Economy-wide Modeling

An input into the **Long Term Mitigation Scenarios** process

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The suite of reports that make up the Long Term Mitigation Scenario study include the following:

A	Long Term Mitigation Scenarios for South Africa
B	Technical Summary
C	Technical Report
C.1	Technical Appendix
D	Process Report

The study was supported by the following inputs:

LTMS Input Report 1: Energy emissions

LTMS Input Report 2: Non-energy emissions: Agriculture, Forestry and Waste

LTMS Input Report 3: Non-energy emissions: Industrial Processes

LTMS Input Report 4: Economy-wide modeling

LTMS Input Report 5: Impacts, vulnerability and adaptation in key South African sectors

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1. Economy-wide Analysis

1.1 Introduction

Climate change mitigation actions have various important implications for the economy. This section reports on results from a series of model simulations examining the economic impacts of mitigation scenarios. The scenarios were developed by the Scenario Building Team (SBT) of the Long-Term Mitigation Scenarios (LTMS) project. The economic analysis follows directly from the energy modelling part of the study, i.e. the implications of various mitigation scenarios for the South African energy system were explored using the MARKAL energy model. Results from this model was then used to inform various policy shocks in an economy-wide model. Thus, the economic model is linked to the energy modelling in a 'top-down' fashion, using key outcome variables from the energy model to define 'shocks' for the economic model.

Given the complexity of scenarios it is necessary to employ a comprehensive economic framework that models interactions between a variety of economic agents, including productive sectors, factors of production (capital and labour), households, incorporated business enterprises, government and the rest of the world. Econometric models, while generally more suitable for making longer term predictions given their focus on trends in economic variables, are usually unable to deal with highly detailed interaction effects. Since policy makers are keen to understand impacts on economic institutions and agents that are too disaggregated for an econometric model, this study opts for a computable general equilibrium (CGE) model. CGE models are economy-wide models that take into account aspects of microeconomic behaviour of producers and households, while maintaining macroeconomic constraints fundamental to economic accounting systems. These models incorporate representations of all markets, including commodity markets, factor (labour) markets and international trade.

CGE models are, however, not very suitable for predictions over long periods of time, given model complexity, and various restrictive assumptions regarding rigidities in the structure of the economy and relationships between economic agents. Instead, these models are useful for showing how one state of the economy may differ from another state in terms of numerous economic variables. Sadoulet and De Janvry (1995:287) write about input-output models that they are "*more useful as guidelines to potential linkage effects* ... [rather] *than as predictive models*". This also applies to CGE models, which fall in the same class as input-output models. In this study we adopt an approach whereby we report on changes in various key economic variables – in particular, gross domestic product (GDP), employment and household welfare levels – relative to a so-called 'business as usual' *reference case*. Following the MARKAL model time horizon, results are generated for selected years over the period 2005 to 2050. However, we only report the results for 2005, 2010 and 2015 given that CGE models are fairly restrictive as far as long term prediction is concerned. More detail about the modelling approach is supplied in section 1.2.3

Most mitigation strategies require large investments in the economy that may have a number of spin-off effects. Ignoring financing requirements for the moment, the immediate effect of an increase in investment is observed as an increase in demand for investment-type goods such as machinery and equipment, or investment-related services such as building and construction works. Those sectors supplying these investment-type goods and services are the immediate beneficiaries of increased investment demand. These sectors react by increasing production in order to satisfy this additional demand, subject of course to production constraints in the economy and also the share of newly demanded investment goods that are imported. The increase in demand for investment goods is only observable during the 'current' economic accounting period or the 'construction phase'. For this reason the first-round or direct effect of an initial investment demand shock is regarded by economists as having only a 'temporary' demand-driven impact on production and employment levels, and mainly in those sectors that supply the investment-type goods and services. Given inter-industry linkages in the economy some downstream effects can also be observed, for example in those sectors that supply intermediate inputs to the primary beneficiary sectors.

The long term effects associated with investments only become observable once investments have been converted to installed production capacity or improved production processes. This effect is very different in nature from the direct short-run effects associated with the initial investment in that the structure of production is now altered, either due to changes in production relationships (e.g. production technology changes or efficiency enhancements) or due to changes in the levels of capital stock employed in productive sectors (production capacity changes). Therefore, while the short-run investment effects are simply modelled as changes in current-period investment demand, the long term effects, require slightly more complex modelling, i.e., production relationships in the model have to be altered. Experience has shown that shifts in current investment levels generally only have small compositional effects in the economy. The real interesting effects are caused by the permanent long-term structural effects (see for example Van Seventer and Davies, 2006).

While we do account for the short-run effects of changes in investment levels in the simulation setup, we are more interested in two types of long-term effects that ultimately overshadow the investment results. The first is **increased energy efficiency** in the mining, manufacturing, commercial and transport sectors. Energy efficiency can be understood as a special type of production efficiency, and is modelled as a reduction in the use of ‘energy inputs’, including coal, petroleum (liquid fuels), gas or electricity, per unit of output. In some of the scenarios considered, fuel switching also takes place.[1] For example, a shift towards electrified transport may reduce petrol or diesel use in the transport sector, but electricity use per unit of output increases. In a fuel switching scenario any efficiency gains in terms of the use of one type of energy input will be offset by increased usage of another, which in a modelling sense would appear like increased inefficiency. Ultimately, overall efficiency changes in a sector will depend on whether production costs under energy efficiency and fuel switching scenarios increase or decrease (see section 1.2.3.1).[2]

A second long-term effect relates to **changes in production capacity**. In the context of energy research we are concerned here with investments that lead to increased production capacity in production processes that are more environmentally friendly. For example, under a strategy whereby electricity supply from renewable sources or nuclear power is increased, the production capacity, measured in terms of capital stock employed in these two electricity sub-sectors (plant, machinery and equipment) are likely to increase. Increased production capacity in nuclear and renewables implies not only an increase in output from these sectors, but also a relative reduction in output from coal power stations, i.e. the output share of coal-fired electricity plants declines. In a comparative static modelling context, such as our CGE model, we model relative production capacity shifts rather than absolute changes in production capacity. In this study we refer to this as structural shifts in the energy output mix.[3] The reason for this approach is explained further in section 1.2.3.2.

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[1] When referring to ‘energy efficiency’ scenarios or ‘wedges’, we imply that this may include fuel switching as we ll. A more apt description would perhaps be ‘changes in intermediate input requirements per unit of output’.

[2] Section 1.4.1 summarises findings from earlier CGE analyses of the energy efficiency ‘wedges’, and specifically considers effects of industrial and commercial energy efficiency in terms of coal and electricity use in mining, manufacturing and commercial sectors.

[3] Section 1.4.2 reports on selected findings from earlier analyses (using a SAM multiplier model) of various structural change ‘wedges’, in particular renewables and nuclear intensive scenarios for the electricity sector, and a biofuels scenario for the petroleum sector.

Three mitigation scenarios are modelled: '***Start Now***' (initial wedges), '***Scale Up***' (extended wedges) and '***Use the Market***' (economic instruments with increased energy efficiency).[4] These are the same scenarios that are simulated in the MARKAL energy model. Selected MARKAL model results are used to inform shocks for the economic model. These results include changes in the energy supply mix (structural shift scenarios), changes in energy efficiency or fuel switching, and capital outlay or investment requirements of alternative scenarios. Both the *Start Now* and *Scale Up* scenarios are made up of combinations of energy efficiency gains and structural shifts energy supply sectors, while the *Use the Market* scenario adds the use of economic instruments, in particular a tax on CO_2 emission.

By assumption, energy efficiency gains are achieved in virtually all the economic sectors in the economy, grouped here into mining, manufacturing, commercial and transport sectors. As far as structural shifts in energy output mix is concerned, we focus on two sectors, namely the electricity and petroleum sectors. In the case of the electricity sector, we consider structural shifts between electricity supplied in coal-fired plants, nuclear plants, electricity from renewable sources and from gas turbines. For the petroleum sector we allow for structural shifts in the output mix of crude oil refineries, coal-to-liquids (CTL) plants, gas-to-liquids (GTL) plants and from biofeuls. In each instance we compare simulated results for various selected years against a 'business as usual' reference case in a comparative static fashion.

The results from the *Start Now* and *Scale Up* scenarios are reported separately from the *Use the Market* results. This is done for a number of reasons. Firstly, the *Use the Market* scenario considers rather extreme structural shifts in output mix. Hence results from this scenario are at a different scale in terms of percentage changes, and therefore not directly comparable with the moderate switching in the other scenarios, which in itself offers policy makers some insight into possible adjustment processes. Secondly, as far as the energy efficiency components are concerned, the scenario is also rather different in that it assumes the future availability – most likely via imports – of natural gas as a viable alternative to coal. It therefore includes substantial fuel switching. Thirdly, the use of a tax instrument makes this scenario very different from the others, and hence their economic impacts are expected to be dissimilar.[5]

The *reference case* against which outcomes under the mitigation scenarios are compared, also assumes some structural shifts in output supply over time that are required in order to meet future energy demand. These shifts obviously involve much less 'decarbonisation' than the mitigation scenarios. We therefore adjust the reference case to reflect these structural shifts in the energy sector. MARKAL model results are further used to determine how the mitigation scenarios differ from the reference case in terms of investment requirements (capital outlay), energy efficiency gains or fuel switching, and, in the case of the *Use the Market* scenario, tax instruments.

This report is structured as follows. Section 1.2 introduces the modelling approach, giving a more detailed description of CGE models and the type of results that they generate, as well as the mitigation scenarios and how these are simulated. Section 1.3 analyses the CGE model simulation results of the *Start Now*, *Scale Up* and *Use the Market* scenarios. Section 1.4 is a summary of results from simulation runs done for previous SBT meetings, specifically various 'individual wedges' (see footnotes 2 and 3). Additional figures and tables are included in section 1.5, which serves as an appendix to this part of the study.

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[4] These scenarios were also previously called the *Start Now*, *Scale Up* and *Use the Market* scenarios.

[5] As part of the background analyses we also looked at the pure economic effects of a CO_2 tax in the absence of structural shifts and energy efficiency. Results from this analysis is reported on in section 1.4.3.

