Modelling the impact of CO_2 taxes in combination with the Long Term Mitigations Scenarios on Emissions in South Africa using a dynamic computable general equilibrium model

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ABSTRACT

A dynamic computable general equilibrium (CGE) model is used to analysie the impact on the economy of taxes on CO_2 emissions combined with the Long Term Mitigation Scenarios. A sales tax is used to model the impact of a CO_2 tax. The mitigation scenarios modelled include structural shifts (for example switching from coal-fired electricity plants to nuclear power stations), changes in energy efficiency and changes in investment required. The extent of the structural shifts, changes in energy efficiency and investment required differs from scenario to scenario.

The results for the mitigation scenarios indicate that the mitigation scenarios have a positive impact on GDP when investment is large. Although economic activity initially declines due to improved energy efficiency, it is followed by a period of economic expansion as lower prices increases output in most industries – this is especially the case when it is combined with higher investment. When CO_2 taxes are levied the economic impact is again positive if this is combined with either tax relief or reinvestment of the additional tax revenue. The scenarios have varied impact on labour, in general employment for semi- and unskilled labour rise if investment is higher. In most scenarios the demand for energy declines, especially for coal and petroleum. However, the demand for electricity increases if investment rises significantly.

When the mitigation scenarios is combined with a CO_2 tax the results indicate that the CO_2 tax is effective in reducing output of CO_2 producing industries as it changes the relative price of the commodities produced by these industries. However, the sales tax is distortionary as it introduces price wedges in the economy while consumers may end up paying large portions of the tax. A CO_2 tax may not be the most appropriate tool to achieve the desired results considering the economic development objectives of South Africa. However, when combined with the LTMS framework its negative impact is negated by higher investment and GDP growth.

Keywords: CO_2 tax, computable general equilibrium model, economic impact; long term mitigation scenarios

1. Introduction

Under the United Nations Framework Convention on Climate Change and its Kyoto Protocal, South Africa has been exempt from taking mandatory action to reduce emissions. However, South Africa has identified strategies through its Long Term Mitigation Scenarios (LTMS) to reduce emissions. In this process the Department of Environment Affairs and Tourism (DEAT) identified two scenarios, the first being the base scenario against which all other scenarios are compared. This is the Growth without constraint (GWC) scenario, and measures the level of emissions if the economy continues to grow at current trends without any significant attempts to mitigate emissions. The second scenario is the Required by science scenario' (RSS) and estimates the required interventions to mitigate emissions to target levels. Within the RSS four strategies have been identified, namely Start-now, Scale-up, Use-the-market, and Reach the goal. Each of these strategies has different investment and cost implications, technological improvements and tax and other incentive packages in mind. (DEAT 2007). Meeting the rising demand for energy in South Africa poses certain challenges which include (1) investment to increase the capacity to produce energy; (2) switching to more environmentally sustainable sources of energy; and (3) increasing energy efficiency. All of these challenges have an impact on the economy, on production and ultimately on the level of CO_2 emissions produced. This paper focuses on a further challenge, looking at the impact of taxes on CO_2 emissions as an effective means to reduce emission output. The reasoning is that a tax on CO_2 emissions will increase their relative price so that production declines. This is measured within the framework set by the LTMS. A dynamic computable general equilibrium (CGE) model is used to analysie the impact on the economy of taxes on CO_2 emissions combined with the LTMS.

Various authors contributed to this topic in the past, including Van Heerden et al (2006), Paauw (2007), and Devarajan et al (2009); they all attempted to measure the impact of taxes on emissions and/or mitigation strategies in South Africa. The paper by Van Heerden et al focuses on finding double or triple dividends from the revenues raised from energy related taxes if recycled to households and industry by lowering existing taxes, while Paauw focused on the impact of the LTMS scenarios specifically. Devarajan et al, in turn, focused on the economic impact of various taxes aimed at reducing carbon emissions. In all these papers a static CGE model was used to evaluate the impact of the strategies and taxes. This paper attempts to add value to this debate by using a dynamic CGE model to assess the combined impact of the LTMS scenarios and taxes on energy emissions.

The advantages of using a dynamic CGE model compared to a static CGE model include the following:

- Comparative-static CGE models estimate the reaction of the economy to certain policy shocks or economic events at only one point in time. A comparative static approach has limitations when linked to scenarios from energy modeling, which project energy demand and emissions up to 2050. Since the purpose is to understand the economic implication of long-term mitigation scenarios, dynamic effects are particularly relevant. The dynamic CGE model on the other hand can trace the impact of a policy shock or economic event on a period-by-period basis (usually over annual periods).
- A further advantage of the dynamic CGE model is that it captures growth in capital stock and therefore productive capacity over time. Capital accumulation is modeled endogenously so that previous period investment generates new capital stock for the next period. The allocation of new capital stock across sectors is influenced by the sectors' share in aggregate capital income, the depreciation rate, and on sectoral profit rates from the previous period. Sectoral profit rates may be important in mitigation scenarios, if investment flows to sectors with different levels of capital stock. Sectors with above-average capital returns will receive a larger share of the new capital stock relative to their share in capital income (and *vice versa*). A predetermined macroeconomic forecast is used to determine the benchmark growth path of the model against which policy shocks can be compared. All exogenous variables in the model are updated within the macroeconomic forecast framework.

The dynamic CGE model used in this analysis is based on a model developed by James Thurlow for TIPS (Thurlow 2004). It is an extension of the comparative static CGE model used by the International Food Policy Research Institute (IFPRI). The IFPRI standard model is based on the neoclassical-structural modelling tradition as introduced by Dervis and De Melo (1982). Various adaptations have been made to the dynamic model as developed by Thurlow, including changes to the specification of labour demand and supply, the determination of wages, and the determination of the base growth path in the model. The two main sources of data used in the dynamic CGE model are a social accounting matrix (SAM) and a macroeconomic forecast.

Designing or evaluating environmental policy requires detailed understanding of the relationship between the economy and the environment. Mathematical models provide the quantitative links between economic activity and the environmental impact. These models allow one to quantitatively measure the impact of policies that restructure the economy to achieve emission reductions in a multi-sectoral economy.

2. Methodology

2.1 The model

The model consists of two basic components, namely the *within-the-period* and the *between-the-period* components. In the *Within-the-period* component the standard IFPRI model is solved. The standard IFPRI model consists of a set of non-linear equations, which are simultaneously solved. Behaviour is captured by non-linear first order optimality conditions where producers maximise profits and consumers utility. The model makes provision for both goods and factor markets. The institutions included are households, firms, the government, and the rest of the world. The model is in equilibrium when demand is equal to supply. A number of macro constraints are also included to ‘close’ the model (Lofgren 2002).

