration with UNU-WIDER: The SATIMel-eSAGE linked modelling framework

The Deep Decarbonization Pathway Project (DDPP)

(Altieri et al. 2016) present two scenarios focussing on employment and poverty reduction under a carbon constraint for South Africa in 2050. The cumulative GHG limit is imposed on SATIM. SATIM is used to find the overall least-cost mix of demand and supply technologies, and the resulting CO₂-eq trajectory for the power sector is imposed on SATIMel¹ in the linked model. The modelled CO₂-eq constrained power sector in the linked model results in some changes in the economy, which results on a new trajectory for future economic activity. This is then relayed back to SATIM for a new iteration. The economic indicators of interest are then extracted from the final run of the linked model. The paper presents two scenarios where the current INDC commitments are not incompatible with some of the other development goals for South Africa, namely, improved employment and poverty alleviation.

Some of the main limitations of this approach are:

- The CO₂-eq constraint in SATIM doesn't only affect the power sector but also some of the other sectors, especially the liquid fuel supply sector. These changes outside of the power sector need to be passed to the economic model to get the full picture of the "socio-economic" impacts of the CO₂ constraint. This is especially crucial if more ambitious CO₂ targets than are currently envisaged are to be adopted as they would have to rely on more mitigating measures taking place in the demand side (e.g. switch to electric vehicles).
- Having two versions of SATIM (SATIM and SATIMel) in addition to the CGE is very cumbersome and caused several version control issues. This approach would be problematic especially if one wanted to explore a broader/larger set of scenarios.

An integrated approach to modelling energy policy in South Africa

(Arndt et al. 2014) present the first application of the linked SATIMel-eSAGE modelling framework to look at the implications of different carbon tax levels with and without trade restrictions on electricity. The CO₂ tax is imposed in eSAGE (and on the price of fossil fuels in SATIMel). The paper shows the benefits of opening up electricity trade within the region with a CO₂ tax in South Africa. It suffers from similar problems to the DDPP study: in the medium to long-term, a CO₂ tax doesn't only change how SA produces electricity but also how it would produce (or procure) liquid fuels, and also how energy would be consumed in other productive sectors (and households). As described below, eSAGE has limited flexibility to respond to these price effects.

3.2 Other current and past attempts to answer similar questions on South Africa

LTMS

(Pauw 2007) describes analysis done on the results of the pre-cursor to SATIM: The Long Term Mitigation Scenario (LTMS) MARKAL energy model (Winkler 2007), using a CGE model for South Africa called STAGE. Like eSAGE, STAGE is also a descendant of the CGE models

¹ SATIMel is a variant of SATIM where only the power sector is represented. A demand for electricity is specified and the optimization computes the least-cost mix of power generating technologies.

introduced by (Dervis et al.1982). The analysis looks at 3 possible mitigation trajectories for South Africa and makes use of the results of the energy model to characterize technical change shocks and investment shocks using hybrid comparative static-dynamic approach. The scenario with energy efficiency results in a loss of GDP compared to the reference, which was unexpected. Possible reasons for this are the limited effort in hybridization of the energy commodities and the method used for passing of investment results from the energy model to the CGE. Aspects, which were significantly refined in the linked SATIM-eSAGE framework.

Green growth and its implications for public policy - The case of South Africa

Similar to DDPP, (Schers et al. 2015) uses a linked CGE-energy modelling framework (IMACLIM-SA and SATIMel) to gain some insights on the trade-off between South Africa's mitigation objectives and the key development challenges. It focuses on economic growth and unemployment, with discussions about inequalities and education. IMACLIM-SA represents the South African economy as a small, open economy with ten sectors (five energy, five non-energy) and five income classes. Calibrated on 2005 SAM, the model produces an economic equilibrium of the economy in 2035 based on assumptions about the evolution of key parameters (notably demography, labour and capital productivity, international prices, etc.). Equilibria in 2035 are computed both without (reference projection) and with mitigation policies, and analysed in terms of GDP growth, employment and income distribution. In this study extensive effort is put on the hybridization of the SAM ²in the CGE model, but as in the case for DDPP, technical change only really happens with the help of SATIMel in the power sector. Energy use in other sectors remains unchanged.

3.3 Other current and past attempts to answer similar questions using methodology to be adopted by this study but implemented in models of other Countries.

Imaclim-Brazil linked to Brazilian MESSAGE model

The approach by (La Rovere et al. 2013) is very similar to the approach used by (Schers et al. 2015) described above, except that it is applied to the Brazilian economy. The energy model is on a platform called MESSAGE, which is very similar to TIMES used by SATIM and the CGE model is IMACLIM-Brazil. The analysis looks beyond just the power sector, and also looks like technical change happening on the other energy supply sectors. The approach used on the demand side is different in that a static MAC curve derived from a bottom-up approach is used to characterize the energy/CO₂ related technical changes in the CGE model.