1.2 Modelling Approach and Scenario Description

1.2.1 Objectives

The objective of this analysis is to develop a better understanding of the likely impact that various mitigation options may have on the economy in terms of GDP, employment and household welfare. As noted in the introduction, outcomes of three mitigation scenarios, *Start Now*, *Scale Up* and *Use the Market*, are evaluated. These mitigation scenarios are combinations of different degrees of energy efficiency that can be achieved, structural shifts in energy output mix and, in the case of the latter scenario, economic instruments used to reduce emissions. Results are compared in comparative static fashion against a 'business as usual' *reference case* called growth without constraints (GWC). This remains a scenario analysis, and by no means can we claim that results are necessarily an accurate reflection of the true outcome. Given the long time horizon and the multitude of economic variables and parameters that may change over time and impact on each other, not to mention factors external to the South Africa economy that cannot be controlled, it is unwise to have too much confidence in results. However, the exercise remains useful. We are upfront about the limitations, the assumptions and the methods used to arrive at results, and given these, the scenario analysis provides a useful starting point for policy discussions around possible outcomes under various different mitigation scenarios for South Africa.

1.2.2 Model and Data

The study makes use of the Standard General Equilibrium (STAGE) model developed by McDonald (2006). This model is calibrated with a Social Accounting Matrix (SAM) for South Africa with base-year 2000, which was compiled by the Western Cape Department of Agriculture (PROVIDE, 2006). This section contains detailed descriptions of the CGE model and SAM data, with a specific focus on adjustments made to the SAM in order for mitigation actions to be analysed more accurately.

1.2.2.1 CGE Modelling Overview

The STAGE model is a member of the class of single country CGE models that are descendants of the approach to CGE modelling described by Dervis et al. (1982). The model adopts the SAM approach to modelling (see Pyatt, 1998). CGE models combine the productive sectors or activities with commodity and factor markets, and also draw linkages between these markets, domestic institutions (households, government and incorporated business enterprises) and the rest of the world. Essentially, CGE models are an extension to simpler IO or SAM-multiplier models. The main differences are the introduction of flexible prices and a variety of substitution mechanisms that allow for a more realistic or accurate representation of economic behaviour in response to relative price changes as opposed to the strict 'linearities' and fixed prices found in multiplier models.

What further makes CGE models unique is that they are macroeconomic or economy-wide models that are based on neoclassical microeconomic foundations. Agents optimise behaviour subject to constraints; for example, households (or consumers) maximise utility subject to prices and a budget constraints, while producers (or activities) maximise profits subject to a production technology constraint. Equilibrium is reached when supply equals demand in all the commodity and factor markets simultaneously, subject to 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).

CGE models are set up with a range of flexible macro adjustment or closure rules. These define the way in which various of the macro-equilibriums are reached, based on beliefs or assumptions about how the economic system operates. The closure rules for this particular study are discussed in section 1.2.3.5, while a more detailed description of CGE models and their limitations is available in the technical appendix of the SBT 5 report.

1.2.2.2 A South African Social Accounting Matrix and Activity Account Disaggregations

When economic agents are involved in transactions with each other, financial resources exchange hands. The objective of a SAM is to capture all these financial resource flows in the economy that take place in a certain period (usually a year or representative year). As such a SAM provides a snapshot picture of the economic and social structure of an economy over that period. It also provides the statistical basis for economic models (King, 1985). A SAM contains information about productive activities in the economy, along with information from non-productive institutions such as factor markets, capital markets, households, government and the rest of the world.

A detailed explanation of a SAM structure, the underlying accounting principles and details of the accounts used in this study is included in the technical appendix of the SBT 5 report, while Table 9 in section 1.5 of this report includes a full listing of the commodity, activity, factor and household accounts. For the purpose of understanding the simulation exercises in this study a proper understanding of how information on the productive sectors, represented in a SAM by so-called activity accounts, are captured. Any firm produces goods by combining intermediate inputs (various commodities that form inputs into the production process) and factors of production. Factors of production may include land, capital and labour, and the combined contribution (in terms of production values) of these factors are called value added. An example of how the production structure is modelled in a CGE model appears in Figure 2 in section 1.2.3.1. The SAM captures information on each activity's use of intermediate inputs and employment of factors of production.

One of the important mitigation options explored in this study is shifting the energy output mix from carbon-based processes towards more environmentally friendly processes. Large shifts are particularly expected to take place within the electricity and petroleum sectors. In the original SAM these two sectors are not disaggregated any further into different types of production processes. However, in order to effectively explore structural shifts in the energy output mix, it is necessary to specify sub-processes. Hence, four different types of liquid fuels production activities and four types of electricity generation processes are created, which are now essentially sub-activities of the original petroleum and electricity activities respectively:

- Petroleum sector: (1) crude oil refineries, (2) gas-to-liquids (GTL), (3) coal-to-liquids (CTL) and (4) biofuels.
- Electricity sector: (1) coal-fired power plants, (2) nuclear power, (3) renewable energy sources and (3) gas turbines.

In order to disaggregate the petroleum and electricity activity accounts it is necessary to understand precisely how the production processes differ in terms of their use of intermediate inputs, the returns to capital, the labour intensity of production and the skills composition of employment. The intermediate input use and employment data in the PROVIDE SAM is based on Statistics South Africa's Supply and Use Tables for 2000 (SSA, 2003) and the Labour Force Survey for September 2000 (SSA, 2002). In both these datasets the electricity and petroleum industries are separate sectors. No further disaggregation is available in any of the national statistical databases. Hence, information had to be sourced from industry associations and firms that operate within these industries.[6] Unfortunately, firms were generally unable or reluctant to release data and a range of assumptions had to be applied where data was unavailable.

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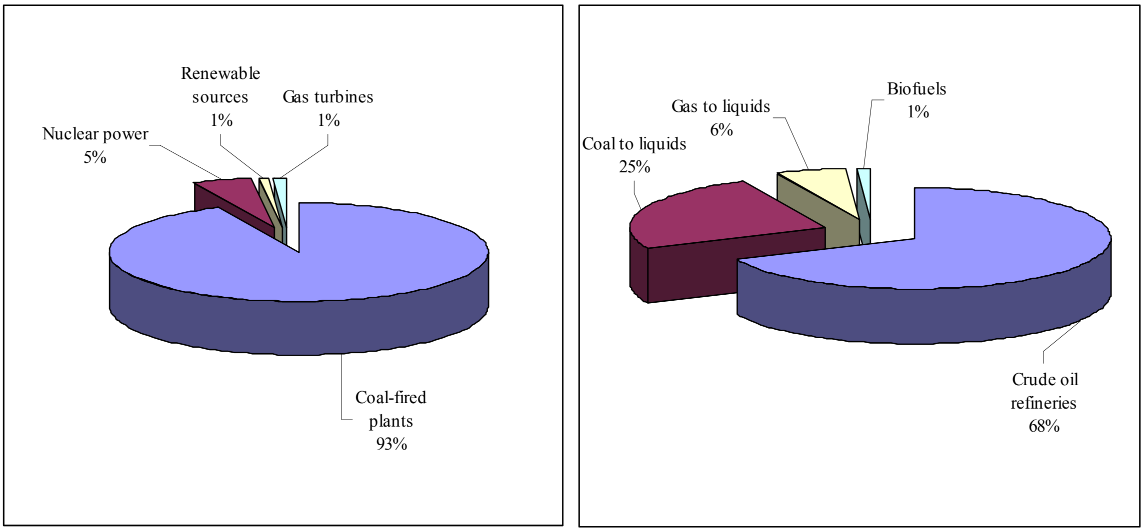
[6] It is a consistency requirement that the disaggregated accounts based on this new information add up to the original aggregate electricity and petroleum accounts which is achieved by means of appropriate scaling.

The main corporations in the South African petroleum industry are members of the South African Petroleum Industry Association (SAPIA). Data from this association was used to obtain liquid fuel output shares for crude oil refineries, CTL plants, GTL plants and biofuels. Figure 1 shows the output shares for petroleum (and electricity – see discussion further below) that was applied to the SAM. SAPIA, however, does not have the mandate to divulge firm-level information on intermediate input usage and employment within each of these processes. Consequently we had to rely on firms' *Annual Reports* and other information sources. Very few firms report on intermediate input usage in the way that it is captured in a SAM, and hence for this part of the data disaggregation we had to rely on a number of assumptions. Fortunately, however, the various production technologies are relatively easy to deduce in terms of the main inputs they use. Crude oil refineries consume all the crude oil in the economy, the CTL process (represented by Sasol) consumes virtually all the coal demanded by the petroleum sector, while GTL (represented by PetroSA) consumes virtually all the gas used in the petroleum industry.[7] Finally, all agricultural inputs (field crops in particular) demanded by the petroleum industry is allocated to biofuels.[8] The remainder of intermediate inputs, which only account for a small portion of overall expenditure on intermediate inputs, was allocated across the sub-industries using the output shares shown in Figure 1.

Figure 1: Energy Output Shares in Base SAM: Electricity and Petroleum Sectors



Source: South African SAM 2000

Since no information could be obtained on differences in labour intensity across the various sub-industries in the petroleum sector, total employment figures are assumed to be directly proportional to the output shares. As far as skills composition is concerned, external data sources were consulted. In particular, drawing on research published by the International Labour Organisation (ILO) on employment and refinery performance, information on skills breakdown at large and small refineries could be found.[9] The occupation categories in this study were

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[7] Natural gas is included under 'other mining products' in the SAM.

[8] Biofuels as a fuel source was virtually non-existent in 2000, which is the base year of the SAM. As a result expenditure on agricultural goods by the petroleum sector was very low and had to be increased if we wanted to assume a 1 per cent output share for biofuels. Hence, some data manipulation was required to produce realistic agricultural input data associated with a 1 per cent biofuels share. However, this did not alter the total output of the agricultural in any meaningful way.

