The incidence of a carbon tax – a dynamic CGE study (#4386)

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Abstract

This paper is a follow up of our 2006 paper entitled "Searching for Triple Dividends in South Africa: Fighting CO2 Pollution and Poverty while Promoting Growth", which appeared in volume 26:2 of The Energy Journal. In that paper we used a static model of the South African economy and simulated both a carbon tax and an energy tax, as well as three possible recycling schemes, to search for the best tax-recycling combination with regard to three goals: (i) a cleaner environment, (ii) a growing economy, and (iii) a decrease in poverty. Improvement in all three of these goals would be considered as "triple dividends".

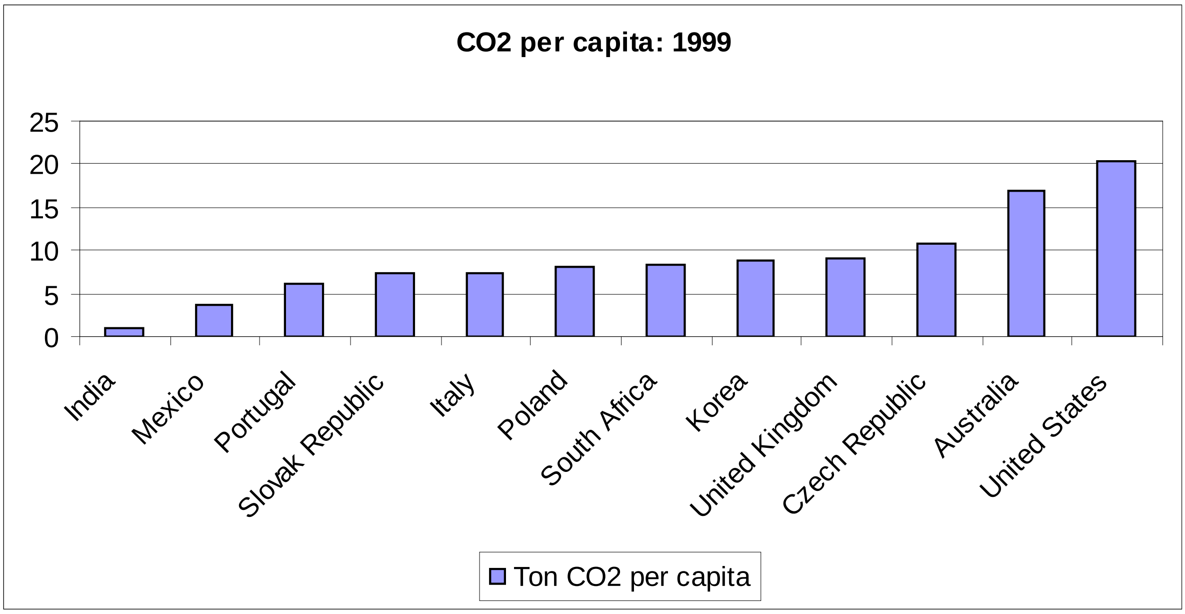
The abovementioned static study was not ideal and we have implemented a dynamic CGE model of South Africa to conduct similar research to repeat the search for triple dividends over time. In this paper, we report how to adjust a standard dynamic CGE model and database to be able to conduct energy related research. We also expand the electricity sector from one industry that produces electricity from coal to a few that produce electricity from coal, nuclear and renewables, with substitution possibilities between them. We levy taxes on energy related commodities and discuss the incidence of the tax on households and industries in South Africa.

1 Introduction

South Africa is a country of different societies. Before independence the two most prominent groups were the small white middle class and a very large group of poor black people. Twenty years later the complexion of the middle class has changed and it has become representative of all the race groups in South Africa, but recent studies have shown that the gap between rich and poor has increased, and the income distribution deteriorated. In this paper we will discuss the implementation of new policies and the reader should remember that South Africa has two societies and that policy makers must always take the effects of the policies on the poor majority into consideration.