HYBTPEP linked to Portugal TIMES model

(Fortes et al. 2014) describe the development of a modelling framework linking a CGE model (HYBTPEP) and an energy model (TIMES_EP) to perform analysis on various climate and energy policies for Portugal. The linking framework is very similar to the one to be adopted for this study. Some differences include the treatment of investment in the power sector. In the SATIMel-eSAGE framework care is taken to separate out the expenditure on new power plants as it occurs during the construction phases, with the power sector capital stock also controlled exogenously by the energy model. In the case of HYBTPEP-TIMES_EP, the focus is purely on the refinements of the production functions inside HYBTPEP based on the TIMES_EP results. It is also not clear

whether changes in labour and capital costs observed in HYBTEP are being passed back to TIMES_EP.

4. Description of Models to be used in the proposed linked modelling framework

4.1 SATIM:

SATIM is an inter-temporal bottom-up optimisation energy model of South Africa built around the TIMES platform. SATIM uses linear or mixed integer programming to solve the least-cost planning problem of meeting projected future energy demand, given assumptions about the retirement schedule of existing infrastructure, future fuel costs, future technology costs, and constraints such as the availability of resources.

Why are SATIM-type models good for doing medium to long-term analysis?

Methods that rely on time-series data (econometric methods) for long-term demand projections are generally not adequate as they cannot incorporate changes that are not present in historical data, and extrapolation techniques often lack the basic checks and balances that would ensure technical feasibility of a future energy system. Thus, more theoretical based models that can allow for significant departures from the current and past system configurations that would be possible in the long-term, while ensuring internal consistency, have to be used. Those models are more useful to explore “what if” scenarios rather than to forecast the future. SATIM is such a model: demand is specified as useful energy demand or demand for energy services (e.g. cooking, lighting, and process heat) and final energy demand (e.g. demand for electricity, gasoline, etc.) is calculated endogenously based on the optimal mix of demand and supply technologies. The flow of energy from extraction to energy services is governed by a set of theoretically derived relations that will ensure technical feasibility of the scenario (e.g., energy conservation, $\text{consumption} \leq \text{production}$, production from a facility in a particular year can't exceed what's technically possible given available installed capacity, availability of resources needed etc...). An objective function specified in terms of the unit activity and unit capacity costs of all the technologies in the model combined with the relations listed above sets the optimization problem. The result of the optimisation is: the supply and demand technology mix (capacity, new investment, and production/consumption) that would result is the lowest discounted system cost for meeting the projected energy demand over the planning horizon subject to the imposed constraints. This more detailed (bottom-up) approach allows for the exploration of scenarios with trade-offs between demand and supply sectors, scenarios where structural changes occur (different sectors growing at different rates, household income profile changing), process changes occur (e.g. switching from Blast Furnace BOF to Electric-Arc-Furnace for steel production), and scenarios where fuel and mode switching (in the case of transport), and technical improvements (mainly relating to efficiency gains) occur.

Why are SATIM-type models not adequate on their own to answer the above questions?

- This type of approach, unlike forecasts, does not pre-suppose knowledge of the main drivers of demand (economic growth, household income, and energy prices). Instead, a scenario consists of a set of coherent assumptions about the future trajectories of the drivers leading to a coherent system, which can form the basis for a credible storyline for each scenario. Given the linkages between the energy sector and the rest of the economy (industrial activity, household income, etc...), this can be very difficult to do without the help of some form of an economic model.
- SATIM can be used to analyse energy policies, for example, renewable energy targets or a nuclear program, however, although the impact on electricity price and GHG emissions

of such policies can be estimated, it is not possible to quantify economy-wide implications (e.g. GDP, employment, household welfare, etc...), without the help of some form of an economic model.

4.2 *eSAGE*

eSAGE is a recursive dynamic Computable General Equilibrium (CGE) country-level economy wide model that simulates the functioning of the South African economy. This is a dynamic variant of the generic static model described in (Löfgren, Harris, and Robinson 2002). A CGE model is the SATIM equivalent model of the economy in that it is governed by a set of theoretically founded equations which are used to rebalance the Social Accounting Matrix (SAM) describing the economy after the SAM is subjected to a (set of) shock(s) (e.g. CO₂ tax, increase in labour supply, etc...). The rebalancing is done by allowing prices to change and by using a variety of substitution mechanisms representing economic behaviour in response to relative price changes, while ensuring that macroeconomic constraints are maintained. Agents optimise behaviour subject to constraints; for example, households maximise utility subject to a budget constraint while producers maximise profits subject to a production technology constraint. Equilibrium is reached when supply equals demand in the commodity and factor markets simultaneously, given various macroeconomic constraints: aggregate demand equals aggregate supply, total investment equals total savings, government and household budgets balance (revenue or income equals expenditure plus savings or deficit), and the foreign account is also balanced (balance of payments). These equilibriums are achieved via changes in relative prices and consequent changes in behaviour of agents.

eSAGE simulates the functioning of the South African economy and provides useful insights on the direct and indirect linkages that connect different groups of profit-maximizing industries and utility-maximizing households, as well as the government and the rest of the world. eSAGE provides a detailed and comprehensive representation of the economy, including multiple industries, commodities, 5 factors of production (capital + 4 labour groups), and multiple representative household groups.

eSAGE's recursive dynamic structure consists of within- and between-period components. Within each time period, eSAGE is solved subject to given levels of population, productivity and capital supply. Between periods, eSAGE is updated to reflect population growth, technical change and capital accumulation. New capital allocation is determined endogenously based on previous period investment levels and the relative profit rates of the different sectors. Once invested, capital becomes sector-specific.