[9] See www.ilo.org/english/dialogue/sector/techmeet/tmor98/tmorr.htm.

mapped to four skills groups used in the SAM to obtain an indication of the skills composition for typical refineries.[10] For CTL technologies the SASOL *Annual Report* for 2006 was used.[11] The social performance section in the report provides a breakdown of employment by skill levels, and these are then mapped to the SAM labour accounts to obtain an estimate of the skills composition in CTL technologies. This same skills composition is assumed for GTL technologies as PetroSA was unable to provide the relevant information. Finally, for biofuels, we assume that employment is biased towards lower skill levels relative to the other sub-industries in the petroleum sector.[12] Table 1 shows the resulting skills composition in the sub-sectors of the petroleum account.

Estimates of total value added were obtained by multiplying the employment levels with the average wages in the petroleum sector as reported in the original SAM. This assumption implies equality of wage rates across the four petroleum sub-sectors. Returns to capital (GOS) was allocated across sub-industries using output shares.

Table 1: Skills Compositions for Petroleum Account Disaggregation and Original SAM

	Crude oil	CTL	GTL	Biofuels	SAM (apetro)
High skilled	30%	29%	29%	17%	30%
Skilled	23%	15%	15%	13%	21%
Semi-skilled	44%	47%	47%	50%	45%
Unskilled	3%	9%	9%	19%	5%
	100%	*100%*	*100%*	*100%*	*100%*

Source: Author’s calculations and South African SAM (2000)

Data from Eskom was used as the primary source of information for the disaggregation of the electricity sector. Eskom supplies over 90 per cent of electricity in South Africa. It was not possible to obtain disaggregated data on intermediate input use, and hence a number of assumptions had to be made about the main types of inputs under each of the four electricity production processes. We consider coal-fired plants, nuclear plants, renewables and gas turbines. All the coal used by the original electricity activity in the SAM was allocated to coal-fired electricity plants. The imported nuclear fuel used at Koeberg is captured under petroleum products account (this is in line with the standard industrial classification scheme used in South African production statistics), hence almost all the expenditure on ‘petroleum’ is allocated to nuclear power plants. Natural gas is included under ‘other mining products’ in the SAM, and all the industry’s expenditure on other mining is allocated to gas turbines. The remainder of intermediate inputs was allocated across the sub-industries using output shares obtained from production capacity of various types of electricity plants owned by Eskom (see Figure 1 above).

Information on labour intensity or ‘jobs per megawatt installed capacity’ is obtained from a report by AGAMA (2003), which draws on Eskom for employment figures in various plants in 2003 and other energy statistics. We use the AGAMA study ‘operational’ employment estimates. In particular, the study finds that there are on average 0.93 jobs/MW in coal-fired plants, 0.54 jobs/MW in nuclear plants, 1 job/MW in renewable energy[13] and 0.13 jobs/MW in

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[10] Labour is disaggregated into high-skilled, skilled, semi-skilled and unskilled workers. Table 9 in section 1.5 provides a detailed listing of all the accounts in the SAM.

[11] Available online at www.sasol.co.za.

[12] This assumption was made after discussions with two experts, Bamikolo Amigun and Harro von Blottnitz, from UCT’s Department of Chemical Engineering.

[13] The study reports separate employment multipliers for hydro, pumped storage and solar energy sources. A simple weighted average employment multiplier is derived and used in the calculations here.

gas turbines. These direct employment multipliers were used to estimate total employment in each of the four electricity sectors given known output shares from each process. Data on the skills composition within these sub-industries was not readily available. Since electricity from coal makes up 93 per cent of total electricity supplied in South Africa, the skills profile in this industry was assumed to be very similar to overall skills profile of the industry. Information from a nuclear skills study in the United Kingdom was used to arrive at a plausible skills distribution in the nuclear power industry.[14] For the renewables sector a skills mix of 65:35 (high skilled to low-skilled) was assumed, whereas for gas turbines this ratio was 70:30. A balancing procedure was applied, resulting in the final skills composition shown in Table 2.

Estimates of total value added were obtained in the same way as before, i.e. by multiplying the employment levels in the respective industries with the average electricity industry wage as reported in the original SAM. Also, returns to capital (GOS) was allocated across sub-industries using output shares. The fully disaggregated petroleum and electricity accounts are shown in Table 10 in section 1.5.

Table 2: Skills Compositions for Electricity Account Disaggregation and Original SAM

	Coal	Nuclear	Renewables	Gas turbines	SAM (aelec)
High skilled	24%	54%	33%	36%	25%
Skilled	17%	20%	17%	18%	17%
Semi-skilled	43%	19%	33%	32%	42%
Unskilled	16%	8%	17%	15%	15%
	100%	*100%*	*100%*	*100%*	*100%*

Source: Author's calculations and South African SAM (2000)

1.2.3 Simulation Setup

In this section we describe how each of the individual 'building blocks', also called 'wedges', of the mitigation scenarios, that is, energy efficiency, structural shifts in output mix, CO_2 taxes and investment requirements, are modelled in a CGE model. We also discuss the so-called 'closure rules' assumed for this study. The formation of the combined scenarios is described in the results and analysis part of this paper (section 1.3).

1.2.3.1 Modelling Energy Efficiency and Fuel Switching

Increased energy efficiency in production refers to a situation where productive sectors such as mining, manufacturing, commercial and transport sectors improve their production processes in such a way that they require less energy inputs per unit of output produced. In a CGE modelling context this is modelled as a reduction in the intermediate input use coefficient. This coefficient is included as a parameter in the model and specifies the fixed proportion of a given input used per unit of output. Figure 2 shows the production structure used in a typical CGE model. QX is quantity produced in a sector or activity, defined in the CGE model as a CES or Leontief function of aggregate intermediate inputs ($QINTA$) and value added (QVA). QVA is a CES function of primary factors of production (capital, labour, land etc.), as denoted by $F_1, \ldots, F_n$. $QINTA$ is a Leontief function of various commodities used as intermediate inputs in production ($C_1, \ldots, C_m$).

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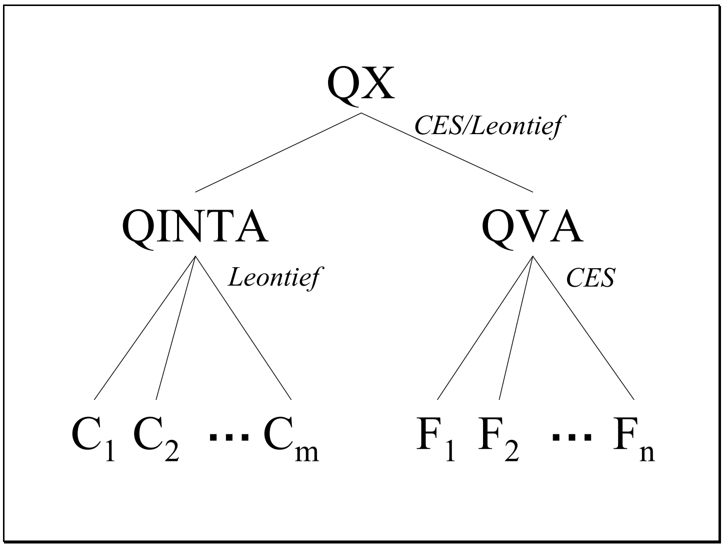
[14] Nuclear Skills Study 2002, UK DTI, www.dti.gsi.gov.uk

Figure 2: Two-tier Production Function in a Standard CGE Model



Increased energy efficiency, therefore, implies that a producer needs less energy (say, C_e) per unit of output (*QX*). Increased energy efficiency causes production costs to decline, which has various downstream effects. Since the standard setup of this class of models assumes perfect competition, output prices are expected to decline with lower production costs.[15] Other producers using output from that industry will benefit from lower prices, which enable them to also lower costs. Also, end-use consumer will increase demand due to lower prices, which causes further economic gains to be realised, both in terms of output, employment and general welfare gains for households. The downside, however, is that decreased demand for energy causes a decline in output and employment in those sectors that supply energy-related goods and services, i.e. coal, petroleum and electricity. With impacts pushing in opposite directions, both positive and negative, the use of an economy-wide modelling framework such as a CGE model is important, as it gives an indication of what the overall outcome is likely to be in terms of economic activity, employment and household incomes.

QX in the figure above represents the output level in a given economic sector. The MARKAL model produces results on savings in electricity, coal, gas or liquid fuels across a variety of economic sectors for each mitigation scenario relative to the reference case. These savings are assumed to be implemented in a ‘costless’ way and used as a proxy for energy efficiency, a valid assumption given that output levels in the various scenarios are assumed to be the same as in the reference case. Results are obtained for various mining and manufacturing sectors, the commercial sector and the transport sector. These percentage savings are applied directly to the appropriate input-use coefficients in the CGE model, i.e. by sector and for specific energy commodities.

Of course, in some instances fuel switching may take place under a mitigation scenario. For example, if a transport mitigation action includes a combination of energy efficiency for normal combustion engines as well as modal shifts towards electric- or hybrid motor vehicles, one may expect an increase in electricity use relative to the reference case. Such an increase in energy use per unit of output is modelled in exactly the opposite way as increased efficiency, and hence

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[15] Imperfect competition is ignored here as we assume that even with a limited number of market players (suppliers) there is effective regulation that ensures that lower production costs are indeed translated in lower production prices.

may appear like increased inefficiency in terms of the results generated. In our modelling framework both increases and decreases in input-use coefficients are considered. Details about the specific changes applied to the input use coefficients are discussed in sections 1.3.1 and 1.3.2 where the setup of the combined scenarios are described.

1.2.3.2 Modelling Structural Shifts

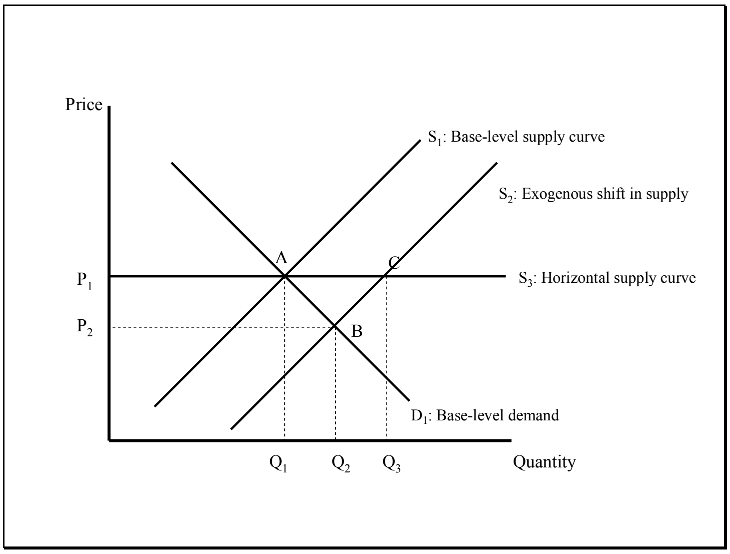
Various mitigation actions are associated with specific structural shifts in output mix. Currently, the South African petroleum and electricity industries are highly dependable on coal and crude oil as intermediate inputs. Coal in particular is associated with high emissions. Therefore, the more progressive a mitigation action, the larger the substitution away from coal is likely to be.