In the *between-periods* component the model is updated to capture effect from the static model into the next period or alternatively to capture economic effects outside the model into the next period. The most important effect to be captured in the in-between year updating process is the impact of current investment on future capital stock (Thurlow 2004). If mitigation leads to current investment in some sectors but not others, this would have implications for differences in capital stock in following periods. Other variables that are updated include total factor productivity, factor specific productivity, labour force growth, population growth, real wages, government consumption, investment, and transfers from the government to household. Most of these are exogenous parameters in the model. These parameters are updated to provide better tracking of a GDP growth path.

2.2 Data

2.2.1 Social accounting matrix

The main source of data used for the CGE modeling is a SAM, which is a comprehensive, economy-wide data framework. It is a square matrix in which each account is represented by a row and a column: each cell shows the payment from its column account to its row account. The CGE model follows the flows captured in the SAM. The SAM used for the modelling was compiled by the Western Cape Department of Agriculture (PROVIDE 2006) and is based on the base-year 2000. The same matrix was used by Pauw (2007), who describes the SAM in his paper.

Table 1: PROVIDE National Accounting Matrix for 2000 (Rm)

		Commod-ities	*Activities*	*Production factors*		*House-holds*	*Enter-prises*	*Government*		*Capital*		*Rest of world*	*TOTAL*
				Capital	*Labour*			*Taxes*	*Expend-iture*	*Invest ment*	*Changes in inventories*		
Commodities			1 088 770			580 802			167348	139 648	7 096	257 011	2 240 675
Activities		1 893 686											1 893 686
Factors	*Capital*		377 770									15 910	393 680
	Labour		442301									2 242	444 543
House-holds				94 883	440299		112 441		29687			260	677 570
Enter-prises				262 865			139 834		51747				454 446
Govt	*Taxes*	117 232	-15155			87 848	33 248						223 173
	Expendi-ture					1 870	9 687	223 173				481	235 211
Capital	*Savings*					6 922	159 156		-20526			1 192	146 744
	Changes in invent-ories									7096			7 096
Rest of the world		229 757		35 932	4244	128	80		6955				277 096
TOTAL		2 240 675	1 893 686	393 680	444543	677 570	454 446	223 173	235 211	146 744	7 096	277 096	

2.2.2 GDP Forecast up to 2050

The dynamic CGE model requires a detailed forecast up to 2050 in order to establish the benchmark growth path of the model against which the alternative scenarios will be compared. A consistent forecast for the real GDP aggregates is required as well as for the level of capital stock in the economy and the size of the labour force.
Table 2 shows a summary of the growth forecast.

The growth path for 2001 to 2007 is based on the actual values for the GDP aggregates as published by Statistics South Africa and the SARB. The growth path for 2008, 2009 and 2010 are based on the National Treasury forecast as published in the Budget Review document of 2007. The ASGI-SA growth targets are built into the forecast for the years 2010 to 2014. Thereafter continued growth is forecasted up to the mid 2020s whereafter growth returns to trend of 4.5%.

The growth for final consumption expenditure, government consumption expenditure, investment, changes in inventories and GDP growth is initially imposed exogenously on the model, while imports and exports are solved for endogenously. The growth path is determined accordingly. A range of parameters is then used to maintain the growth path set while variables such as consumption, investment and GDP are made endogenous to the modelling process.

Table 2: Summary of the GDP growth forecast up to 2050

GDP components (R million)	*2001-2005*	*2006-2010*	*2011-2015*	*2016-2020*	*2021-2025*	*2026-2030*	*2031-2040*	*2041-2050*
Real final household consumption								
% change y-o-y	4.2	5.7	5.0	5.8	6.7	6.5	6.5	6.5
% of GDP	63.6	67.3	65.5	63.5	63.0	65.5	66.1	66.1
Real gross fixed capital formation								
% change y-o-y	6.3	13.4	8.6	7.3	2.6	2.4	3.1	3.1
% of GDP	15.9	22.2	28.2	30.2	27.4	23.2	22.9	22.9
Real government consumption								
% change y-o-y	5.1	4.9	5.2	6.0	7.0	6.6	6.5	6.5
% of GDP	18.7	19.1	18.7	18.1	18.1	19.1	19.3	19.3
Real change in inventories								
% of GDP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Statistical discrepancy: Real GDP								
% of GDP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Real exports: Total								
% change y-o-y	1.6	6.6	6.8	6.6	5.6	5.2	5.2	5.2
% of GDP	26.7	27.6	29.4	30.0	29.3	28.9	28.9	28.9
Real imports: Total								
% change y-o-y	7.0	11.3	8.6	7.5	6.2	5.0	5.0	5.0
% of GDP	25.8	36.7	43.0	46.5	46.8	46.4	46.4	46.4
Real GDP								
% change y-o-y	3.6	5.2	5.7	6.7	6.3	4.9	4.5	4.5

2.3 Emissions

The input-output structure within the SAM as used in the CGE model allows one to calculate the emission levels of the various industries according to its use of the different energy sources in their respective production processes. This allows the model to capture the change in emission levels due to structural shifts in production. The present study calculates the change in energy demand for coal, petroleum, and electricity in the economy and uses this as a proxy for emission levels. The changes from intermediate demand and final use are included. The limitation of this is that changes in the composition of demand for coal, petroleum and electricity will have an impact on the emission levels which this approach will not pick up.

2.4 Scenario modelling

The shocks in the various scenarios are modelled as follows:

- *Structural shifts* are modelled by relocating capital stock to the growing sector while keeping the total supply of energy unchanged.
- Improved *energy efficiency* is modelled by reducing the intermediate input use coefficient in the model.
- Changes in *investment required* are modelled by adjusting the investment level in the model. It is assumed that household and firm savings increase to finance the higher investment required.
- A sales tax is used to model the impact of a *CO_2 tax*. Two alternative scenarios are modelled here: It is first assumed that government invests the additional revenue and, second, that government use the additional revenue for tax relief. The tax relief is given to firms and households proportionally to their current tax contribution.

2.4.1 Start-now, Scale-up and Use-the-market scenarios

The mitigation scenarios Start-now (initial wedges), Scale-up (extended wedges), and Use-the-market (economic instruments with increased efficiencies) are modelled using the same approach as applied by Pauw (2007) in the static modelling process. The mitigation scenarios include structural shifts (for example switching from coal-fired electricity plants to nuclear poser stations), changes in energy efficiency and changes in investment required. The extent of the structural shifts, changes in energy efficiency and investment required differs from scenario to scenario. The main impacts of the three scenarios are set out in Table 3.