The hybridization process

eSAGE differentiates itself from other more standard CGE model (e.g. SAGE) by the important extra calibration step that was undertaken on the flow of energy commodity flows in the economy, sometimes referred to as a “hybridization” process. This process involves the calibration of the monetary flows in the SAM that represent flows of energy commodities to be adjusted to reflect the actual physical flows. This is normally done by combining flows reported in national energy balances and energy commodity prices paid by different sectors/households. The difference is allocated to other commodity flows (e.g. services) in order to rebalance the SAM. The hybridization process followed for eSAGE is described in (Arndt, Davies, and Thurlow 2011).

Why is eSAGE a good model for doing medium to long-term analysis?

As in the case of SATIM, eSAGE can be thought of as an experimental lab which can be used to explore what-if scenarios of how the economy could evolve over time given various shocks to

characterise policy changes, the supply of labour, technology change or international fuel and technology costs, while ensuring a strong “internal consistency”.

Why is eSAGE not adequate on its own?

eSAGE in its current configuration, and as other models of its type, has limited ability to endogenously capture technical change, while ensuring technical feasibility for very long term scenarios and in case of large departures from baseline projections.

4.3 How SATIMel and eSAGE are currently linked (more details in (Arndt et al. 2014))

Alternate runs of SATIMel and eSAGE are performed from 2006 to 2040, each time exchanging information via data links. Given an initial electricity demand, SATIMel computes the least cost power plant mix, and the resulting investment plan. The investment (capital growth and expenditure on power plant construction), share of electricity production by technology group and changes in average electricity generation cost are passed onto eSAGE. The change in electricity generation cost is used to calculate the change in electricity price over time in eSAGE. The problem is that if both the price and capital growth are imposed onto eSAGE for the entire model horizon, there is little room for demand to react. Demand tracks the investment (capital growth), which defeats growth), which defeats the point of using a CGE model to estimate the demand response.

To circumvent this, only the price projection and the production mix are imposed onto eSAGE for the entire model horizon, and capital growth and expenditure is only gradually imposed. In order to accommodate the fixed electricity price, the indirect sales tax on electricity is freed up. The result of this is that by the end of the planning horizon, the demand projection that is consistent with price, and can react to price changes. Based on this consistency, we can analyse the economic impacts of the investment decisions that were made in the power sector subject to constraints defined in that sector, such as a nuclear programme or a renewables programme, or how the energy and economy would respond to CO₂ mitigation policies.

5. Description of improvements made to linked modelling framework in this Study:

The work carried out in this study builds on the foundations of the existing linked SATIMel-eSAGE modelling framework and expands the framework to increase the breadth of energy and climate policy analysis that can be performed as well as improve on the quality of the analysis. The improvements are achieved mainly by:

- Revisiting some of the hybridization steps in the SAM³ of eSAGE
- adding new links between the two models:

eSAGE -> SATIM link:

- Instead of electricity demand projections:
 - o Industry Sectors: activity level changes by the various economic sectors are passed onto SATIM via a demand module that converts the activity level changes to changes in demands for energy services in the industry sectors. The electricity demand from industry is determined endogenously by SATIM.

³ SAM: Social accounting matrix, which includes Supply and Use Tables (SUTs) and the government (income/savings/consumption), household (income/savings/consumption), and “rest of the world” (imports/exports) sectors.

- Households: income levels by the different household groups are passed onto SATIM via a demand module that converts the changes in income levels to changes in demand for energy services by the households. The demand module includes a mode-switching feature for passenger transportation – mode switching is currently specified exogenously.
- CGE results to feed into SATIM cost parameters: changes in labour costs, cost capital goods (incl. changes in the exchange rate) as observed in the economic model used to adjust the investment and running costs of technologies in SATIM.

SATIM -> eSAGE links:

- Adjustments to the production coefficients in the CGE based on the results of SATIM for the use of energy in other economic activities (other than just electricity).
- Adjustment of the household energy consumption (including for transportation) based on the results of SATIM.
- One of the useful aspects the SATIM framework is that it is forward looking and it allows for the specification of a cumulative CO₂ constraint. This generates a CO₂ marginal trajectory that can be imposed on the CGE as a CO₂ tax, for example.