As with energy efficiency, the structural change simulations are set up on the basis of outcomes from the MARKAL energy model. Producers' output levels are demand-driven in a CGE model, thus under normal circumstances an increase in productive capacity would not lead to an increase in output unless there is demand for the good. One way, however, to induce the model to shift away from the base-level output mix is by reallocating capital stock so that the capacity in targeted industries increases. At the same time capacity in those sectors for which relative output is expected to decline, is decreased, again assumed to be a costless exercise.

The CGE model is set up with a so-called commodity aggregation function, which allows the commodity market to 'choose' the sector from which it wishes to source a particular commodity. Suppose, in the electricity commodity market, electricity can be sourced from either coal-fired power plants or from renewable sources. When capacity is increased in renewables and decreased in coal-fired plants, it becomes more expensive for coal-fired plants to produce at the original output level, since they would now be producing beyond capacity. Renewables therefore becomes a relatively cheaper option, and since spare capacity now exists, the cost of taking up this spare capacity is favourable. This leads to a shift along the commodity aggregation function whereby coal-fired electricity is substituted for renewables. This is the desired result of the mitigation action. The degree of substitutability, or the ease with which the model can substitute between different processes, is determined by the elasticity of substitution parameter, which is set exogenously by the modeller. The degree of substitutability may have important implications (as we see later on, especially in the CO_2 emissions tax scenarios) for energy production costs.

This approach of reallocating capital stock between alternative producers rather than simply increasing production capacity in the growing sector is crucial in this modelling context. When increasing total supply of a commodity (say petroleum or electricity) by increasing the production capacity exogenously without adjusting the demand side, market prices will fall. This can simply be explained as supply and demand forces at work (see Figure 3). This is not a desirable outcome as we work from the assumption that petroleum and electricity suppliers will always aim to meet demand, not to exceed it. Therefore, the options in a comparative static framework are to either increase demand in line with increases in supply, or as is the case in these specific simulations, to consider a *relative* change in the composition of energy supply from different sources, but keeping the total supply of energy unchanged. The latter approach is preferred, as it avoids the need to forecast demand, not only for energy, but for all other commodities as well.

Figure 3: Shifting Supply in an Industry



When interpreting the simulation results of structural shifts in output mix, it is important to bear in mind that the simulations represent outcomes under a relative shift in output composition and not an absolute increase in production capacity. Thus, we are interested here in how the structure of the economy might be altered in line with mitigation scenarios, and how this in turn may affect employment and income distribution patterns in the economy. Given that results are reported throughout relative to the reference case this should be straightforward to interpret.

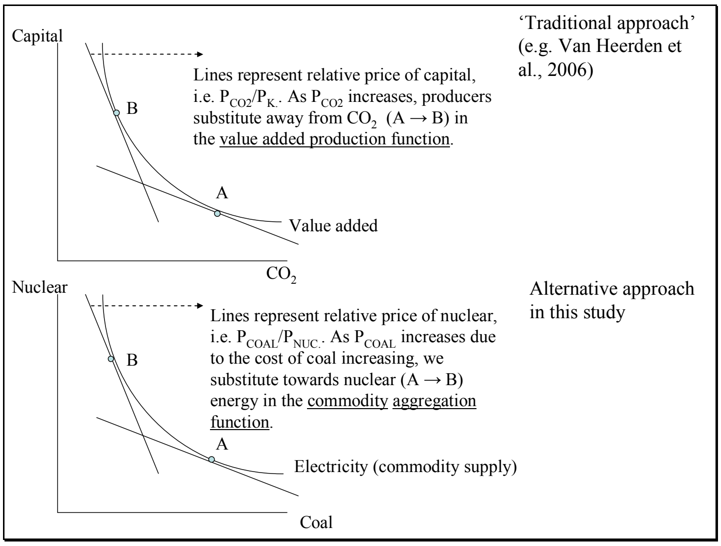
1.2.3.3 Modelling the Impact of a CO_2 Emissions Tax

One of the proposed economic instruments that could be used to reduce emissions is a tax on CO_2 emissions, something that can be readily analysed in a CGE model. The STAGE model does not make provisioning for CO_2 emissions as a measured 'by-product' of production, hence a tax on CO_2 emissions cannot be modelled directly. The standard approach to modeling CO_2 emissions in CGE models is to include emissions as a by-product of production by including it in the production structure. Some form of substitution away from CO_2 emissions is then allowed for if the 'price' of emissions increases. Thus, under such a model setup, a CO_2 tax levied will increase the cost of emitting greenhouse gases, which then acts as an incentive for producers to alter their production processes so that emissions decline. This technology change is represented as a shift along the value-added production function away from CO_2 towards more capital (see Van Heerden et al., 2006 for this type of application).

We adopt a suitable alternative modelling approach that works particularly well here, given that the energy accounts (petroleum and electricity) have been disaggregated into various sub-processes. This method involves calculating the implied taxes on the prices of coal, crude oil and natural gas of a given emissions tax level and using these as the proxy for an economic shock of a CO_2 tax. This approach is reasonable since an emissions tax is effectively a tax on those inputs that, when processed, emit greenhouse gases. Coal, in particular, and to a lesser extent crude oil and natural gas, all cause emissions. Given information on the relationship between emissions levels and intermediate input use of coal, crude oil and natural gas in various industries, it is possible to derive the implicit taxes on these commodities. As an example, consider the top row of Table 6 in section 1.4.3, which shows various possible CO_2 tax levels, expressed as a Rand value per ton of CO_2 emitted. The three rows below show the associated taxes on coal, crude oil and natural gas. Emissions taxes have the largest implicit impact on the price of coal. Even a R25/ton emissions tax equates to a 59.4 per cent tax on the price of coal. A R1000/ton tax is equivalent to the price rising by a factor of 25. The equivalent crude oil and gas prices are much lower.[16]

To explain the difference (from a technical modelling perspective) between the 'traditional approach' to modelling a CO_2 tax and the approach taken here, consider the following example. If a CO_2 emissions tax is levied on electricity generation processes, it becomes 'expensive' to emit greenhouse gases. For electricity producers it then becomes economically sensible to alter their production processes by installing additional capital, since the cost of doing so is lower than maintaining the status quo and paying higher emissions taxes. In the traditional approach this is represented as a shift along the value added function (see top part of Figure 4). Under the alternative modelling approach, the increase in the implicit tax of coal causes electricity generation in coal-fired plants to become more expensive. This now means that nuclear power, for example, becomes relatively less expensive, and hence we observe a shift between production technologies in the commodity aggregation function (bottom part of the figure). This approach is only feasible when your model is set up to so that energy commodities (electricity and petroleum) can in fact be produced by alternative processes. This is in fact the case in our model here given the disaggregation of the electricity and petroleum sectors as explained previously.

Figure 4: Modelling a CO_2 Emissions Tax in a Standard CGE Model



Under our approach emissions associated with a given level of output stay unchanged for each sector. The sectors themselves have no option of reducing emissions through adopting new technology. The only option is to shift production capacity to completely different sectors. Ultimately, Van Heerden et al.'s approach will produce results that show a decline in CO_2 emissions, but coal use (for example) will stay proportional to energy supply. Our approach, contrast, will show a decline in coal use, which is certainly a desired outcome. Of course, neither approach is perfect, and certainly both have their advantages and disadvantages.

The CGE model contains various instruments that can be used to simulate the impact of changes in the tax regime. The most appropriate for analysing the effect of an emissions tax is the sales

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[16] Gas falls under the 'other mining' category in the model and only makes up a small part of this sector. In reality gas prices are likely to rise by about 200 per cent for a R1000 CO_2 tax, but this equates to only a 4 per cent rise in other mining prices.

tax. The base-level sales tax rate, which is set as a model parameter during the calibration process, is increased in additive fashion using the percentages in Table 6 in section 1.4.3. Thus, if PQS_c is the before-tax supply price (equivalent to the producer price), PQD_c, the price faced by consumers (including firms purchasing intermediate inputs), can simply be calculated by levying the sales tax (ts_c) and the emissions tax (te_c) as follows:[17]

$$PQD_c = PQS_c \times (1 + ts_c + te_c)$$

A CO_2 tax can potentially become an important source of revenue for government. Government's choice about how to allocate this extra revenue may have implications for growth, job creation and welfare levels of different households. One option is to use additional revenues to finance production subsidies in cleaner energy production technologies (e.g. nuclear or renewables subsidies). Such subsidies will mitigate the impact of higher emissions taxes on energy prices in general, and also further enhance the substitution away from emissions-intensive processes. Government could also recycle revenue through a variety of other mechanisms, including food subsidies, a reduction in VAT, income tax relief or to increase welfare payments to poor households. Various of these options are explored in the economic impact assessment (section 1.4.3).

1.2.3.4 Modelling Investment Requirements

The MARKAL model produces results on various types of 'costs' associated with mitigation scenarios. These include capital outlays (building of new plants, or installation of machinery and equipment required) as well as total energy systems costs. Since production costs are inherently captured in a CGE model, we are only interested in the capital outlay cost under each mitigation scenario. In the CGE model this is captured as investment costs. Since we compare mitigation scenario outcomes against the reference case, we are specifically interested in the marginal investment costs as opposed to the absolute level thereof under each scenario, the rationale being that costs under the reference case are investments that would have been made in any event. In the *Start Now* scenario the investment costs are actually lower than in the GWC reference case, as energy efficiency measures provide cost savings. Hence the target investment level is reduced. For both the *Scale Up* and *Use the Market* scenarios investment costs are higher, hence the target investment level is increased and additional funding has to be raised. One of the macroeconomic balances in a CGE model is the savings-investment balance (see further discussions below in section 1.2.3.5). As investments go up, savings have to increase to meet the targeted investment level. When household increase their savings, their disposable incomes decline, thus leading to welfare losses in the current period.