Table 3: Structural shifts

	Structural shifts in electricity generation	*Structural shifts in petroleum production*
GWC	Electricity from coal remains the most important method for electricity generation. However its importance starts to decline from the early 2020s. Nuclear power becomes more important from the 2030s but is still small. At the end of the period, electricity from coal still constitutes 80% of total output and nuclear about 15%.	Petroleum from oil is and remains the most important production method for petroleum. Its contribution to total petroleum supply increase marginally – in 2050 it accounts for 75% of total petroleum supply. The contribution of the other methods declines somewhat or remains constant.
Start-now	Electricity from coal starts to rapidly decline from 2010 onwards. Its contribution declines to 45% from 2030 onward. Electricity from nuclear and gas becomes more important: each contributes around 25% to electricity generation from 2030 onwards.	The contribution from petroleum from oil declines somewhat to 65% in 2050. The production of petroleum through coal-to-liquid is more important – its contribution increases to around 30% in 2050.
Scale-up	Electricity from coal declines from 2010 onwards. Its contribution is almost 0% in 2050. The contribution of nuclear power increases to about 50% in 2050 with the electricity from gas making up the rest (just below 50%).	The Scale-up picture is very similar to the Start-now picture. The importance of petroleum from oil is marginally lower, while the importance of petroleum from coal-to-liquid is marginally more important.
Use-the-market	The contribution of electricity from coal declines faster and reach almost 0% in 2040. Nuclear is more important, but only contributes 25% in 2050. Gas is the most important source for electricity generation (75%).	Petroleum from oil becomes significantly more important. In 2050 it represents 95% of petroleum production.

Table 4: Energy efficiency

	Energy efficiency in electricity use	*Energy efficiency in coal use*	*Energy efficiency in petroleum use*	*Energy efficiency in gas use*
Start-now	The energy efficiency of most industries in the use of electricity improves except for wholesale and retail trade. The industry with the largest improvement is 'other manufacturing' followed by non-metal products.	The energy efficiency in the use of coal improves for all industries.	The energy efficiency in the use of petroleum improves for wholesal and retail trade – there is also a slight improvement in the energy efficiency of services.	Not applicable
Scale-up	The same as Start-now	The same as Start-now	The same as Start-now	Not applicable
Use-the-market	The energy efficiency of most industries in the use of electricity improves except for wholesale and retail trade. The improvement is however much lower compared to Start-now and Scale-up.	Initially the improvement in energy efficiency in the use of coal is lower than when compared to Start-now and Scale-up. However since the mid 2040s there is a sharp increase in the efficiency of coal use.	The same as Start-now and Scale-up	Most industries see a decline in the efficienct use of gas from the mid 2040s onwards.

Required investment

Figure 1 shows the required investment by each of the scenarios. The required model is derived as input from the MARKAL model. The required investment in the Start-now scenario is lower than in the Growth without constraints (GWC) scenario as the improved energy efficiencies demand reduces demand and thus investment. In the Scale-up and Use-the-market scenarios the required investment is higher; it is the highest for the Scale-up scenario.

CO_2 taxes

In the Use-the-market scenario CO_2 taxes are imposed as a sales tax on the use of commodities producing high levels of emission including electricity, coal and petroleum. The purpose of this is to adjust economic behaviour by making the use of electricity, coal and petroleum more expensive. The tax increase rates are derived from the MARKAL model. There is a significant increase in the tax on coal (especially for the generation of electricity), and smaller increases in the tax on crude oil and gas (as seen in Figure 2). The revenue generated from the CO_2 taxes is modelled using two alternative scenarios: (1) to increase investment or (2) for tax-relief. The approach used to model CO_2 taxes is similar to the approach used by Devarajan et al (2009) where they model the impact of a carbon tax on coal, petroleum, and electricity. The results of Devarajan et al (2009) show that the carbon tax has a welfare loss, but much lower than the other taxes investigated (this includes a sales tax on energy use).

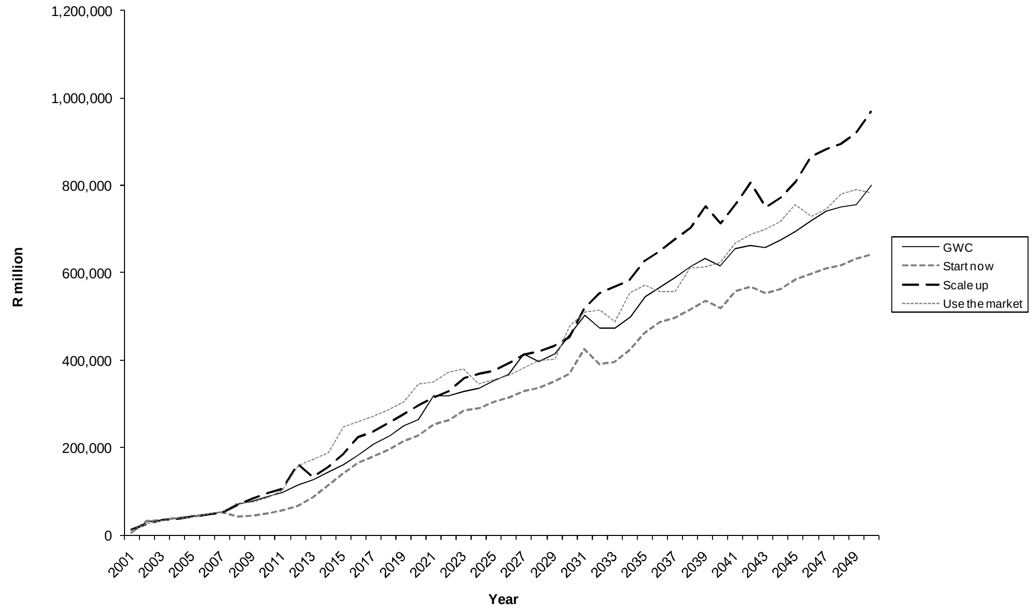

Figure 1: Required investment (in R million)

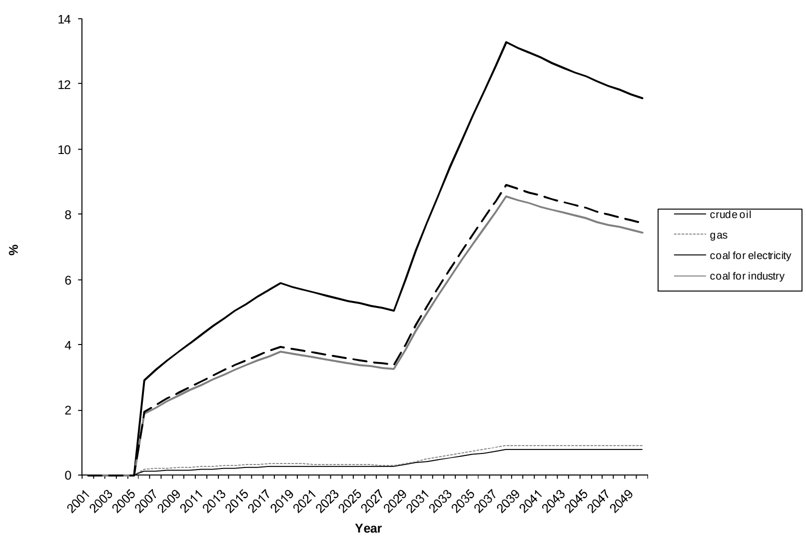

Figure 2: CO_2 taxes imposed in the Use-the-market scenario

2.4.2 Additional scenarios

Two sets of additional scenarios are conducted. The first set of scenarios estimates the impact of an increase in the capacity of the electricity from coal industry versus the electricity from nuclear industry and the electricity from,renewables industry. The purpose of these scenarios is to investigate the economy-wide impact of the three methods in generating electricity and to answer questions such as which is most costly, which industries would be affected, which labour groups would be influenced, and what the welfare impacts and the macro economic effects would be. In these scenarios it is assumed that the capital stock of electricity generation using coal, nuclear and renewables increases by R10 billion in 2010, respectively.