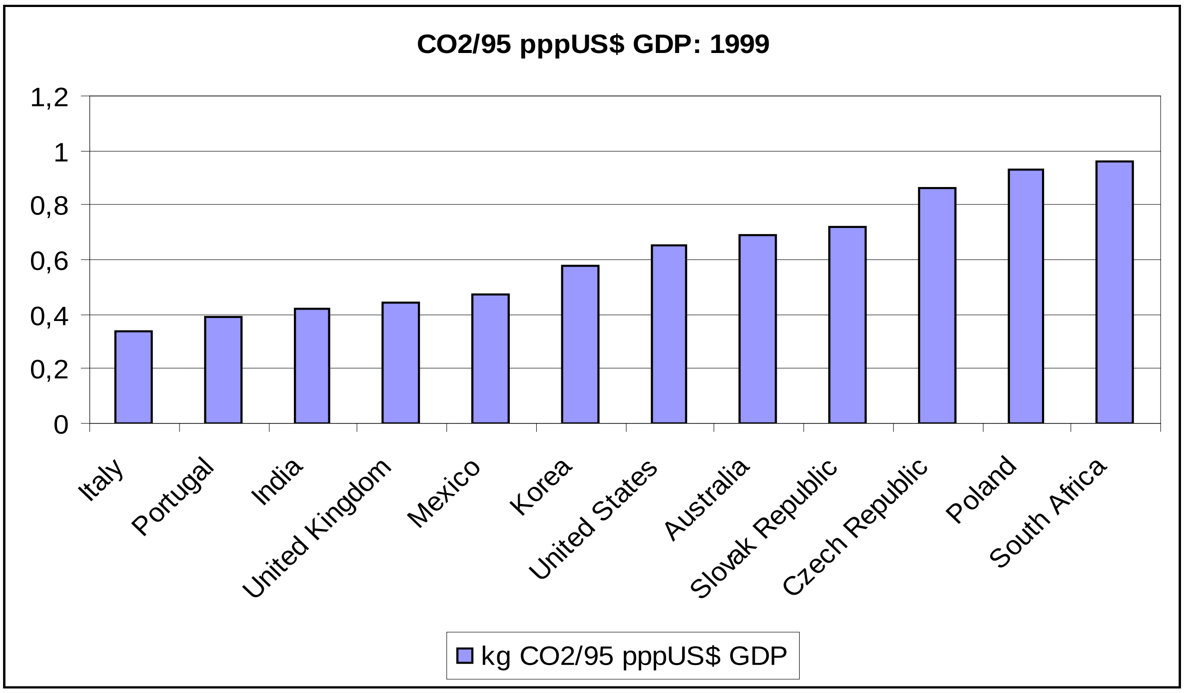
Visitors to South Africa are often stunned by the beautiful infrastructure and the fact that it looks just like another developed economy. The first heart transplant took place there and the first town to have electric street lights was there. They hosted the Soccer World Cup very successfully four years ago and recently joined the BRIC countries (now BRICS) who are leading the world's growth.

Figure 1 South Africa' relative carbon footprint



South Africa will become the first BRICS country to implement carbon taxes, and one of a few countries in the world. It has signed the Kyoto protocol and promised to decrease its significant carbon footprint. The footprint comes from the fact that South Africa is endowed with huge coal resources which is used to produce most of its electricity. The electricity is inexpensive and therefore the demand for it is high. However the technology of producing electricity is dirty and hence the carbon footprint much larger than expected. Figure 1 shows that the CO_2 emissions per capita in 1999 ranked among those of developed economies in the world, while Figure 2 shows that its emissions intensity was the highest in the world in 1999. This means that South Africa produced more carbon in the production of one dollar's GDP than any other country. The country is still relying mostly on coal fired power stations to produce its electricity, so that this picture is still very relevant fifteen years later.

Figure 2 Emissions intensity of South Africa in 1999



2 Policies to decrease the South African carbon footprint

The government of South Africa has decided to implement policies that would ensure that the country's GHG emissions be reduced by 34 per cent by 2020 and 42 per cent by 2025 below the business-as-usual trajectory (Treasury, 2013). The Department of Environmental Affairs drafted the "National Climate Change Response White Paper" in 2011 that provides an overarching policy framework for enabling this transformation in the short, medium and long term. It consists of a broad range of policy measures necessary to reach the said goals, but in this paper we will focus only on two of these policy measures: the "Institutional Resource Plan for electricity" and the planned carbon taxes.

The institutional resource plan (IRP) for electricity

The IRP 2010 is the official government plan for new electricity generation capacity and it is intended to be updated regularly (DOE, 2010). The November 2013 update report focuses on the following aspects:

- How the landscape has changed since 2010 in terms of electricity demand
- The relationship between electricity demand and economic growth
- New developments in technology and fuel options in South Africa and abroad
- Scenarios for carbon mitigation strategies and their impact on electricity supply, and
- The affordability of electricity.

Various possible future scenarios are presented in the IRP, but the core of the plan is to decrease the contribution of coal powered electricity in the total supply, i.e., increase green