As mentioned above, eSAGE is a recursive (myopic) dynamic model, where the SAM is rebalanced in each time period (annually). The linkages from SATIM are shocks imposed in the in-between periods, which can be described as follows:

- Iteration 1:
 - Run SATIM forward looking model with optimization performed for the whole period (to 2050) with initial growth projection
 - Start with balanced 2007 SAM
 - Implement shocks for 2008:
 - Labour supply (high skill linked to population)
 - Capital supply (based on savings of previous period and putty-clay accommodation)
 - Global commodity prices
 - Labour and Capital productivity
 - Update production function of power sector given results of SATIM
 - Update production function of other sectors given results of SATIM
 - Update consumption function of households given results of SATIM
 - Update capital stock of electricity sector based on increment observed in SATIM
 - Deduct expenditure on power plants (from SATIM) from total savings
 - Allocate the rest of Savings for 2011
 - Update CO₂ tax if any
 - Balance SAM for 2009 given shocks listed above
 - Implement shocks listed above for 2010
 - ...
 - Repeat until 2040
- Iteration 2:
 - Take Activity Growth projection, and household income projections and pass them on to SATIM for a new run to get updated energy sector results
 - Start again with balanced 2007 SAM
 - ...
- Repeat as above until convergence is reached (3-5 iterations)

As mentioned above, it was observed that if the capital stock for the power sector was exogenously imposed for the whole period from Iteration 1 that there is not much response by the economy to changes in electricity price. So instead, the period for which the capital stock for the power sector (as well as the deduction of expenditure on power plants from savings) is specified exogenously is gradually increased with each iteration. In parallel, the investment decisions made in the power sector are gradually frozen in the power sector for this gradually increasing period. The “exogenous capital periods” used in the results presented in this paper are:

- Iteration 1: 2007-2010
- Iteration 2: 2007-2015
- ...
- Iteration 7: 2007-2040.

Results are then only reported for the final iteration.

6. Scenario Descriptions

Four scenarios are used to illustrate the new insights obtained with the new linkages:

1. Lim.Link: Only power sector is linked
2. Full Link+EE: all sectors and households are linked, and energy efficiency improvements are specified in the energy model
3. Lim.Link+CO₂: Only the power sector is linked and a CO₂ tax trajectory for reaching a 10GT cumulative level for the period 2015-2040 is imposed on the CGE.
4. Full Link+CO₂: Same as ”Full Link+EE”+a CO₂ tax trajectory for reaching the 10GT cumulative level is imposed on the CGE.

Other assumptions common to all scenarios:

eSAGE (more details are given in (Arndt, Davies, and Thurlow 2011)):

- 2007 SAM with hybridization using 2006 and 2007 Energy Balances
- CO₂ tax revenues are recirculated via reductions in sales tax on all goods
- Upward sloping labour supply curves for less-educated workers
- “Putty clay” capital and endogenous capital accumulation
- Fixed current account with flexible real exchange rate
- Savings-driven investment
- TFP annual growth is adjusted homogenously across all sectors to “shape” GDP growth to match historical GDP growth from 2007 to 2014. It is then ramped up to reach 0.9% annual growth in 2017, and decline to 0.67 in 2040.

SATIM (more details are given in (ERC 2013)):

- 2006 calibrated
- Real discount rate: 8%
- Power sector technology costs, domestic coal prices and global commodity prices follow the median trajectory in (UNEP, 2016)
- Electricity import options include those considered in (DOE, 2013) up to a maximum of 8 GW (of which 5 GW are hydro)
- Cheap shale gas is not available
- Transport sector is modelled as per (SANEDI, 2016)

- Iron&Steel, Pulp&Paper, Non-metallic minerals sectors are modelled as per (NAPP 2014)
- Biofuels are excluded as an option for the transport sector
- Energy Efficiency improvements:
 - o Households can adopt more efficient appliances if they are cost effective
 - o The commercial sector adopts current and projected building codes for South Africa
 - o Passenger vehicle efficiencies improve by 1% annually (as per (SANEDI, 2016))
 - o Freight vehicle efficiency improve by 0.5% annually (as per (SANEDI, 2016))
 - o Modal splits and vehicle occupancies are assumed to be constant over time
 - o Iron&Steel, Pulp&Paper, Non-metallic minerals sectors are modelled as per (NAPP 2014)
 - o Other industrial sectors adopt current industry standards (as per Hughes et al, 2014)

7. Results

Figure 1 shows the 2040 shares of total final energy consumption and the final energy intensity relative to 2007 for the 4 scenarios considered. The figure shows that without the Full Link, the final energy intensity stays at the 2007 level, but drops by around 40% in the Full Link cases. A switch away from coal to electricity and natural gas is observed.