1.2.3.5 Additional Modelling Information: Model Closures

The model is set up with a range of flexible macro adjustment or closure rules. Model closure rules are typically selected with the objective of providing a realistic representation of the adjustment to shocks in the economy under investigation. Mathematically speaking, closure rules ensure that the number of variables and equations in the model are consistent, a necessary condition for the model to solve. In economic terms closure rules define fundamental differences in perceptions of how economic systems operate under adjustment. In particular, the modeller should select closures for the following markets or accounts:

- The *foreign exchange market* is cleared via a flexible exchange rate, which is consistent with South Africa's exchange rate regime. Therefore, the external balance (or current account balance) is fixed. The alternative closure is a fixed exchange rate and a flexible external balance, which is not considered appropriate for South Africa.

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[17] In each instance the subscript refers to the commodity (*c*), e.g. coal, crude oil or other mining, plus all other commodities in the model. For commodities not affected by the emissions tax $te_c = 0$.

- The *capital account* (also called the savings-investment account), which records all savings and investment related transactions, can be closed in a variety of ways, ultimately ensuring that investment equals savings in the economy. Under the so-called savings-driven closure the investment level is determined by the level of savings in the economy, with average savings rates of households and enterprises fixed. A further option, often regarded as a more balanced approach, is allowing the share of investment expenditure in total final domestic demand remains constant. Since the analyses here use information on required investment levels, we opt for an investment-driven closure. Under this closure the investment level can be considered as fixed at some target level, which implies that households and enterprises generate enough savings to finance investments. This is achieved by allowing average savings rates of households and enterprises to vary.
- The *government account* in a CGE model is either closed by variations in the level of government borrowing or savings, i.e. the size of the budget deficit or surplus, whereby all tax rates remain constant, or by allowing tax rates to vary in order to generate a level of government revenue sufficient to maintain the base-level budget deficit or surplus. In this model we opt for the latter. In the *Start Now* and *Scale Up* scenarios household income taxes are flexible. Under both these scenarios there is very little variation in government revenue, hence taxes are virtually unchanged. The *Use the Market* scenario affects government revenue directly and significantly, hence in this scenario we opt for a food subsidy as the optimal way (from a welfare perspective) to recycle additional revenue generated through the CO_2 tax.[18]
- The *factor market* closure typically involves different treatments for different factors. If labour categories are subdivided into high-skilled and low-skilled groups – a useful distinction in the South African context – a suitable closure is to assume full employment (flexible wages) for high-skilled workers and unemployment or excess capacity (fixed wages) among low-skilled workers. Workers are usually assumed to be mobile across sectors. Capital stock is often treated as activity-specific and fully employed in the short run, while long run simulations sometimes allow capital mobility between sectors. Land is typically fixed and immobile. In these analyses we treat capital stock as fixed and activity specific, since we want to impose structural shifts in production capacity in the various scenarios.

1.2.4 Final Remarks About the Modelling Approach

1.2.4.1 Combined Scenarios: Economic Effects and Modelling

The four separate sets of input parameters from the MARKAL model, namely structural change, energy efficiency/fuel switching, investment requirements, and tax instruments, each have their own unique impacts on GDP, employment and household income and welfare levels. For example:

- *Structural change* in electricity involves switching from coal-fired plants to nuclear and renewables. These two electricity generation processes have very different skill compositions and labour intensities. Renewables is assumed to be relatively labour intensive compared to coal-fired and nuclear plants. Nuclear, on the other hand, is highly skill

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[18] Arguably a more appropriate way of recycling revenue in this context is to subsidise the cleaner alternative energy supply processes. In fact, this may well be something that policymakers would consider as it would link the CO_2 tax directly to processes associated with lower emissions, thus in a sense ‘ring fencing’ the tax. In the analyses here we opted for the recycling scheme that seems optimal from an economy-wide welfare perspective as the default. In a similar study by Van Heerden et al. (2006) this recycling option was also deemed optimal from a welfare perspective. In section 1.4.3 we elaborate by considering a variety of alternative revenue recycling options.

intensive and has a low labour intensity when compared to other electricity generation processes.

- *Energy efficiency* gains generally have positive economic effects due to their associated production price decreases. However, these gains may be offset by increased use of other energy sources due to fuel switching (for example, electricity in transport). Both energy efficiency and fuel switching are considered as part of this study, so the outcome depends on the degree to which these two processes offset each other in terms of economic effects.
- The *investment effects* observed in a comparative static general equilibrium framework generally only have small compositional effects. When investments increase, additional financing has to be raised. The model closure selected for this study assumes that this is achieved through increasing household and enterprise savings rates. Thus, households' disposable incomes declines, which reduces final demand, while the increase in investments increase final demand. The compositional effects arise due to the fact that structure of household demand is different from that of investment demand in terms of the types of commodities consumed. Any change in GDP, employment or household welfare depends on the differences in production structures (intermediate input use and value added or employment) of the declining sectors versus those of the growing sectors.
- *Increased CO_2 taxes* have implications for the cost of intermediate inputs associated with high emissions levels, i.e. coal, crude oil and gas. This affects energy prices in the economy, which has adverse effects for all energy users, including productive sectors and households. However, CO_2 taxes are also a source of revenue for government, and in the event that increased CO_2 tax revenues outweigh income tax losses due to the economic decline associated with the tax, overall government revenue may increase. This allows government to redistribute these funds in a variety of ways, which may mitigate some of the effects of increased CO_2 taxes.

The overall outcome of individual wedges are sometimes hard to predict beforehand, and so much more so for combined scenarios. For this reason, the use of an economy-wide model that takes into account complex interactions, is important.

1.2.4.2 The Reference Case, Forecasting and Analysis Period

The decision not to attempt to predict or forecast actual trends in all variables in the reference case may seem surprising. The only structural change that we introduce in the reference case is the change in the energy output mix as determined by the MARKAL model. As such the approach here is a kind of hybrid comparative static-dynamic model, i.e. some form of (re)allocation of capital stock is modelled, which is a key element in dynamic models that explicitly model the link between current period investments and changes in capital stock, but we do not adjust the model for changes in production levels, (un)employment levels, population size and so on. Thus, in terms of the rest of the economy (non-energy sectors) the structure and levels of production remain virtually unchanged, apart from the indirect effects of the structural shifts that take place under the reference case. Given the very long modelling period, we do not want a situation where other dynamic changes over time simply overwhelm the mitigation effects. This approach allows us to focus specifically on mitigation, *ceteris paribus* (keeping all other things constant).

This approach is however justified bearing in mind that what matters most in comparative static modelling where changes are reported relative to a reference case, are the assumptions about *how* the economy operates, and not necessarily the *level* at which it operates. The way in which the economy operates is defined by the behavioural assumptions, which are expressed as mathematical equations and based on micro- and macroeconomic theory. The real concern therefore, when looking at results over a very long period of time, is not necessarily whether *levels* in the base or reference case are correct, but whether the assumptions about how changes filter through the economy via these behavioural equations are accurate. Put differently, one may ask whether the underlying assumption that the adjustment path from the reference case to the outcome stays unchanged over a 50-year time horizon is relevant? This is difficult to say. While the actual functional forms used in CGE models to define behaviour are based on economic theory, the parameters in these functional forms are calculated during the calibration process, which uses the base data, in this case the SAM for 2000. If there is a strong argument that these parameters will change over time, then model results for distant future periods become less reliable.

Given these concerns it was considered advisable to only present results up to 2015, although the model was in fact set up to cover the same period as the MARKAL model, i.e. up to 2050. We turn to the model results for the combined scenarios, *Start Now*, *Scale Up* and *Use the Market* in the next section.

1.3 Results and Analyses

1.3.1 *Start Now* and *Scale Up*

1.3.1.1 Simulation Setup

Results from the MARKAL model are used to obtain estimates of structural shifts in the output mix under various scenarios, including the reference case. The model predicts that electricity supply from coal will drop from around 94 per cent in 2005 to 81 per cent by 2050 in the reference case (see Table 12 in section 1.5). Also in this scenario the nuclear and renewables shares rise from 6 to 14 per cent and zero to 4 per cent over the same period. However, by 2015 the reference case is not much different from the base, with the electricity share from coal actually predicted to rise marginally to 95 per cent, while the share from nuclear, renewables and gas are virtually unchanged.

Under the *Start Now* scenario the electricity supply from coal declines to 46 per cent by 2050, while nuclear and renewables each contribute around 27 per cent at this point. Most of this relative decline in electricity from coal takes place after 2015, as shown by the MARKAL model results that predict this share to still be quite high in 2015 (87 per cent). The shares from nuclear and renewables are predicted to reach 8 and 5 per cent respectively by 2015. Under the *Scale Up* scenario a more aggressive decarbonisation strategy sees the coal share drop further to 17 per cent, with nuclear and renewables each contributing about 41 per cent to electricity supply by 2050. However, again much of this change takes place after 2015, as the shares from coal, nuclear and renewables are fairly close to the base at this point, i.e. 86, 8 and 6 per cent.

The *Start Now* and *Scale Up* mitigation scenarios in the petroleum sector (also in Table 12) are less aggressive, with little variation in output shares from crude oil refineries and CTL processes in either of these scenarios relative to the reference case. The reference case itself also differs only marginally from the original base in 2000. However, in both the *Start Now* and *Scale Up* scenarios the biofuels sector grows from a base of around zero to almost 4 per cent of liquid fuels supply by 2050. While this presents a large growth for the biofuels sector itself, it does not alter the liquid fuels mix significantly and is therefore unlikely to have a large impact on the economy. By 2015 there is very little difference between the petroleum output shares at that point compared to the model base in 2000.