Table 1 IRP 2010 Policy Adjusted Plan with Ministerial Determinations

	New build capacity								Committed			
	Coal	Nuclear	Import hydro	Gas - CCGT	Peak - OCGT	Wind	CSP	Solar PV	Coal	Other	Wind	Other renew
	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW
2010	0	0	0	0	0	0	0	0	380	260	0	0
2011	0	0	0	0	0	0	0	0	679	130	0	0
2012	0	0	0	0	0	0	0	300	303	0	400	100
2013	0	0	0	0	0	0	0	300	823	333	400	25
2014	500	0	0	0	0	400	0	300	722	999	0	100
2015	500	0	0	0	0	400	0	300	1444	0	0	100
2016	0	0	0	0	0	400	100	300	722	0	0	0
2017	0	0	0	0	0	400	100	300	2168	0	0	0
2018	0	0	0	0	0	400	100	300	723	0	0	0
2019	250	0	0	237	0	400	100	300	1446	0	0	0
2020	250	0	0	237	0	400	100	300	723	0	0	0
2021	250	0	0	237	0	400	100	300	0	0	0	0
2022	250	0	1143	0	805	400	100	300	0	0	0	0
2023	250	1600	1183	0	805	400	100	300	0	0	0	0
2024	250	1600	283	0	0	800	100	300	0	0	0	0
2025	250	1600	0	0	805	1600	100	1000	0	0	0	0
2026	1000	1600	0	0	0	400	0	500	0	0	0	0
2027	250	0	0	0	0	1600	0	500	0	0	0	0
2028	1000	1600	0	474	690	0	0	500	0	0	0	0
2029	250	1600	0	237	805	0	0	1000	0	0	0	0
2030	1000	0	0	948	0	0	0	1000	0	0	0	0
Total	**6250**	**9600**	**2609**	**2370**	**3910**	**8400**	**1000**	**8400**	**10133**	**1722**	**800**	**325**

generation, and secondly, to replace old and dirty power stations by two new coal fired power stations using much cleaner technology. From Table 1 it is clear that the future composition of electricity generation will change in South Africa by expanding green generation capacity significantly and by replacing the (committed) dirty coal generation by cleaner coal technology (new build capacity).

A Carbon Tax for South Africa

In December, 2010, the National Treasury of South Africa wrote a discussion paper for public comment, entitled “Reducing Greenhouse Gas Emissions: The Carbon Tax Option”. In the document the government shows that they understand the severity of the South African footprint and makes suggestions towards addressing the problem. A carbon tax is compared to an emissions trading scheme in detail in the document, but we would not repeat the reasons here why the government prefers the carbon tax.

They considered three possible tax bases for the carbon tax. Firstly, a tax applied directly on the emissions of CO2, at the source of combustion. However, this would be administratively complex, difficult and costly with a large number of sources. Few of the producers are measuring the amount of carbon that they emit. Secondly, the carbon content of energy products could be used as a proxy for actual emissions, and used as a tax base. This could be an upstream tax at the point where the fuels enter the economy, namely, a fossil fuel input tax on coal, crude oil and natural gas, or, thirdly, a downstream tax on energy outputs such as electricity and transport fuels.

The South African government announced the implementation of a carbon tax from January of 2016. The intended tax rate will be R120 per tonne CO2, increasing by 10 per cent per annum for the first five years, after which time the tax rate will be re-considered. The tax will be phased in by giving all industries a basic tax free threshold of 60% for five years, as well as graduated relief to trade-intensive industries; relief to industries where the potential for emissions reduction is limited, such as process emissions (cement, iron and steel, aluminium and glass), and permission for industries to reduce their carbon tax liability by using offsets.

3 The database and model

3.1 Database

The database of our “standard” dynamic model of South Africa had to be amended in two ways before we could simulate a carbon tax on fuel inputs. The carbon tax will be in terms of Rand per terra joule (TJ) and we therefore need to know how many TJ’s of each fuel each industry is consuming as intermediate input. We used the IPCC conversion tables to create a data matrix in terms of TJ, with dimensions FUEL x INDUSTRY. The main source used to construct this matrix was (Seymore, R, Inglesi-Lotz, R and JN Blignaut, 2014).

The second modification to the database was to split the single electricity industry into nine industries, namely eight generating industries (nuclear, coal, wind, hydro, solarPV, etc.) and a single electricity distributing industry, called “Elecsupply”. The original database had one electricity industry and one commodity as in Table 2. The yellow column and green row each would be split into nine columns and nine rows.

Table 2 Original database with one electricity industry

		Industries		**House-holds**	**Govern-ment**	
COM	V1BAS	ElecSupply	Rest IND	V3BAS	V5BAS	
	ElecSupply	4424	10291	5876	202	**20793**
	Rest COM	5793				
	Capital	7479				
	Labour	2115				
	Other costs	982				
	TOTAL	**20793**				

Summary table with illustrative numbers in them. The South African National Treasury does not want the true numbers to be presented yet, since the study is still underway.

We know from historical data what the composition of electricity output was in 2011 and split the column total according to those given weights. The various electricity generators have different capital and labour intensities and we therefore split the original values for capital and labour inputs accordingly. We also took an informed guess to split the intermediate commodity demand among the various generators. For example, we assumed that all nuclear commodity inputs are earmarked for the nuclear electricity generator, while all coal is used by the coal fired power stations. Wind generation does not use intermediate commodities as inputs, but only capital and labour.