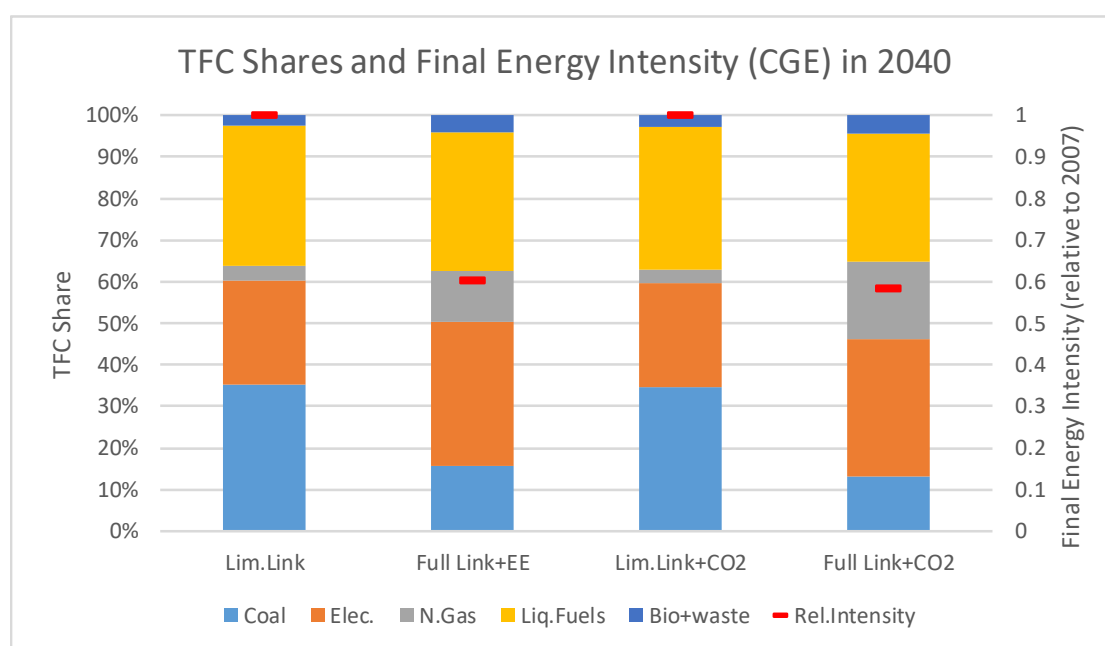


Figure 1 Total Final Energy Consumption for the 4 scenarios in 2040

Figure 2 shows the power generation mix for the 4 scenarios considered. It shows that the shares are the same with and without the full link, as expected – given that the power sector is linked, but that the total production is lower in the Full Link Cases, given the lower electricity demand

resulting from the energy efficiency improvements. The CO₂ constrained cases show shift away from coal to renewables and nuclear, with a complete phase out of coal by 2040.