The last scenario conducted investigates the impact of a structural shift in the economy on energy demand and therefore emissions. A structural shift in the economy to a service based economy is imposed, while it is assumed that the contribution of the primary sector in the economy decline. It is assumed that the tertiary sector's productive capacity grow by R2 billion a year, while the productive capacity of the primary sector decline by R2 billion a year.

The impact of the additional scenarios is compared against the GWC scenario.

2.4.3 Closures and assumptions

The closures will be, as far as possible, kept in line with the closures used in the comparative-static modelling. The specific closures used will include the following:

1. The savings rate of households and firms will adjust to finance the higher investment levels.
2. The dynamic model makes provisions for specific levels of labour supply and unemployment for each type of labour. Semi-skilled and unskilled labour are unemployed, while skilled and high-skilled labour are very close to full employment. Employment levels will adjust for all types of labour until full employment is reached, whereafter wages will adjust. For skilled and high-skilled labour, wages will adjust sooner as these types of labour are much closer to full employment (a certain level of natural unemployment is assumed).
3. The exchange rate is flexible with a fixed level of foreign savings (fixed at the base growth path level).

3. Results

3.1 Start-now, Scale-up and Use-the-market Scenarios

GDP impact

The Start-now scenario shows a decline in GDP (compared to GWC) from 2008 until 2024 mainly due to the improved energy efficiency. The improved energy efficiencies lead to a decline in economic activity as the demand for electricity, coal and petroleum declines in intermediate use by industries. From 2024 onwards GDP (compared to GWC) increases, due to the positive impact on prices in the economy stemming from the improvement in energy efficiency. The prices of coal, petroleum, and electricity from nuclear and electricity from gas are lower. This translates into lower prices for most of the commodities in the economy. The commodities that do not see a decline in prices are electricity from coal, electricity from renewables, and commodities that are mostly sold to households (such as wholesale and retail trade, and services). The increase in the price of consumption goods is driven by higher demand. Consumption is higher in the Start-now scenario (compared to the GWC scenario) as investment is lower: households therefore need to save less to finance investment and consumption increase. This is a result of the closure rules used in the model: it is assumed that household savings adjust to finance additional investment and *vice versa*. As can be seen in Table 5 the decrease in GDP is mainly driven by higher consumption (compared to GWC), investment is lower (compared to GWC), while exports and imports decline. Exports decline as the price of exports decline. More goods are therefore sold domestically. Imports also decline as it is assumed that exports are the only source of foreign exchange to pay for the imports (assumed that foreign savings is fixed). Over the entire period average GDP is 0.06% lower when compared to GWC.

The GDP impact of the Scale-up scenario is positive (compared to GWC). The energy efficiencies in the Scale-up scenario are very similar to those in the Start-now scenario and one would have expected the GDP impact to show a decline initially, as was the case in the Start-now scenario. However, investment in the Scale-up scenario is significantly higher, so that the additional economic activity generated through the increase in investment outweighs the decline in economic activity from the improved energy efficiency. The improved energy efficiency and structural changes also result in lower prices for most commodities in the economy. The lower prices in this instance are further driven down by large declines in the price of capital (return on capital) due to higher investment. Some prices in the economy decline to a large extent (coal, petroleum from oil, petroleum from coal-to-liquid, petroleum from biofuels, and electricity from gas) but others, in turn, increase significantly (electricity from coal, electricity from renewables, and electricity from nuclear). Most investment and consumption industries also see an increase in prices. However, over the period the decline in prices outweighs the increase and there is an overall decline in producer prices. Initially consumption by households will fall as savings increase to finance the higher investment. However, consumption soon rises as the lower prices lead to an increase in demand. As can be seen in Table 5, the higher GDP is a result of an increase in consumption and investment. Over the entire period, average GDP is 1.26% higher when compared to GWC.

The GDP impact in the Use-the-market scenarios is the same whether the additional revenue from the CO_2 taxes gets reinvested or whether it is used for tax relief. The macroeconomic effect of the two scenarios is the same due to the assumptions of this model. When the additional revenue is reinvested it results in a decline in the required savings by households and firms, which is equivalent to tax relief extended in the second scenario. Investment levels in both cases remain the same, but the source of investment differs. In the reinvestment case governments invest the additional revenue, while in the tax-relief case the higher investment comes from firms and household who receive the tax relief. The main difference would be in the distributional and welfare impact as the people who save in the economy are not necessarily the same as the taxpayers. According to the SAM used, the high-income household group contributes 67% to total taxes paid by households, and 65% to total savings. The low-income group contributes 8.5% to total taxes paid by households and 8% to savings, while the middle-income groups contribute slightly more to savings compared to taxes (27% and 24%) respectively. Tax relief is therefore expected to benefit higher income households more, while the impact of the reinvestment scenario depends on industry structure.

In the Use-the-market scenarios, GDP increases sharply from 2010 to 2018 due to a sharp increase in investment. Although the GDP impact is still higher compared to GWC it declines from 2018 to 2036 due to a bigger decline in consumption. There is a short period where the GDP impact is lower when compared to GWC, however the GDP impact again rises from 2044 onwards. Over the entire period, average GDP is 0.73% higher compared to GWC, for both the Use-the-market scenarios.

The required investment levels as imposed in the model are somewhat higher than in the GWC scenario. However, the additional revenue generated with the CO_2 taxes results in even higher investment (either from the reinvestment or from tax relief to households and firms). This results in investment being significantly higher compared to GWC. Consumption will therefore decline as households need to save more to finance the increase in investment. Investment increases the capital stock in the model and will therefore increase production capacity in future periods. At the end of the period the taxes levied decline, causing the level of investment to decline. Exports increase initially as domestic prices rise (due to the increase in tax) relative to world export prices and more output is sold domestically. This results in a real depreciation of the exchange rate and a rise in imports. At the end of the period this is reversed due to domestic prices declining.