Table 3 Illustrative database with green generators in Australia

		INDUSTRIES						House-holds	Govern-ment	NEM	TOTAL
COMMODITIES	V1BAS	ElecCoal	ElecGas	ElecOil	ElecOther	ElecSupply	Rest IND	V3BAS	V5BAS	V8BAS	
	ElecCoal	0	0	0	0	237	0	0	0	6452	**6689**
	ElecGas	0	0	0	0	1392	0	0	0	1653	**3045**
	ElecOil	0	0	0	0	164	0	0	0	105	**269**
	ElecOther	0	0	0	0	29	0	0	0	670	**699**
	ElecSupply	0	0	0	0	4424	10291	5876	202	0	**20793**
	Rest COM	2864	876	70	116	1867				**8880**	
	NEM	0	0	0	0	**8880**	0				
	Capital	2866	1503	133	457	2520					
	Labour	510	266	24	82	1233					
	Other costs	449	400	42	44	47					
	TOTAL	**6689**	**3045**	**269**	**699**	**20793**					

Source: (Adams)

The original single electricity row is also split into nine commodities. The generators sell only to the Elecsupply industry who distributes all electricity to other industries and final consumers. We adopted the principles of the database split from a version of the MMRF model of the Centre of Policy Studies (CoPS), which is depicted in Table 3. In this table there are four generators and one supplying industry, as well as the National Electricity Market (NEM) who is a final user of electricity. The single supplier buys all the electricity from the NEM also.

Our database looks a bit simpler than the MMRF data because only one distributor sells electricity throughout South Africa, while they have the NEM in Australia, selling electricity in some states, while other states have their own suppliers off the national grid. We could therefore structure the database as in Table where there is no NEM row or column. All electricity is sold to Elecsupply who distributes it to final consumers.

Table 4 A picture of the South African electricity split

		INDUSTRIES						House-holds	Govern-ment	TOTAL
COMMODITIES	V1BAS	ElecCoal	ElecGas	ElecOil	ElecOther	ElecSupply	Rest IND	V3BAS	V5BAS	
	ElecCoal	0	0	0	0	6689	0	0	0	**6689**
	ElecGas	0	0	0	0	3045	0	0	0	**3045**
	ElecOil	0	0	0	0	269	0	0	0	**269**
	ElecOther	0	0	0	0	699	0	0	0	**699**
	ElecSupply	0	0	0	0	4424	10291	5876	202	**20793**
	Rest COM	2864	876	70	116	1867				
	Capital	2866	1503	133	457	2520				
	Labour	510	266	24	82	1233				
	Other costs	449	400	42	44	47				
	TOTAL	**6689**	**3045**	**269**	**699**	**20793**				

3.2 Description of the model

The model structure is the standard mini-Monash style dynamic model. The only adjustments necessary were to add (i) a set of equations to be able to simulate the carbon taxes, and (ii) a set of equations to model the interactions between the electricity generators, electricity distributor and all other industries.

Without presenting the elaborate equations on the energy side, one can summarise by saying that CO_2 -equivalent gas could be taxed when it is emitted by combusting fuel, or an industry could be taxed when consuming fuel either in terms of its standardised energy content or native units format. The carbon tax or energy tax rates are shocked in the model simulations, and the resulting changes in real government revenue and gross domestic product calculated, along with all the other endogenous variables of the model. The percentage change in CO_2 emissions is also calculated, to be able to determine the most efficient way of reducing the emissions. The change in tax revenue is approximately equal to the tax rate times the change in the tax base plus the base times the change in the tax rate:

$$dR = T.dX + X.dT \quad (1)$$

Since the Orani tradition of modelling linearises all equations before solving the model, by converting all prices and quantities into percentage change forms, (1) is equal to:

$$=T.X.x/100+X.dT \quad =R.x/100+X.dT \text{ , with x the percentage change in X} \quad (2)$$

In the model the equation looks like this:

delGASTAX1(c,s,i) = 0.01*GASTAX1(c,s,i) *[xCO2(c,s,i)+gastaxindex]
+CO2(c,s,i)*delGASTAX1Rate(c,s,i);

with:

delGASTAX1 (c,s,i)	*Change in emission tax revenue (dR)*;
GASTAX1(c,s,i)	*Emission tax revenue from industries (R)*;
xCO2(c,s,i)	*% change in emissions (x)*;
gastaxindex	*index at which nominal revenue changes*