Given that we only report the results up to 2015, it should be clear from the above that not much of the changes observed under the combined scenarios, *Start Now* and *Scale Up*, are due to structural shifts. Most of the structural shifts in energy output mix are predicted by the MARKAL model to take place after 2015. Changes observed are therefore largely explained by energy efficiency and fuel switching. We turn to this next.

MARKAL model results are also used to obtain estimates of changes in intermediate input demand associated with energy efficiency or fuel switching. Table 13 in section 1.5 shows percentage changes in fuel use per unit of output relative to the reference case. The reference case assumes no efficiency gains or fuel switching. The first part of the table shows savings in electricity used as intermediate inputs into mining, industrial and commercial production processes for the *Start Now* scenario. Due to shifts towards electrified transport, overall electricity used in the economy declines by about 2 per cent by 2050.[19] This is not significantly higher than the savings by 2015, which suggests that much of the efficiency gains are predicted to take place within the next decade. By 2050 the estimated decline in coal use due to energy efficiency under the *Start Now* scenario is about 15 per cent total coal supplied. This efficiency gain takes place more gradually over time, with the decline by 2015 estimated at only 7 per cent. Also shown are declines in petroleum use, driven largely by fuel savings in the transport sector. By 2050 petroleum use (liquid fuels such as petrol and diesel) is likely to decline by almost 9 per cent per unit of output, compared to 7 per cent by 2015.

The *Scale Up* scenario assumes very similar industrial and commercial efficiency increases (electricity and coal). However, a greater shift towards electrified transport actually causes electricity use to increase marginally by 2050 (0.4 per cent). By 2015, however, fuel switching has not yet caused a net increase in electricity, with electricity savings of around 4 per cent expected by this time. Petroleum savings are slightly lower under this scenario compared to the *Start Now* scenario.

The investment cost estimates (in terms of capital outlay required) under each mitigation scenario is expressed relative to the reference case. In the *Start Now* scenario these are actually negative, implying that capital outlay under this scenario is less than under the reference case with no loss in terms of production. Investments are initially about 5 per cent below that of the reference case, and thereafter drops further to around 10 per cent below the reference case (see Figure 22 in section 1.5). The *Scale Up* scenario is almost the opposite, with investments required estimated to be about 5 to 10 per cent higher than under the reference case level over most of the period, reaching a high of 12 per cent by 2050.

1.3.1.2 GDP, Employment and Welfare Effects

Before looking at the results, a brief note on the degree of substitutability assumed in the commodity aggregation function and how this affects prices (see previous discussions in section 1.2.3.2). In the analyses here we are particularly interested in how easily substitution can take place within the electricity and petroleum sectors once capital has been reallocated in the structural shift simulations. We select a moderate elasticity of substitution for all the scenarios. This causes energy prices to rise, especially in the latter periods when substitution away from carbon-based processed is 'pushed hard'. If we were to assume perfect substitutability, for example, prices would not have risen as much, if at all. Our approach, although more conservative, is considered more appropriate given the general consensus that mitigation actions will probably lead to rising energy prices. A lower substitutability also reflects the fact that commodities produced using different processes are ultimately not homogenous, and that some adjustment costs will have to be borne by the economy, particularly when producers have to alter production processes to accommodate slightly different commodities.

We first consider the impact under the *Start Now* and *Scale Up* scenarios on GDP. Figure 5 shows the percentage difference between GDP under each scenario relative to the reference case. Under the *Start Now* scenario GDP is marginally lower than in the reference case during the initial period, but recovers to a very similar level as the reference case by 2015. Since

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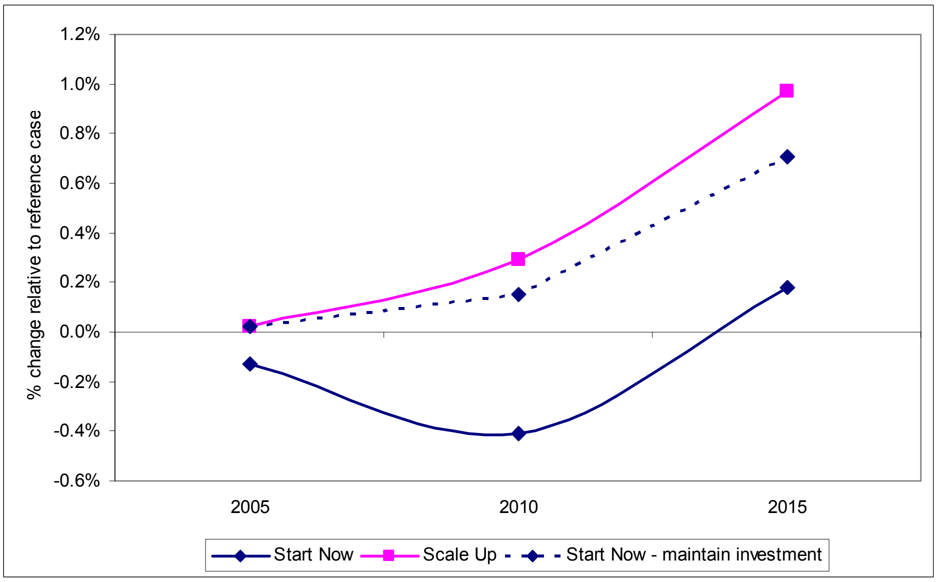
[19] Table 13 also shows the percentage decline in electricity demanded as an intermediate input in the economy. Here we only discuss the decline (or increase) in total electricity demand. The same applies to other energy inputs, i.e. coal, petroleum and gas.

investment costs under the *Start Now* scenario are lower than under the reference case, some interesting household effects are observed, which are discussed in more detail below. This, however, has important implications for GDP levels. Lower investment levels allow consumers (households) to reduce savings, which frees up more funds for consumption. While this is good for consumers from a hedonistic welfare perspective, it is probably short-sighted. If investment levels were maintained, the future production capacity of the economy could be increased more; this would have positive production and employment effects. The dashed line in Figure 5 represents GDP that could be realised if investment levels were maintained at the base level rather than allowing these levels to decline. This 'potential' GDP measure excludes the impact that such investment could have on the future production capacity in the economy, and as such only measures the immediate or short term impact of increased investment flows. Clearly, however, maintaining investment levels would imply that positive growth effects are in fact observed over the period, and hence this is something that should be encouraged.

Figure 5: GDP Effects of the *Start Now* and *Scale Up* Scenarios



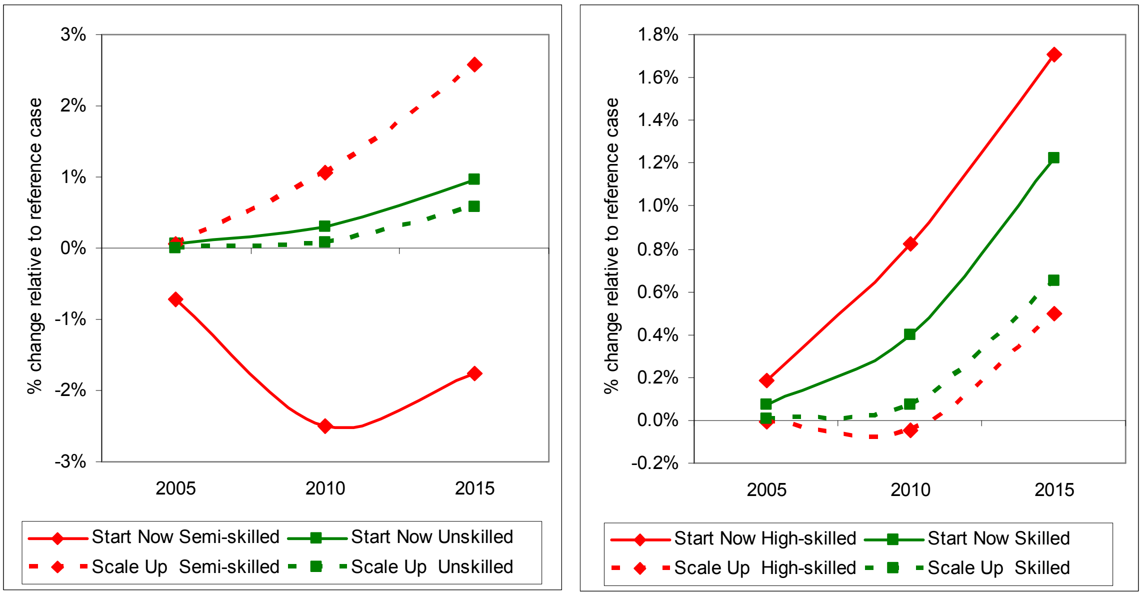
Source: CGE model results

The *Scale Up* scenario compares favourably to the reference case and the *Start Now* scenario as far as GDP is concerned. This is driven largely by the higher level of energy efficiency modelled under this scenario, and also possibly by the higher investment levels under this scenario.

GDP is effectively a measure of value added in the production, which is the sum of producers' payments for labour (wages), capital and land. Thus, employment effects generally look similar in shape to the GDP effects, at least in the aggregate. As discussed, the factor market closure in the model assumes that excess capacity (unemployment) exists among semi- and unskilled workers (referred to as low-skilled workers), hence their employment levels are flexible and wages are fixed. Skilled and high-skilled workers (high-skilled), on the other hand, are fully employed at flexible wages, reflecting the skill constraints in the South African economy. Figure 6 shows the employment and wage effects for these two groups of workers respectively. At this disaggregated level a better picture is obtained of the relative gains and losses of different types of workers.

Under the *Start Now* scenario employment levels of semi-skilled workers is below that of the reference case. By 2015 semi-skilled employment is likely to be about 2 per cent lower than the reference case. Unskilled employment, on the other hand, remains above that of the reference case, reaching about 1 per cent by 2015. Under the *Scale Up* scenario, semi- and unskilled employment levels both remain positive relative to the reference case, with semi-skilled employment peaking at about 3 per cent by 2015. Unskilled employment is marginally lower under this scenario compared to the *Start Now* scenario.