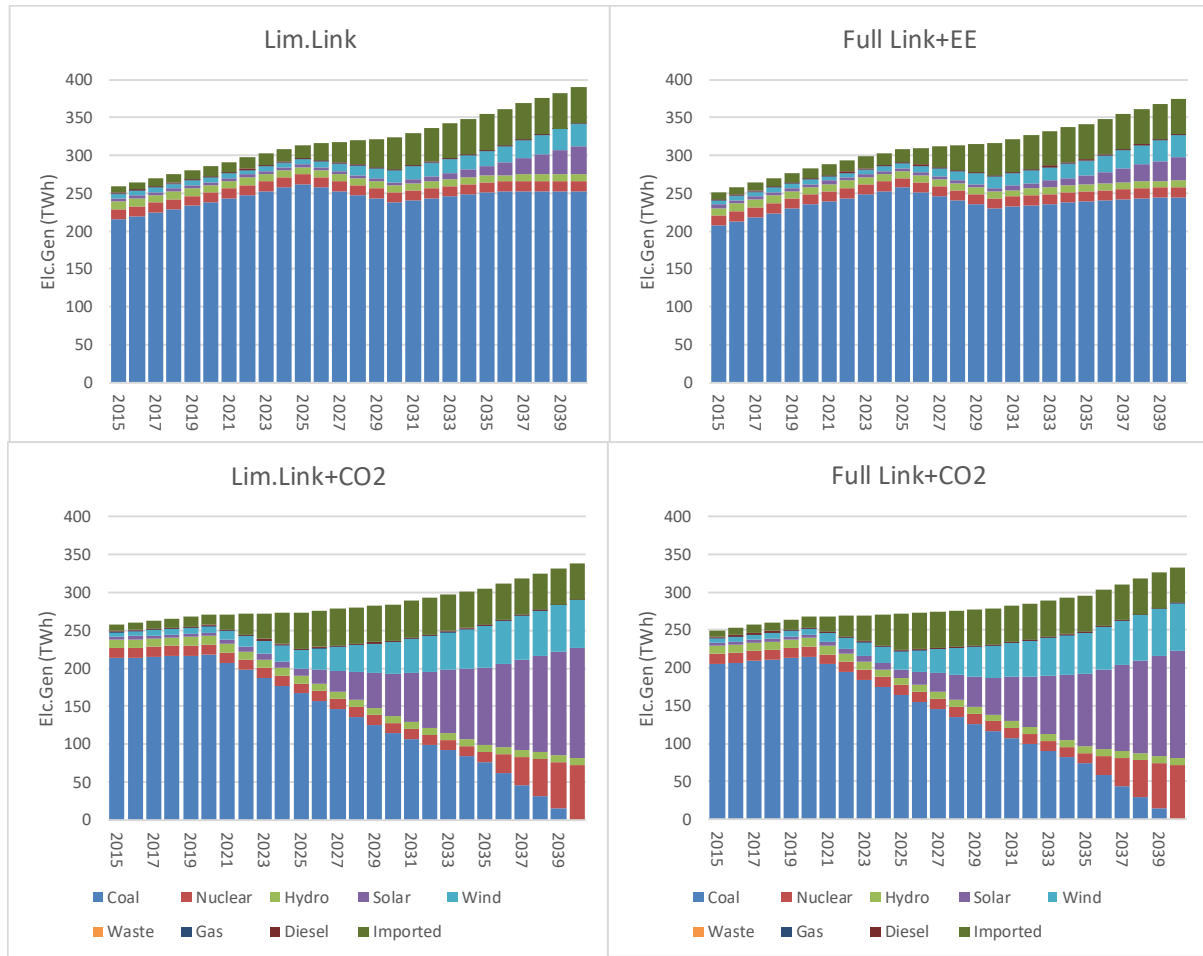


Figure 2 Electricity Generation Mix for the 4 scenarios considered

Figure 3 shows the supply of petroleum products for the four scenarios considered. The petroleum sector is not linked to the energy model in the Limited Link scenarios. The result is that regardless of the CO₂ price, the sector keeps the base year structure. In the Full Link+EE scenario, we see an increase in the share of CTL production and a phase out of GTL as the gas resource of PetroSA is depleted. We also see that the demand for petroleum products is significantly lower in 2040. In the Full Link+CO₂, we see a phase out of CTL, as it is much more CO₂ intensive.

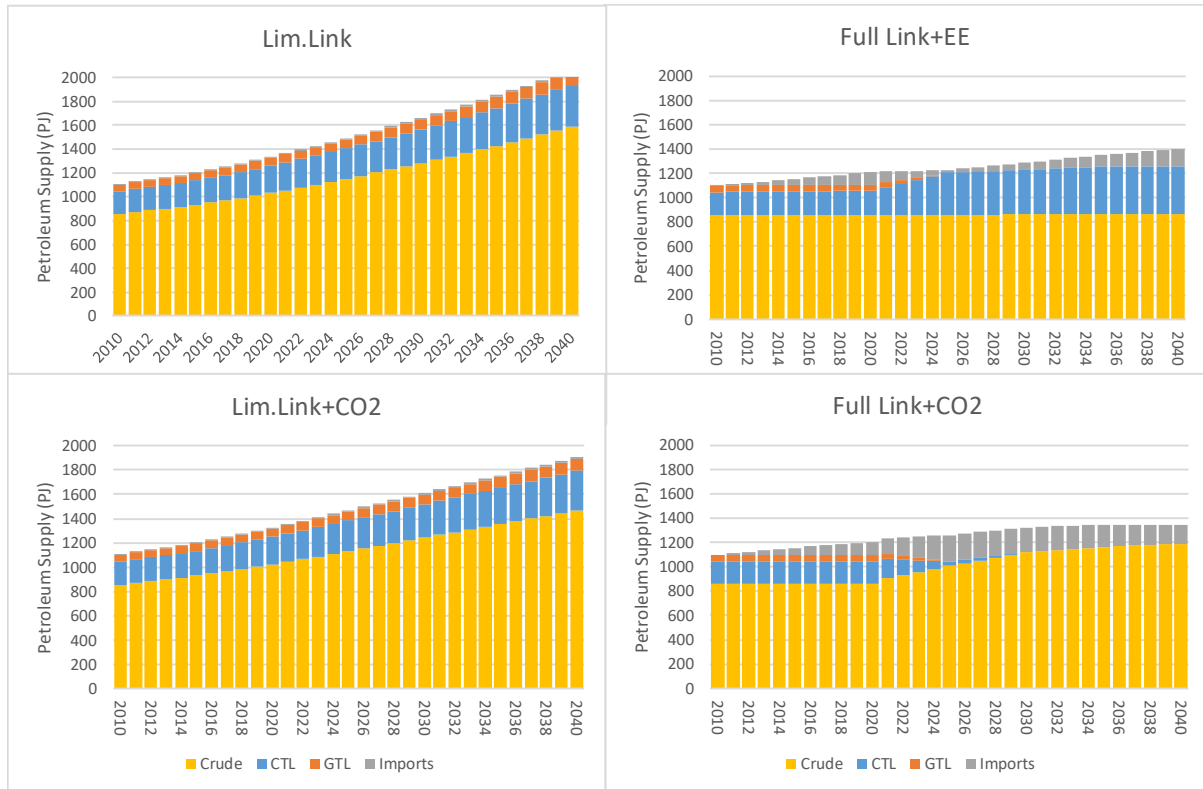


Figure 3 Petroleum Products Supply

Figure 4 shows the CO₂ emission trajectories as seen by the eSAGE for the 4 scenarios considered. Without a CO₂ constraint and without the full link to SATIM, the CO₂ emissions rise up to around 750 Mtons/yr by 2040. When the CO₂ tax trajectory for the 10GT cumulative cap is imposed on the CGE with only the power sector linked, the CO₂ emissions peak around 2025 and then come back down to around 2010 levels in 2040, and so completely overshoots the 10GT cumulative target. The emissions of the Full Link scenario slowly drift down due to slow growth and energy efficiency improvements, then goes up as the new coal power plants: Medupi and Kusile come online, as well as the new CTL refinery, before stabilizing again around the 450Mton level. In the Full Link + CO₂ scenario, the emissions decline to around 100Mton/yr by 2040. This is below the level seen in 2040 by the energy model (175Mton/yr), showing that there are still some outstanding calibration issues between the two models.