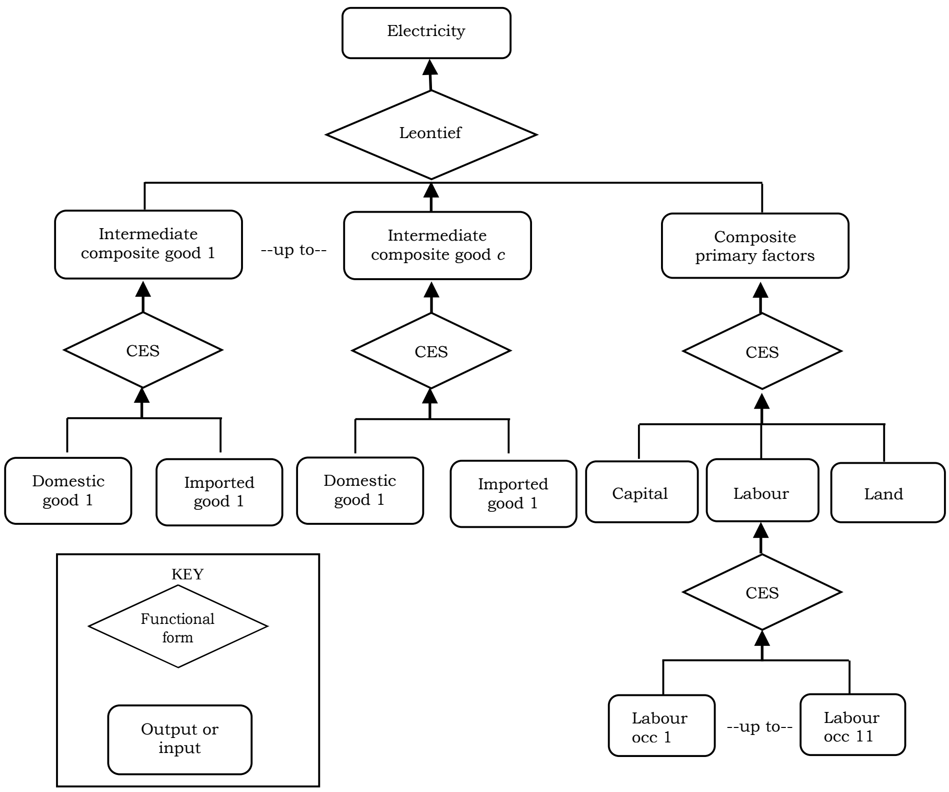
CO2(c,s,i) *volume of CO2 emissions*;

delGASTAX1Rate(c,s,i) *Change in the tax rate on emissions (dT)*;

(c,s,i) indicates that the variables are defined over commodities, sources, and industries.

In most of the CGE models that have been built around the world, the production of electricity is modelled as a Leontief function of intermediate inputs and a combination of factors of production. The intermediate inputs consist of other commodities that have been produced earlier, and that are not consumed by final consumers like the households or government. The factors of production consist of labour, capital and land, while labour could be subdivided into different occupation types. A schematic representation of the production function is given in Figure 3.

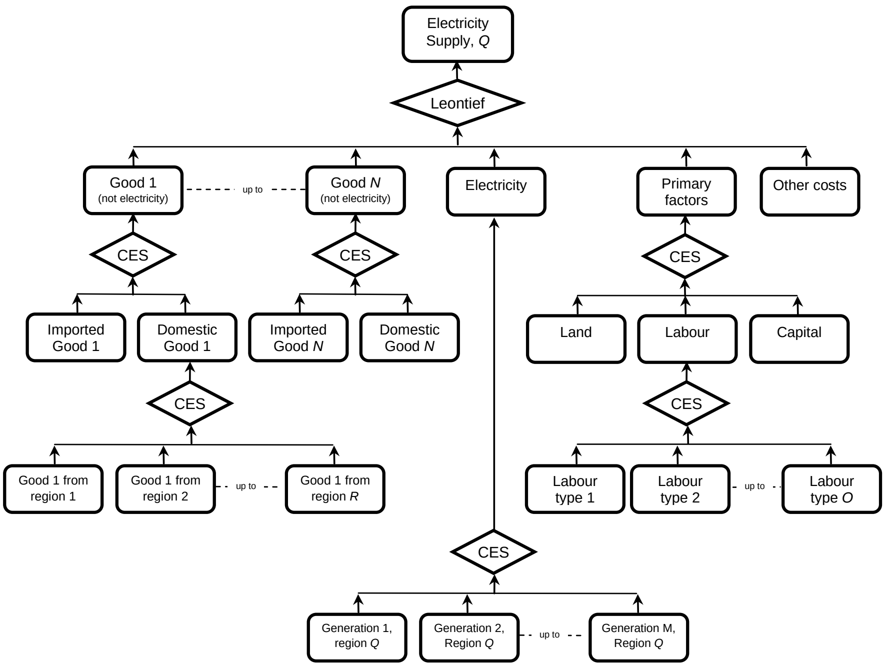
Figure 3. Typical structure of production in CGE



There is some flexibility with the demand for each commodity that forms an ingredient into the production process, in that it could either be imported, or sourced from the local market. Figure 3 above shows that a CES demand function is used to model the choice between imports and domestic goods. This means that prices and elasticities of substitution play a role to determine in what combination the imported and domestic goods will be used. It is not *either* the one *or* the other. If domestic goods become relatively expensive, imported goods will be substituted for them, and *vice versa*.

The second adjustment to the model is to add CES demand functions for the demand for generated electricity by the single electricity supplier, as depicted in Figure 4. All other demands for intermediate composites remain of the Leontief type.