Figure 6: Employment and Wage Effects of the *Start Now* and *Use the Market* Scenarios



Source: CGE model results

Wage changes under the *Start Now* and *Scale Up* scenarios are quite similar for skilled and high-skilled workers respectively, all showing increasingly higher levels relative to the reference case up to 2015. High-skilled workers are set to gain the most in the Start Now scenario, with wage levels almost 2 per cent higher than the reference case by 2015. In contrast, skilled workers gain marginally more in the *Scale Up* scenario, with wages estimated to be about 0.7 per cent above that of the reference case.

Welfare is measured using the equivalent variation (EV) measure. This index measures the welfare levels of households taking into account changes in disposable income (i.e. net income, after tax and savings have been deducted) as well as movements in household-specific price indices. Under the investment-driven closure selected households will reduce savings when, as happens in the *Start Now* scenario, required investment levels decline. Since high income households contribute the bulk of savings in South Africa, they also benefit the most from a reduction in required savings rates. This results in a large and significant increase in disposable income for this household group. Therefore, as shown in Figure 7, despite the fact that GDP is lower than that of the reference case between 2005 and 2010, high income households experience large, positive welfare effects at significantly higher levels than any of the other household groups. In fact, all the household groups experience positive welfare effects because of their increased disposable incomes, at least during the period under consideration.

Figure 7: Household Welfare Effects of the *Start Now* and *Scale Up* Scenarios

Source: CGE model results

Under the *Scale Up* scenario the effects are almost the exact opposite. Increased investment requirements cause households, in particular high income households, to increase savings rates in order to generate funding for the investments, which reduces spending power and hence welfare. Even the generally favourable employment effects do little to counter these welfare losses, except for low-income households by 2015.

1.3.1.3 Sensitivity of Results

The preceding discussion already raised the importance of the assumed elasticity of substitution in the commodity aggregation function. An increased substitutability, for example, will cause the negative impacts in the latter periods to be less severe than what the current model results suggest. Also, learning-by-doing or improved technologies are often important in bringing down production costs over time. It may well be that some of these alternative energy supply processes become least-cost optimal production choices in any event if their associated production costs decline in line with technological gains. It may further be that adverse movements in world prices of crude oil and coal could create further incentives for energy supply sectors to switch to alternative processes.

The way in which investment is modelled here also has implications for the outcome. Although investments, as argued, usually only have small compositional effects on the economy, the way in which they are financed may be important in determining the direction of the small compositional effects. The way in which the model is set up assumes that households and enterprises raise additional funding through increased savings. This affects current consumption and welfare levels of households, as shown. Investments may also simply crowd out other investments if the economy is savings-constrained, something that is quite a likely in South Africa given low savings rates, especially among middle- and lower income households. Another alternative that could be considered is to raise funding (through loans) offshore. While, ultimately, such loans still have to paid back with interest, the full impact is not felt within a single year or observation period as we model it here.[20] Finally, the import content of new

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[20] In reality we only model the *incremental* cost (in the case of rising investment requirements as in the *Scale Up* scenario), so the full effect of the energy system cost is not borne by the economy in that year that the investment is made. We further smooth the investment cost vector using moving averages so as to ‘spread’ the burden over longer periods of time.

investments matters. If the investments under a scenario lead to an increased demand for imported equipment and machinery, funds will leave South Africa, which ultimately impacts negatively on current GDP. The modelling here basically assumes that the import shares of the base period are preserved, with some degree of flexibility depending on how relative prices of imports versus domestically produced goods vary. It may well be that the types of investments required under the mitigation scenarios have higher import propensities than general investments in the economy.

1.3.2 *Use the Market*

1.3.2.1 Simulation Setup

Selected MARKAL model results are also used as simulation parameters in the *Use the Market* scenario. This scenario sees the use of coal in electricity generation virtually wiped out by 2030, with output share of coal-fired electricity plants declining to 2 per cent, and zero per cent from 2040 onwards (see Table 12 in section 1.5). Again we only analyse and discuss results for the period 2005 to 2015. Even by 2015 coal-fired electricity drops down to 64 per cent, with each of nuclear and renewables contributing a rather substantial 18 per cent each. In terms of the petroleum output mix the *Use the Market* scenario is also quite aggressive, with CTL output falling to zero by 2030. The share by 2015 is 21 per cent. Most of the CTL output is replaced by crude oil refineries, which implies larger dependence on imported crude oil.

The *Use the Market* scenario takes a very different angle than the *Start Now* and *Scale Up* scenarios as far as energy efficiency is concerned (see Table 13 in section 1.5). The focus in this scenario is much more on fuel switching. Electricity use in mining, manufacturing and commerce does not decline as much as in the other scenarios, while the use of electrified transport is increased even more than in the *Scale Up* scenario. Consequently electricity use increases quite substantially by about 6 per cent by 2050. However, by 2015 electricity use is down by just over 1 per cent, which implies that fuel switching has not yet started to take place at this point. The *Use the Market* scenario also considers switching away from coal towards gas as a thermal fuel source. Much of this fuel switching only happens after 2040, and hence does not affect results much in the 2005 to 2015 period reported on here. The MARKAL model results predict that coal use is likely to decline by about 21 per cent relative to the reference case, while natural gas use is likely to increase by over 300 per cent by 2050.[21] However, by 2015 none of these changes have yet set in. Petroleum use declines by about 9 per cent by 2050 due to fuel efficiency in transport. This decline is of a similar magnitude to the *Start Now* scenario. The related decline by 2015 is just over 4 per cent.

As far as investment is concerned the *Use the Market* scenario initially (by 2015) requires investment levels of up to 20 per cent above the reference case investment levels, but thereafter it drops back to similar levels as the reference case between 2030 and 2050. The CO_2 emissions taxes that form a core part of the *Use the Market* scenario are implemented as an incremental tax in the MARKAL model, ranging from about R250 per ton of emissions in 2008 and increasing to R750 by 2050. The level in 2015 is R353 per ton of CO_2. As explained previously (see discussions in section 1.2.3.3) the actual CGE model shock is implemented as an increase in taxes on coal, crude oil and gas. Table 14 in section 1.5 shows the CO_2 tax levels in selected years together with the related commodity taxes. Additional revenue from the CO_2 tax is recycled in the form of a food subsidy, given that this form of recycling appears to have the most favourable outcome in terms GDP, employment and welfare levels among the poor (see section 1.4.3). This finding is also consistent with that of Van Heerden et al. (2006). Whether

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[21] This is a very crude estimate. Natural gas is not captured as a separate commodity in the model and falls under other mining commodities, thus making calculations and the modelling of this scenario very difficult. See discussions below.

this recycling option is politically feasible remains a question for policymakers to consider (see footnote 18).

1.3.2.2 Modelling Issues

Various modelling problems were encountered when attempting to model the *Use the Market* scenario in a similar way as the *Start Now* and *Scale Up* scenarios. The structural change shock under the *Use the Market* scenario is very severe, especially towards the latter periods. Given the assumption about imperfect substitutability in the commodity aggregation function, energy prices rise significantly in the CGE model, causing the entire economy to take a very big knock as far as real GDP levels are concerned. When run in isolation, the structural change 'wedge' of the *Use the Market* scenarios offers solutions up to 2050, by which time there is virtually no coal used in the domestic economy. However, once the other 'building blocks' or wedges of the scenario are added, i.e. energy efficiency/fuel switching, investment requirements and the CO_2 tax, the model only offers solutions up to the 2030. It is especially the large increase in gas demanded under the energy efficiency/fuel switching wedge that causes this scenario to create infeasible solutions for the period 2040 to 2050. As expected, the impact of the CO_2 tax is small towards the latter period, since most carbon-based processes are removed from the economy by this time. In the absence of modelling some exogenous change in the model that mitigates the negative effects of the Use the Market scenario towards the latter end of the analysis period, results beyond 2030 may seem outrageous

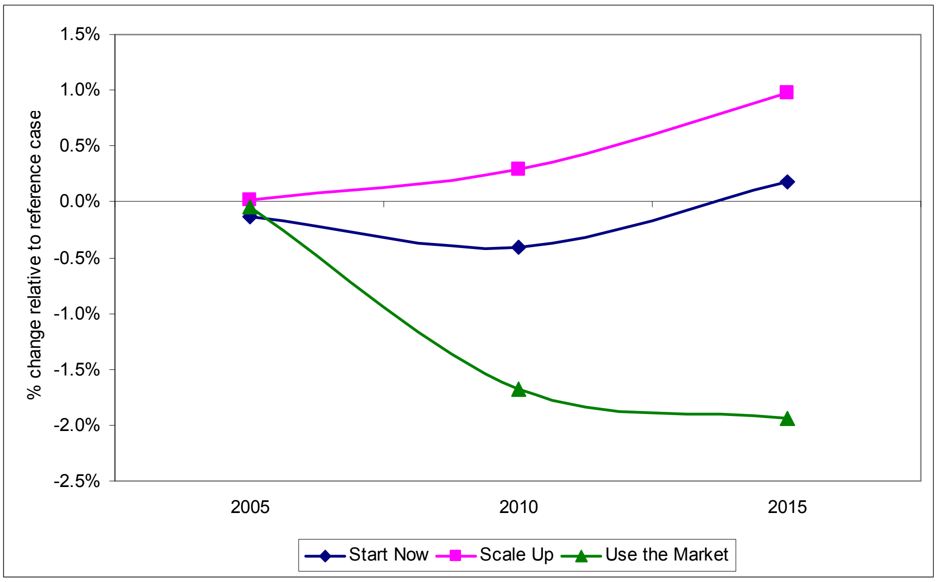
Another concern, as mentioned briefly before, is that natural gas is not a separate commodity in the SAM. Hence it is difficult to define the simulation parameters, as assumptions have to be made about what share of other mining commodities is made up of gas. While in reality additional gas will most likely be imported, it is difficult to 'force' the model to choose this option since demand for imports in this model ultimately depends on the relative prices of domestically produced goods vis-à-vis imported goods.

These concerns contributed to the decision to only report results up to 2015, by which time structural shifts, energy efficiency and fuel switching, and CO_2 tax levels are not too restrictive to the economy. A more comprehensive analysis of the impact of CO_2 taxes in the absence of other mitigation wedges was also done and is reported on in section 1.4.3.