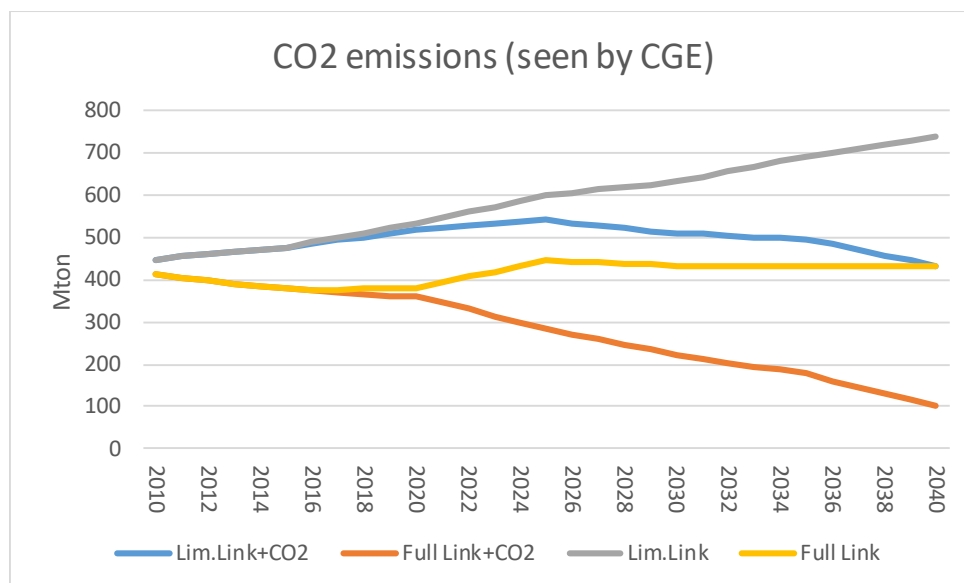


Figure 4 CO₂ Emissions with limited link vs full link with EE and EE+CO₂

Figure 5 shows the CO₂ marginal trajectory that is obtained from SATIM when a 10GT cumulative limit is specified for the period 2015-2050. The CO₂ marginal goes up over time as the model runs out of the lower cost mitigation options (in power and petroleum products), and requires more onerous fuel switching in the other sectors (industry, transport, commerce and residential).

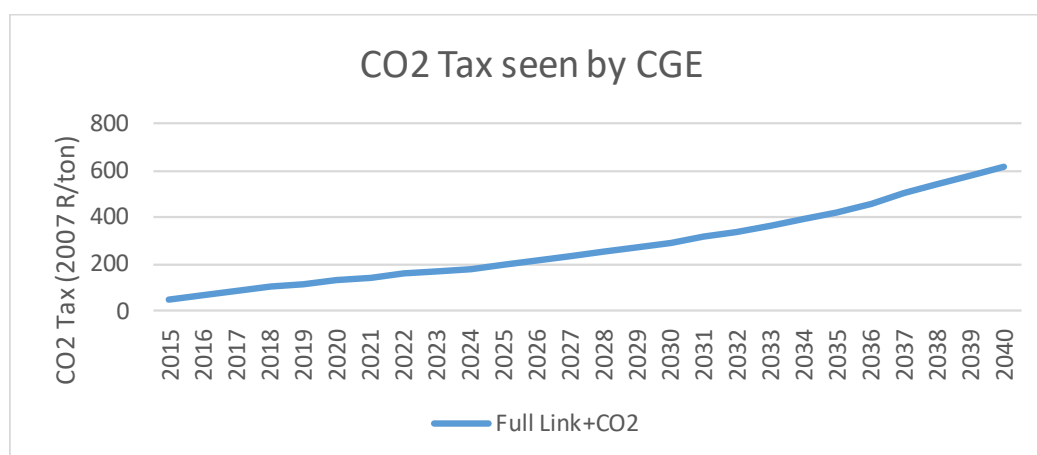


Figure 5 CO₂ marginal given the 10GT CO₂ Cap 2015-2050

Figure 6 shows projected average GDP growths, GDP growths for aggregate sectors, overall household welfare, and welfare growth for different household income groups for the four scenarios considered. The results show that there is a 0.2% annual average growth benefit for having better energy efficiency as modelled in SATIM, compared to an economy that uses energy to 2040 as it did in 2007. It also shows that when a CO₂ price is imposed without taking into account the possibility of higher energy efficiency and fuel switching that growth would be 0.19% slower on average than the no energy efficiency (EE) case, and 0.39% slower than the (EE) case without a CO₂ price. When EE and fuel switching are considered across all sectors, meeting the

ambitious 10 GT target doesn't actually cost anything relative to not having EE in place, and costs 0.16% average growth compared to having EE and no CO₂ taxes. This is assuming that revenues from taxes are recycled through reductions in sales taxes.