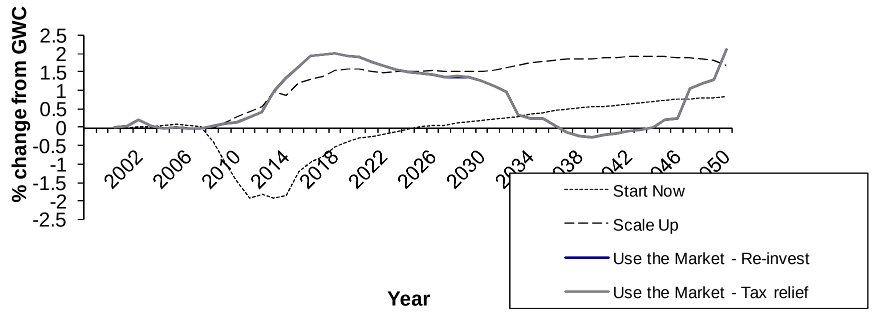

Figure 3: GDP impact (percentage deviation from GWC)

Table 5: GDP components (percentage deviation from GWC)

	2000-2004	*2005-2009*	*2010-2014*	*2015-2019*	*2020-2024*	*2025-2029*	*2030-2039*	*2040-2050*
Private consumption								
Start-now	-0.03	0.96	0.44	0.38	2.13	2.41	2.55	2.27
Scale-up	0.07	-0.09	-0.51	0.34	1.53	1.67	0.70	0.62
Use-the-market – reinvest	0.07	0.07	-1.37	-1.43	-0.03	-0.68	-1.23	-0.97
Use-the-market – tax relief	0.07	0.07	-1.37	-1.43	-0.03	-0.68	-1.23	-0.97
Gross fixed capital formation								
Start-now	0.19	-3.37	-6.97	-2.85	-3.97	-4.40	-4.96	-5.05
Scale-up	0.13	0.23	3.12	3.32	1.64	1.28	3.83	5.10
Use-the-market – reinvest	0.13	-0.10	4.62	7.67	4.63	5.32	3.68	3.96
Use-the-market – tax relief	0.13	-0.10	4.62	7.67	4.63	5.32	3.68	3.96
Change in inventories								
Start-now	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scale-up	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Use-the-market – reinvest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Use-the-market – tax relief	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Government consumption								
Start-now	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scale-up	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Use-the-market – reinvest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Use-the-market – tax relief	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	2000-2004	2005-2009	2010-2014	2015-2019	2020-2024	2025-2029	2030-2039	2040-2050
Exports								
Start-now	0.04	-0.74	-3.80	-2.50	-2.66	-2.58	-2.54	-2.08
Scale-up	0.04	0.04	1.31	1.78	0.57	-0.05	-0.20	-0.43
Use-the-market – reinvest	0.04	0.01	1.75	4.44	2.79	2.13	0.66	-0.54
Use-the-market – tax relief	0.04	0.01	1.75	4.44	2.79	2.13	0.66	-0.54
Imports								
Start-now	0.04	-0.53	-2.64	-1.73	-1.89	-1.93	-2.18	-2.00
Scale-up	0.05	0.03	0.91	1.23	0.40	-0.04	-0.17	-0.41
Use-the-market – reinvest	0.05	0.01	1.21	3.08	1.99	1.59	0.55	-0.52
Use-the-market – tax relief	0.05	0.01	1.21	3.08	1.99	1.59	0.55	-0.52
GDP								
Start-now	0.01	-0.23	-1.79	-0.77	-0.18	0.08	0.37	0.71
Scale-up	0.05	0.01	0.62	1.42	1.54	1.54	1.74	1.89
Use-the-market – reinvest	0.05	0.02	0.62	1.89	1.67	1.40	0.35	0.51
Use-the-market – tax relief	0.05	0.02	0.62	1.89	1.67	1.40	0.35	0.51

GDP industry impact

Table 6 shows the industry impact for the Start-now scenario. Electricity from gas, petroleum from coal-to-liquid, and electricity from nuclear are the industries that benefit the most in the Start-now scenarios. The industry that benefits the least is electricity from renewables, mostly due to the structural shifts imposed in the model. The industry seeing the largest percentage change compared to the GWC scenario is electricity from gas. However, this is mainly because it is from a very low base: electricity from gas is a very small industry.

Table 6: Start-now GDP industry impact (percentage deviation from GWC)

	2000-2009	2010-2019	2020-2029	2030-2039	2040-2050
Best performing industries (excluding electricity and petroleum industries)					
Metal industries	-0.64	-2.68	2.04	3.66	3.52
Water	0.22	-0.82	0.79	0.98	0.86
Worst performing industries (excluding electricity and petroleum industries)					
Machinery	-1.51	-4.56	-4.34	-4.70	-4.05
Other manufacturing	-0.92	-4.07	-4.09	-4.36	-3.79
Vehicles	-0.54	-3.67	-3.77	-4.17	-3.92
Construction	-1.99	-3.88	-3.38	-3.79	-3.69
Petroleum industries					
Petroleum from oil	-0.10	-6.58	-12.75	-12.70	-10.76
Petroleum from coal-to-liquids	0.01	41.80	242.75	340.73	341.20
Petroleum from gas-to-liquids	-0.65	-6.03	-16.48	-28.30	-37.24
Petroleum from biofuels	-0.16	-5.06	4.14	7.19	1.72

	2000-2009	2010-2019	2020-2029	2030-2039	2040-2050
Electricity industries					
Electricity from coal	-0.25	-11.97	-29.05	-33.93	-31.87
Electricity from nuclear	0.10	46.55	57.79	43.40	57.02
Electricity from renewables	1.81	-89.54	-85.08	-69.23	-98.79
Electricity from gas	0.18	589.07	2584.14	3416.93	3516.87

The GDP impact on industries in the Scale-up scenario is shown in Table 7. The industries that benefit the most from this are again electricity from gas, petroleum from coal-to-liquid, and electricity from nuclear. Other industries that are likely to benefit here are investment-oriented ones such as metals and construction, due to the significant increase in investment. Industries that do not benefit include electricity from renewables, electricity from coal, and petroleum from gas-to-liquid. This is again a function of the structural shifts imposed in the model.