Figure 4 Production technology for the electricity supply industry in South Africa



We could therefore write all intermediate demands by all industries in 3 sets of model equations, as follows:

(a) We have 53 industries in the model and all but one of them (Elecsupply) has Leontief demands for all intermediate use of commodities:

Equation E_x1_sa *# Demands for commodity composites #*

(**all**,c,COM)(**all**,i,IND52) x1_s(c,i) - **[**a1_s(c,i) + a1tot(i)**]** = z(i);

(b) The Elecsupply industry also has Leontief demands for all other commodities than the Electricity generated commodities:

Equation E_x1_sb *# Demands for commodity composites #*

(**all**,c,COM45) x1_s(c,*"ElecSup"*) - **[**a1_s(c,*"ElecSup"*) + a1tot(*"ElecSup"*)**]**
= z(*"ElecSup"*);

(c) Finally, the Elecsupply industry has CES demands for the Electricity generated commodities:

Equation E_x1_sc
(**all**,c,GEN) x1_s(c,*"ElecSup"*) - a1_s(c,*"ElecSup"*)

= z(*"ElecSup"*) - SIGMAGEN(c)***[**p1_s(c,*"ElecSup"*) + a1_s(c,*"ElecSup"*) –

p1_gen**]**;

with p1_gen the share weighted average of generation industry prices.

4 Policy simulations

4.1 Baseline forecast

In our baseline forecast we make use of a few econometric forecasts by acknowledged macroeconomists as well as some features of the South African government's Institutional Resource Plan for electricity. The macro forecasts come mostly from CEPII and will not be given in any detail here. The 2010 IRP (SO low option) forecasts that coal fired power generation will increase but decrease again to reach the same annual level in 2035 as in 2011. Since these are envisaged to materialise within the forecast period, we did not simulate them as policy shocks, but rather incorporated them into the baseline forecast. Total electricity demand is also modelled to grow according to Eskom's predictions, namely, somewhat below the annual GDP growth rates. Green electricity is allowed to react endogenously to the said baseline shocks.

4.2 Policy shocks

In the policy simulations we implement carbon taxes on all fuel inputs according to the carbon contents of the various fuels, while taking the various thresholds mentioned in Section

2 above into consideration. The basic tax is R120 per TJ[1] , growing at 10 per cent per annum, with the proposed exemptions to the various industries given in Table 5. The reader would notice that the thresholds are quite generous. These are intended for the first five years of the carbon tax, but we modelled them until the end of the forecast period.

Table 5 Proposed emissions tax free thresholds

Sector	Basic tax free threshold (%)	Maximum additional allowance for trade exposure (%)	Additional allowance for process emissions (%)	Total (%)	Maximum offset(%)
Electricity	60	-	-	60	10
Petroleum	60	10	-	70	10
Iron & Steel	60	10	10	80	5
Cement	60	10	10	80	5
Glass & ceramics	60	10	10	80	5
Chemicals	60	10	10	80	5
Pulp & paper	60	10	-	70	10
Sugar	60	10	-	70	10
Agriculture, forestry and land use	60	-	40	100	0
Waste	60	-	40	100	0
Fugitive emissions from coal mining	60	10	10	80	5
Other	60	10	-	70	10

Source: (Treasury, 2013)

5 Results

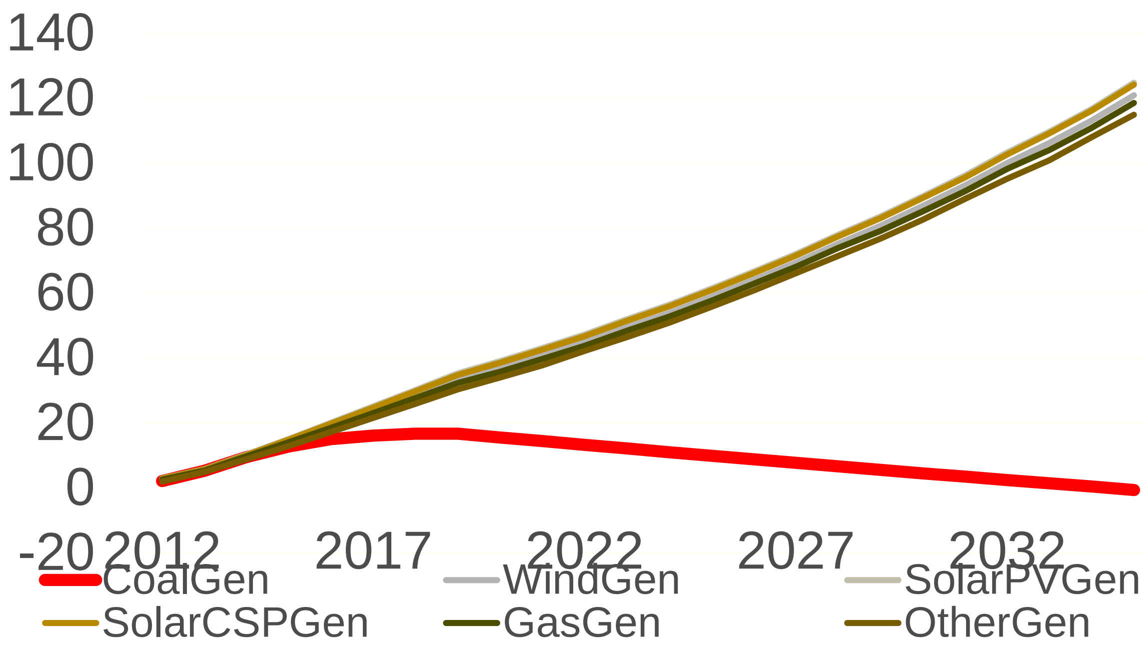
5.1 Reaction of green generation to the baseline shocks