Similar observations are made on household welfare, but with slightly larger impacts, namely a 0.43% improvement in welfare growth when EE is included. This welfare impact is higher in the Poor (0-50) income percentiles and in the top (90-100) income percentiles.

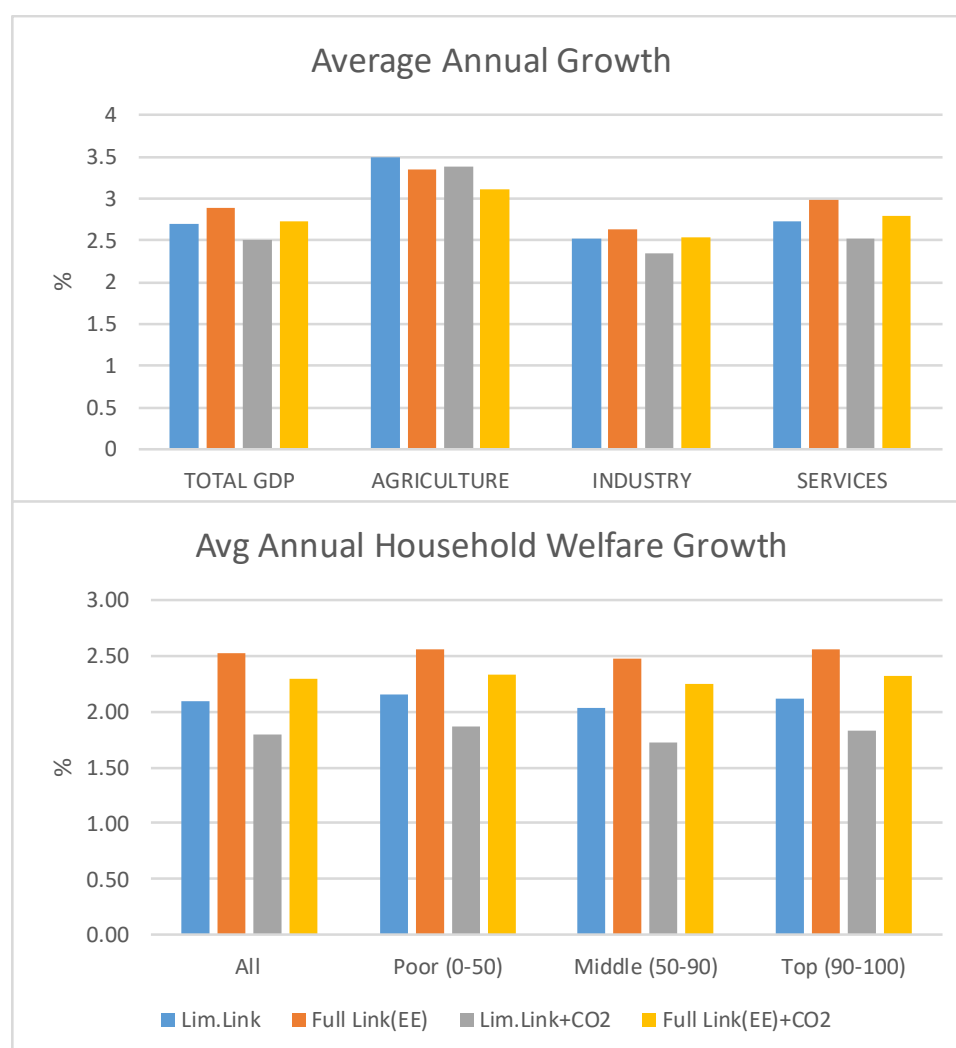


Figure 6 Socio Economic Impacts

8. Conclusions and further work

This paper here describes the methodology used to couple a CGE model of South Africa (eSAGE) and an energy model of South Africa (SATIM) across all sectors consuming energy. The coupling approach starts from some previous work where only the power sector was linked. The results show that the additional links between both models do significantly improve the insights that could be obtained from analysing ambitious energy efficiency and mitigation policies for South Africa.

Further work includes: the update of the base year from 2007 to the latest available SAM for South Africa, namely, 2012; the refinement of the hybridization process, perhaps with better alignment

of the disaggregation of the economic sectors and households in both models; detailed analysis of a wider range of mitigation target to get a better understanding of the possible trade-offs; other scenarios including other technologies that could lower the CO₂ marginals of meeting ambitious targets such as: biofuels, electric cars, modal switching in transport; storage options, better characterization of the solar and wind resource; sensitivities around the gas price (e.g. with availability of shale); sensitivities around other technology costs; better characterization of the households in eSAGE and SATIM, etc... On the economic side more analysis can be done to identify the winners and losers for different levels of ambition as well as different CO₂ taxation and tax recycling strategies; and sensitivities around assumed TFP growth projections, border tax adjustments, etc...

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