Table 7: Scale-up GDP industry impact (percentage deviation from GWC)

	2000-2009	2010-2019	2020-2029	2030-2039	2040-2050
Best performing industries (excluding electricity and petroleum industries)					
Metal industries	0.06	4.25	6.01	5.89	3.79
Construction	0.17	2.90	1.64	3.88	5.53
Machinery	0.05	2.27	-0.07	1.57	2.30
Non metallic products	0.07	1.66	0.35	0.76	0.91
Water	0.02	0.61	1.73	0.94	0.57
Wholesale and retail trade	0.02	0.78	0.60	0.48	0.75
Worst performing industries (excluding electricity and petroleum industries)					
Fertiliser	0.02	-0.29	-3.18	-6.07	-6.02
Vehicles	0.02	1.18	-1.00	-1.63	-2.87
Beverages	0.02	-0.03	-0.98	-2.16	-2.35
Agriculture	0.02	-0.03	-0.53	-1.66	-1.80
Petroleum industries					
Petroleum from oil	0.12	-4.26	-12.66	-13.54	-11.34
Petroleum from coal-to-liquids	0.13	38.87	228.55	352.31	438.95
Petroleum from gas-to-liquids	-1.76	-10.81	-35.44	-56.23	-66.75
Petroleum from bio-fuels	-0.14	-4.90	-5.51	-6.40	-7.79
Electricity industries					
Electricity from coal	-0.19	-10.22	-27.90	-42.91	-75.51
Electricity from nuclear	0.16	50.68	60.96	89.89	278.35
Electricity from renewables	0.02	-92.04	-91.38	-65.35	-98.20
Electricity from gas	0.22	617.85	2589.14	3986.44	8559.62

The industry impact in the Use-the-market scenario is relatively the same as in the Scale-up scenario with the exception that investment industries such as metals, construction, and machinery benefit more from the additional revenue from the reinvestment of CO_2 tax revenue. Industries that benefit include electricity from nuclear, petroleum from coal-to-liquid, and petroleum from biofuels. When compared to the Scale-up scenario, the petroleum from coal-to-liquid industry benefits to a lesser extent. There is still a general move toward petroleum generated through coal-to-liquid processes compared to oil, but due to the higher coal taxes the increase in petroleum from coal-to-liquid is smaller. Petroleum generation through biofuels, however, now increases with more than in the Scale-up scenario as some substitution to this method of petroleum production is less costly in the presence of CO_2 taxes. Industries that do not benefit include electricity from coal, electricity from renewables and petroleum from oil. These industries' GDP is lower compared to the Scale-up industry. The industry results for the Use-the-market Tax Relief scenario are similar.

Table 8: Use-the-market GDP industry impact (percentage deviation from GWC)

	2000-2009	*2010-2019*	*2020-2029*	*2030-2039*	*2040-2050*
Best performing industries (excluding electricity and petroleum industries)					
Metal industries	-0.02	7.18	7.97	7.76	5.32
Construction	-0.04	5.95	5.10	5.55	6.77
Machinery	0.04	4.83	3.33	2.63	2.61
Other manufacturing	-0.02	3.93	3.08	2.90	2.14
Non metallic products	-0.01	3.24	2.46	1.21	0.53
Other services	0.03	-0.23	0.23	0.37	0.45
Worst performing industries (excluding electricity and petroleum industries)					
Fertiliser	-0.03	-1.56	-4.66	-9.57	-9.67
Agriculture	0.03	-0.60	-0.68	-1.94	-2.53
Beverages	0.03	-0.54	-0.75	-1.66	-2.02
Vehicles	0.03	-0.60	-0.68	-1.94	-2.53
Petroleum industries					
Petroleum from oil	0.07	0.41	-3.20	1.95	-1.10
Petroleum from coal-to-liquids	0.30	35.37	136.30	-24.08	136.20
Petroleum from gas-to-liquids	-1.38	-20.73	-47.27	-60.30	-70.86
Petroleum from bio-fuels	-0.01	-5.89	-6.12	18.73	23.21
Electricity industries					
Electricity from coal	-0.31	-12.75	-17.01	-80.31	-93.94
Electricity from nuclear	0.30	12.57	-27.93	146.59	149.72
Electricity from renewables	1.82	-88.36	-79.47	-38.89	-97.75
Electricity from gas	5.46	2047.64	5588.93	19019.63	27932.82

Employment and wages

The combined impact on employment and wages is shown in Table 9. In the Start-now scenario, wage income for high-skilled and skilled categories increases over the entire period (compared to GWC), while factor income for the semi-skilled and unskilled groups decline. This result follows the industry results. Industries that benefits in this scenario (such as petroleum from coal-to-liquid, petroleum from biofuels and electricity from nuclear) use high-skilled and skilled labour most intensively.

In the Scale-up scenario wage income for all labour groups increases even for the semi- skilled and unskilled. The semi-skilled and unskilled benefit in this scenario from the increase in investment. Investment industries such as construction and machinery use semi-skilled and unskilled labour most intensively. The construction industry for example uses 56.4% semi-skilled and unskilled labour in production and contributes 10.4% to total employment of semi-skilled and unskilled labour in the economy.

In the Use-the-market scenario the wage income for all labour categories increases initially. This is due to the additional demand from higher investment or tax relief. At the end of the period the wage income for high-skilled and skilled labour declines. These results also follow the industry results. Industries such as petroleum from gas-to-liquid, electricity from coal, and electricity from renewables employ high-skilled and skilled labour intensively.

Table 9: Employment and wage impact

Average over period (deviation from GWC)			
	Start-now	*Scale-up*	*Use-the-market*
High-skilled labour	*3.6*	*24.1*	*8.4*
Skilled labour	*8.8*	*29.4*	*8.8*
Semi-skilled and unskilled labour	*-11*	*17*	*13.7*

The returns to capital are higher in the Start-now scenario as investment is lower (14.7% on average over the period). In the Scale-up and Use-the-market scenarios the returns to capital are lower as investment is higher (-6.1 and -13.1% on average over the period). In the Scale-up and Use-the-market scenarios the demand for capital increase more. Industries such as petroleum from coal-to-liquid, electricity from nuclear, and the metals industry are capital-intensive and use 74.3%, 81.6% and 60.1% capital in their production respectively.

Household welfare

The equivalent variation measure (as shown in Figure 4) measures the welfare impact of the scenarios by measuring the change in utility for all household groups. The equivalent measure incorporates the welfare impact of changes in income and prices at a household level. In the Start-now scenario welfare for all households (over the entire period and compared to GWC) improves. The high-income household group sees the largest improvement in welfare as their income increased the most over the period. The high-income household group receives a large share of their income from high-skilled and skilled labour (70%). All households are better off due to the decline in prices from higher investment and improved efficiency.

In the Scale-up scenario the highest income group sees a decline in welfare due to lower returns on its capital. This household group receives 18% of its income from capital. In the Scale-up scenario the low-income group is the best off. Low income households receive most of their income (53%) from unskilled labour and are also most intensively employed in investment industries such as construction which benefit in the Scale-up scenario.

In the Use-the-market scenarios all households are better off. The high-income household group is marginally better off. The wage income of the high-income groups is higher, but the returns they receive on capital are lower. Most of the welfare impact for the high-income groups is from lower prices. In the tax-relief scenario high–income households are marginally better off when compared to the reinvestment scenario. This is because the high-income groups pays a larger portion of total taxes and therefore benefits more from the tax relief. In the reinvestment scenario low-income households are marginally better off, as they receive a large portion of their income from semi- and unskilled labour, which factor-income increase the most.