In the baseline we forecast total electricity demand to increase just below the level of GDP growth (assuming some productivity improvements over time), while we are restricting coal fired electricity generation to increase much slower than total output, and to end at the same absolute levels in 2035 as in 2011.

[1] 1 US $ = R10.50

The green generating industries react very nicely to these shocks, but not nearly enough to make up for the decrease in coal generation. The "problem" is that the technology variable a1_s("coalgen",*"ElecSup"*) in the third equation above, is endogenous and it decreases in the model solution. This means that total Elecsupply could still grow significantly by using coal much more efficiently, while not substituting the dirty technology for green electricity enough. Nevertheless, shows how the green generation is growing by more than 100 per cent over the forecast period, while total coal generated electricity is forced downwards.

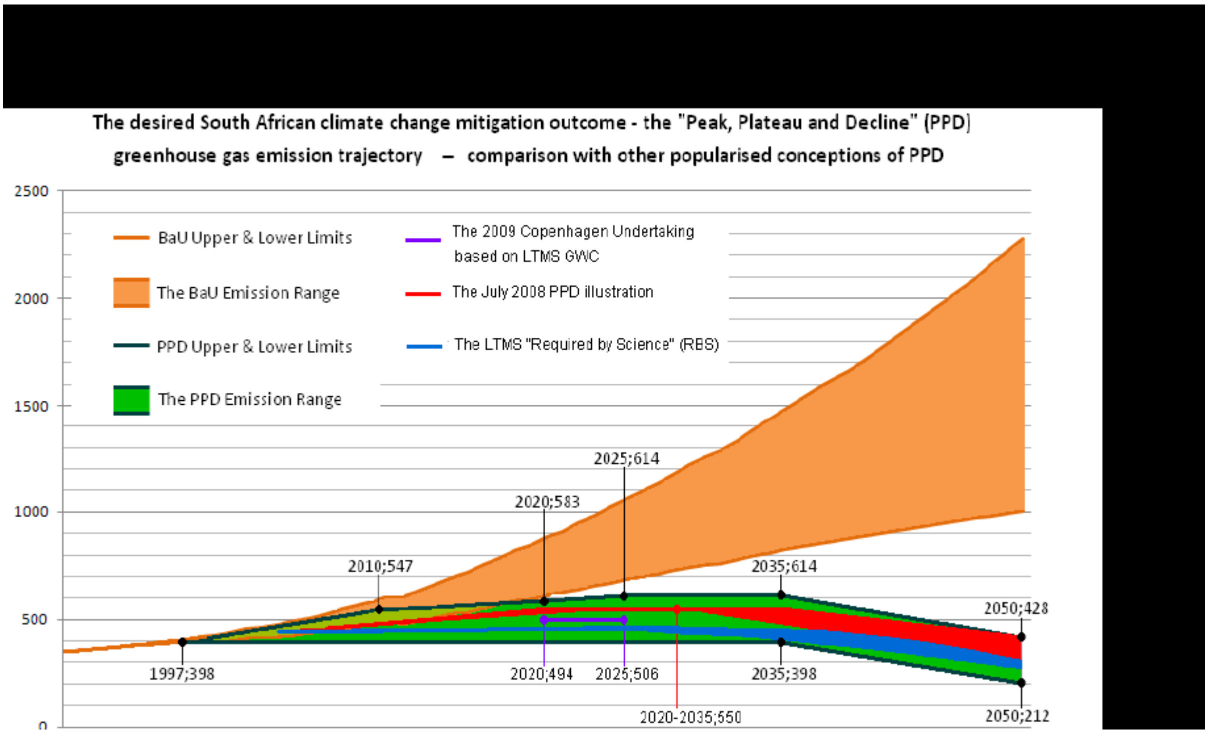
Figure 5 Per cent change in output growth for different power generation sources (cumulative)



5.2 Policy simulation

In the government document "Reducing-greenhouse-gas.pdf" they have a graph of possible carbon emissions trajectories under various scenarios. Figure 6 shows the range of possible emissions under the "business as usual (BAU)" scenario in orange. Their BAU is different from our baseline forecast in that coal generation is not restricted, and no carbon taxes are levied. The green band in the bottom of the picture shows the "peak, plateau and decline (PPD)" levels of emissions which would be the ideal levels for South Africa, according to our government.