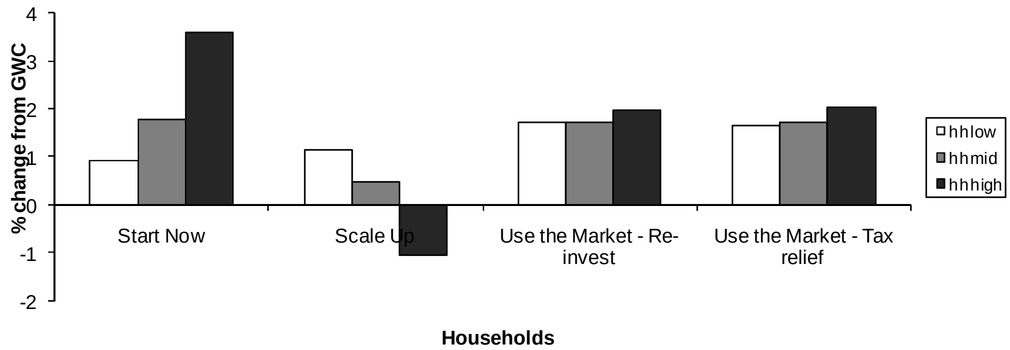

Figure 4: Equivalent variation (deviation from GWC)

Energy demand and emissions

Error! Reference source not found. shows the changes in energy demand for coal, petroleum and electricity. In the Start-now scenario the demand for coal, petroleum and electricity decline. The demand for coal declines with less compared to the other scenarios, while the demand for petroleum and electricity decline with more. This is due to improved energy efficiency in the use of petroleum and electricity. In the Scale-up scenario the demand for investment is higher (when compared to GWC and Scale-up) which leads to an increase in the demand for petroleum and electricity. Structural changes in the economy (away from coal) lead to a relative large decline in coal demand. In the Use-the-market scenarios the demand for coal decreases significantly mainly due to the demise of the coal industry. The demand for petroleum also decreases. However, in the Use-the-market scenario the demand for electricity increases (especially at the end of the period) due to an increase in demand for electricity from higher investment and exports.

The results are in line with results generated by Pauw (2007). Devarajan et al (2009) found that the impact of the taxes on GDP is negative and that the taxes have negative welfare impacts for most of the taxes investigated, especially when the tax revenue is used for tax relief. The dynamic CGE modeling results shows that when the tax is combined with the mitigating scenarios the net impact on GDP is positive through increased investment. It is also assumed that the tax revenue is channelled to either increased investment, or tax relief. Although the increase in GDP puts pressure on energy demand it is countered with the improved energy efficiencies as well as the CO_2 taxes assumed, so that the demand for coal, petroleum and electricity falls. It is expected that energy emissions will decline.

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	2000-2004	*2005-2009*	*2010-2014*	*2015-2019*	*2020-2024*	*2025-2029*	*2030-2039*	*2040-2050*
				Coal				
Start-now	0.032	-0.474	-3.138	-6.746	-8.476	-10.433	-11.835	-12.240
Scale-up	0.055	-0.041	0.039	-4.559	-7.417	-9.781	-13.028	-19.630
Use-the-market – reinvest	0.054	-1.294	-6.572	-9.268	-10.777	-12.035	-42.922	-64.800
Use-the-market – tax-relief	0.054	-1.299	-6.576	-9.268	-10.777	-12.036	-42.923	-64.802

Petroleum								
Start-now	0.037	-0.150	-1.980	-0.760	-0.552	-0.829	-1.804	-2.976
Scale-up	0.062	-0.037	-0.349	0.008	-1.591	-3.279	-3.970	-2.183
Use-the-market – reinvest	0.062	0.005	0.649	2.067	1.129	0.013	-1.622	-2.587
Use-the-market – tax-relief	0.062	0.002	0.645	2.066	1.129	0.013	-1.623	-2.590
Electricity								
Start-now	0.011	-0.382	-4.343	-5.670	-5.161	-4.746	-5.974	-6.452
Scale-up	0.038	-0.315	-2.348	-3.637	-3.489	-3.536	-5.399	-6.176
Use-the-market – reinvest	0.039	-0.408	-1.341	2.720	9.051	13.599	16.536	12.142
Use-the-market – tax-relief	0.039	-0.415	-1.348	2.720	9.051	13.599	16.534	12.137

When the mitigation scenarios is combined with a CO_2 tax the results indicate that the CO_2 tax is effective in reducing output of CO_2 producing industries as it changes the relative price of the commodities produced by these industries. However, the sales tax is distortionary as it introduces price wedges in the economy while consumers may end up paying large portions of the tax. However, this is negated to some extent if the tax revenue from the carbon tax is allocated to tax relief.

3.2 Additional scenarios

3.2.1 The impact of additional capacity in coal versus nuclear electricity generation

The productive capacity of electricity generation by coal and nuclear is increased by R10 billion in 2010 in each scenario, respectively. The purpose of these scenarios is to see how the distributional impact of the two scenarios differs. The relative impact of the increase in capital stock is largely determined by the structure of the two respective industries. The electricity from coal industry supplies 93% of electricity, while the electricity from nuclear industry supplies 5%. The value added in both industries is very similar; value added in the electricity from coal industry is slightly higher at 55% compared to 54% in electricity from nuclear. The electricity from coal industry uses commodities from more industries in the generation of electricity, with large inputs from coal itself, construction, other manufacturing, electricity, and services. Large inputs into the electricity from nuclear industry are petroleum, construction, other manufacturing, and electricity. The electricity from nuclear industry is more capital-intensive than the electricity from coal industry (81% compared to 78%). High-skilled labour is used more intensively by the electricity from nuclear industry (14% compared to 10%). The electricity from coal industry uses unskilled labour more intensively (8.5% compared to 2.3%).

The macroeconomic impact of the two scenarios is very similar. In 2010 GDP increases by almost 0.25% as a result of the increase in capital stock. The additional capital stock increases the productive capacity of the economy and GDP remains higher than GWC for a time until it returns to GWC levels in the late 2030s. Over the entire period, average GDP is 0.02% higher compared to GWC. The increase in GDP is mainly driven by higher consumption, as the additional capital stock results in an increase in employment and wages and, therefore, disposable income. Lower prices from the increase in the supply of electricity also stimulate consumption. In the electricity from coal scenario the higher consumption is mainly due to lower electricity prices, while in the nuclear scenario it is mainly due to higher wages. Exports also increase as the lower electricity prices lower domestic prices relative to world prices resulting in a real exchange rate depreciation. Imports also increase, as more foreign exchange is available from the higher exports to finance imports. Imports increase with marginally more in the nuclear scenario indicating that electricity from nuclear may be marginally more import-intensive than electricity from coal.