Figure 6 Possible GHG emissions trajectories

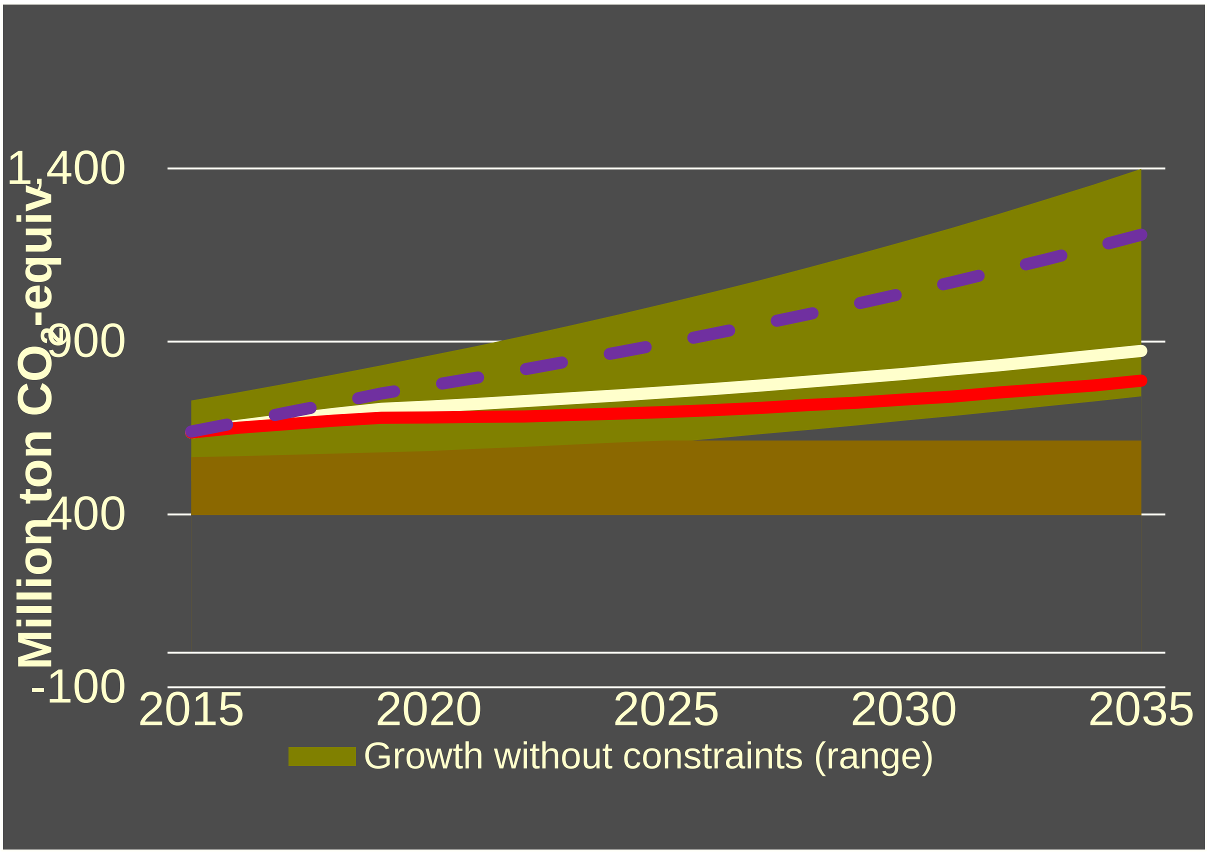


Our results show that (i) the carbon tax alone, without a restriction on coal generation and with the high margins of exemptions, would not be very effective. The purple dotted line in Figure 7 shows that the emissions trajectory would end up about 25 per cent below the high end of emissions under the BAU scenario.

(ii) the restriction of coal generation alone, however, without a carbon tax, would be much more effective than the diluted carbon tax. The yellow line in Figure 7 shows that carbon emissions would decrease into the bottom 25 per cent of the BAU spectrum; and

(iii) a combination of these measures would be quite effective by almost reaching the very bottom of the BAU spectrum (red line).

Figure 7 Results of baseline assumptions and policy simulations



6 Conclusion

From a modeling perspective we found that implementing CES demand functions for generated electricity by the supplying industry causes a switch to green electricity but not nearly enough. Currently the supplier merely uses coal generated power much more efficiently and not enough substitution takes place. We would like to improve the modeling technique here by perhaps introducing a reduction in capital in the production process, simulating the moth balling of old power plants.

With regards to the carbon tax by itself – especially with all the exemptions for the first five years – we found that its impact is marginal. The government will have to get rid of the tax free thresholds if the tax is to be successful. Regulation of coal generated power, as well as pro-active stimulation of green generation together with the tax will be necessary to reach the targets.

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