Most industries benefit from the increase in the capacity of the electricity from coal industry, for the following reasons:

- The electricity from coal industry has large backward linkages with other industries. As output here increases it will need more intermediate goods. The industries that supply intermediate goods such as coal, construction, other manufacturing, electricity, and services to the electricity from coal industry, benefit.
- The electricity from coal industry supplies a large portion (93%) of the total electricity supply. The increase in supply of electricity from coal will therefore have a large price impact on the economy. Most industries that use electricity in its production process benefit from this, including metals, mining, pharmaceuticals, electricity from coal, wholesale and retail trade, and services.

The electricity from nuclear industry does not benefit from the increase in the capacity of the electricity from coal industry as there is substitution away from it to the cheaper electricity from coal. The GDP impact on industries from the increase in the capacity of the nuclear industry is similar to that of an increase in the capacity of electricity from coal. The backward linkages between the electricity from nuclear industry and the electricity from coal industry are very similar except for coal used in the 'electricity from coal' industry. The demand for all energy sources increase as the economy expands.

3.3 The impact of a structural shift in the economy from the primary to the tertiary sector

This scenario assumes that there is a structural shift from the primary sector to the tertiary sector in the economy. From 2001 onwards it is assumed that the capital stock of the tertiary sector increases by R2 billion per year, while the capital stock of the primary sector decline by R2 billion per year. The aim of this scenario is to see whether this structural shift in the economy will lead to changes in energy demand and therefore emission levels.

The GDP impact is initially positive as consumption and exports increase. However, from 2024 GDP is lower when compared to the GWC scenario. Over the entire period average GDP is 0.05% higher when compared to the GWC scenario. The increase in production capacity of the tertiary sector leads to an increase in supply, which in turn leads to an increase in employment and income. Prices will also go down as the returns to capital in the tertiary sector fall. The combined impact of higher income and lower prices leads to an increase in consumption. Since the tertiary sector sells more output to households compared to the primary sector, household consumption would therefore not be influenced as much by the rise in prices in the primary sector. The tertiary sector also employs high-skilled and skilled labour more intensively compared to the primary sector. The primary sector combined employs 24.9% and 8.6% high-skilled and skilled labour as a percentage of total factor use, compared to the tertiary sector that employs 59.1 and 31.9%, respectively. The tertiary sector is also a larger employer of high-skilled and skilled labour and employs 80.2% and 87.3% of total high-skilled and skilled labour in the economy. Higher income in the tertiary sector is therefore expected to outweigh the decline in income from the mining industry.

The mining industry is an important earner of foreign exchange in the economy and the decline in mining exports is expected to influence the real exchange rate. Exports of the mining industry in 2000 contributed 33% to total exports in the economy compared to the tertiary sector that contributed 13%. Initially exports increase as the increase in exports in the tertiary sector outweighs the decline in exports from mining. However, mining exports start to decline rapidly as the real exchange rate appreciates and the price of mining commodities relative to international prices increase. This also impacts negatively on tertiary sector exports and from 2024 total exports decline.

Inter-industry linkages influence the impact of this scenario on the various industries. One would have expected agriculture to decline and wholesale and retail trade and services to increase more. The mining industries also show a larger decline than expected. The reasons for this are that (1) agriculture is used intensively in industries such as food and beverages that benefit from the increase in consumption; (2) wholesale and retail trade and services do not benefit as they are used by industries such as petroleum from coal-to-liquid, and petroleum from gas-to-liquid; and (3) the mining industries decline more than expected due to a large decline in exports especially from 2024 onwards. Industries that benefit in this scenario are those that sell mostly to consumption, including food and beverages, industries that supply the inputs into these industries such as machinery, and industries that use services (wholesale and retail trade and other services) intensively in their own production processes. These industries benefit from the lower prices associated with the service industries. Industries that do not benefit are either used intensively in the production of mining commodities or suffer from the real exchange rate appreciation (from 2024 onwards).

Employment and wages increase initially as the tertiary sector is a larger employer than the primary sector. The tertiary sector also employs high-skilled and semi-skilled labour more intensively and these labour groups see a large increase in factor income. The semi-skilled and unskilled labour group benefit more than expected since they are more intensively employed in the primary sector. However, other industries that benefit such as construction and the metals industry also employ semi-skilled and unskilled labour intensively. At the end of the period all labour categories see a decline in wage income as exports declines

The demand for coal, petroleum, and electricity initially rises as the services sector (and the economy) expands. However, with the decline in mining the demand for all these commodities starts to decline. The demand for coal and electricity declines the most, as it is intensively used in the mining industries.

4. Summary and conclusions

The GDP impact in the Start-now scenario is lower when compared to the GWC scenario. This is because the increased energy efficiencies result in a contraction of economic activity as less electricity is used. This is accompanied by a loss of wage income due to lower employment and wages for semi-skilled and unskilled labour. However, most households are better off due to lower prices in the economy from the increased energy efficiencies.

The GDP impact in the Scale-up scenario is higher when compared to the GWC scenario. The impact of the substantial increase in required investment in this scenario outweighs the decline in economic activity associated with the increase in energy efficiency. Wage income for all household groups increases; return on capital is lower due to the increase in investment. This results in higher-income households not benefitting from this as they receive most of their income from capital. The low-income household group benefits the most as they are intensively employed in investment-oriented industries.

The GDP impact in the two Use-the-market scenarios are very similar, as the adjustment mechanisms in the model results in the same macroeconomic impact. The GDP impact is higher compared to the GWC scenario due to the increase in investment. Investment is higher due to firstly, higher required investment and, secondly, higher investment associated with the CO_2 taxes levied. The CO_2 taxes levied are either reinvested or the tax relief extended generates higher savings by firms and households, which in turn generates higher investment. The higher investment again results in a decline in the return on capital. Wage income rises especially for the semi-skilled and unskilled labour groups as they are intensively employed in the investment-oriented industries. There are marginal differences in the distributional impact. In the tax-relief scenario the high-income households are marginally better off, while low-income households are marginally better off in the reinvestment scenario. All household groups are better off, with the high-income households best off when compared to the GWC scenario.

There is a general decline in the demand for coal and petroleum in all the scenarios. The decline in demand for coal is the largest in the Use-the-market scenario. Demand for electricity increase in the Scale-up and Use-the-market scenarios due to the large increase in investment and exports associated with these scenarios.

In conclusion: A CO_2 tax may not be the most appropriate tool to achieve the desired results considering the economic development objectives of South Africa if it leads to higher prices for energy. However, as seen from the results, if the CO_2 tax is combined within the LTMS framework its negative impact is negated through higher investment and GDP growth. The mitigation scenarios have a positive impact on GDP when investment is large as is the case with the Scale-up scenarios. Although economic activity initially declines due to improved energy efficiency, it is followed by a period of economic expansion as lower prices increase output in most industries – this is especially the case when it is combined with higher investment. When CO_2 taxes are levied the economic impact is again positive if this is combined with either tax relief or reinvestment of the additional tax revenue.

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