1.3.2.3 GDP, Employment and Welfare Effects

The combined effects of a sharp decline in the coal sector and sharply rising energy prices, driven initially by a CO_2 tax, and later by rising energy prices associated with the structural shifts in the energy output mix, causes GDP to decline fairly rapidly in this scenario (see Figure 8). By 2015 GDP is likely to be about 2 per cent below the reference case level, which stands in stark contrast to the *Start Now* and *Scale Up* scenarios where gains are in fact expected.

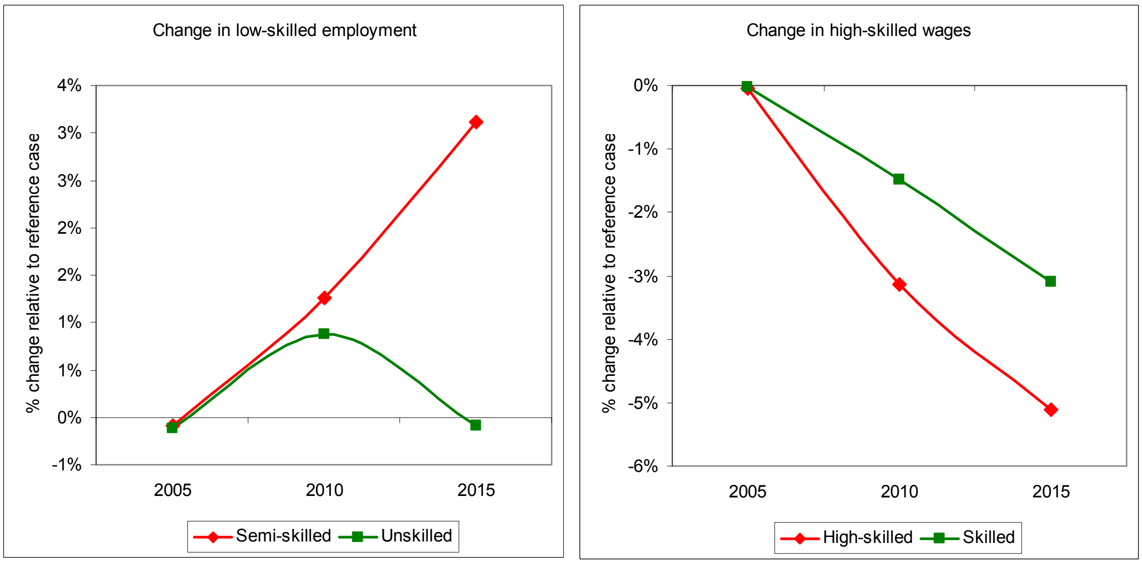
Figure 8: Comparing GDP Effects of Mitigation Scenarios



Source: CGE model results

The employment effects are interesting, with unskilled and semi-skilled employment initially increasing. This is thanks largely to strong initial growth in the food sector as additional revenue from the CO_2 tax is recycled back into the economy as a food subsidy. Output and employment in this sector, as well as the agricultural sector, which is an important supplier to the food processing industry, increases due to strong consumer demand growth. However, by 2015 and beyond (not reported here) the employment impact for low-skilled workers becomes zero and then negative as the sharp decline in economic activity and employment losses in other economic sectors outweigh the small employment gains in the initial period. Wages of skilled and high-skilled workers decline from the outset. High-skilled workers suffer the biggest losses, with wages falling by about 5 per cent relative to the reference case by 2015.

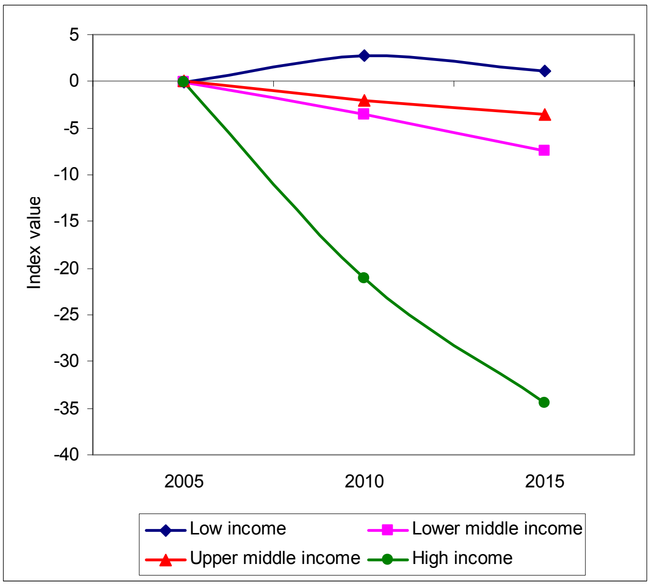
Figure 9: Employment Effects of the *Use the Market* Scenario



Source: CGE model results

The welfare effects are generally negative, with rising prices and reduced wage income impacting negatively on spending power and hence welfare levels. High income households experience the greatest welfare losses, given that they have to raise most of the additional savings required to finance investments, while in relative terms they do not gain as much from food subsidies. As expected, low income households initially benefit from employment growth and the large food subsidy. Low-income households spend a large proportion of their budget on food, hence this result. However, by 2015 much of the initial gains are mitigated by disposable income losses due to the negative labour market effects and rising prices in the economy.

Figure 10: Household Welfare Effects of the *Use the Market* Scenario



Source: CGE model results

1.3.2.4 Final Remarks

In conclusion, we have to reiterate that these results are only indicative of an outcome under a highly restricted economy. In order to try and reproduce structural shifts as predicted by the MARKAL model, the capital stock levels in the energy supply sectors are 'locked down' to try and force a certain output mix. It may well be that if the CGE model was allowed to allocate capital in the most efficient way (as is done in the additional CO_2 tax analyses reported on in section 1.4.3), that the effect on the economy would not be so large. This highlights one of the difficulties in linking the MARKAL model and the CGE model is sequential manner, as these two models overlap in certain respects.

1.4 Analysing the Effects of Individual Mitigation Components (Wedges)

1.4.1 Energy Efficiency Wedges[22]

1.4.1.1 Overview

The comparative static computable general equilibrium (CGE) model for South Africa mentioned in the previous section is used to model the effects of increased energy efficiency, one of the proposed mitigation components or 'wedges' of the LTMS process. These and other components discussed in this section are combined in various ways to create the *Start Now*, *Scale Up* and *Use the Market* scenarios discussed in the previous section. This section should therefore be seen as informing the reader about the underlying individual impacts.

Energy efficiency in an economic sector is modelled as a reduction in demand for primary or transformed energy sources per unit of output. The analysis considers mining and industrial energy efficiency, commercial energy efficiency and energy efficiency in the freight and passenger transport sectors. Increased residential energy efficiency cannot be analysed in this modelling framework. Below we report on some selected results obtained for industrial and commercial energy efficiency. Results are reported as percentage changes relative to a reference case which assumes zero energy efficiency gains. The simulation parameters, that is, the percentages by which energy demand declines per unit of output are obtained from MARKAL model results for related mitigation wedges.

1.4.1.2 Industrial Energy Efficiency

The industrial energy efficiency scenarios consider efficiency gains in the use of electricity and coal in the production processes of manufacturing and mining sectors. Under the industrial energy efficiency scenario electricity demand declines by 22 per cent in 2020, reaching 29 per cent by 2050. Coal use declines by 20 per cent by 2020 and 45 per cent by 2040 (see Table 3 below). These reductions are expressed per unit of output.

The industrial energy efficiency simulation results are summarised in Table 3. For the electricity savings scenarios the CGE model shows a 7.7 and 10 per cent decline in electricity output. Despite this, overall economic activity increases by about 0.2 per cent in both periods. This is partly due to lower producer prices brought about by electricity savings (see PPI in Table 3), which acts as a stimulus for aggregate demand. This results in an increase in demand for labour relative to the base case: wages of skilled workers rise by 0.5 and 0.7 per cent, while employment among low-skilled workers rises by 0.5 per cent in both periods.[23] The GDP

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[22] A summary of results is supplied in this section. Please refer to the earlier SBT 5 Technical Document for further details.

[23] The model assumes full employment among high skilled workers, and excess capacity (or unemployment) among lower skilled workers.

measure increases only marginally by 0.4 and 0.5 per cent in 2020 and 2050.[24] Given the small changes in employment income there are no significant income distribution effects. However, positive welfare effects (as measured in Table 3 by aggregate household expenditure levels) are experienced across all representative household groups in the model.

Under the thermal energy efficiency scenarios overall coal production declines by 12.2 and 29 per cent in 2020 and 2040 respectively. Again, despite these relatively large declines in one sector's output levels, overall economic activity increases by 0.2 and 0.5 per cent in the two periods, with aggregate demand stimulated by lower producer and consumer prices. The employment effects are slightly higher than under the electricity scenarios; skilled wages increase by 0.5 and 1.1 per cent, and low-skilled employment increases by 0.3 and 0.8 per cent in the two periods. The comparative static GDP impact is also slightly higher, measured at 0.4 and 0.9 per cent respectively. Changes in household expenditure levels are marginally higher among high income households.

1.4.1.3 Commercial Energy Efficiency

The commercial energy efficiency scenarios consider efficiency gains in the use of electricity in the production processes of various services sectors. The weighted average decline in electricity use in the commercial sectors is about 8 per cent in 2015, reaching 15 per cent by 2030 and staying at this level through 2050 (Table 3). Despite the relative size of the commercial sectors in terms of contribution to GDP, electricity use is relatively low compared to industrial sectors. As a result the commercial energy efficiency scenarios have a limited impact on the economy in terms of overall production levels, GDP, employment and household income changes. As shown in Table 3, overall electricity supply declines by 1.5 and 2.7 per cent in 2015 and 2030. A small rise in aggregate demand, however, leads to a 0.02 and 0.04 per cent increase in overall economic activity. Changes in skilled wages, low-skilled employment and household expenditure levels (welfare) are all small but positive (around 0.1 and 0.2 per cent).

Table 3: Results from Energy Efficiency Simulations: Percentage Changes Relative to Base Case

	Industrial Energy Efficiency				**Commercial Energy Efficiency (Electricity)**	
	Electricity Efficiency		**Thermal Efficiency (Coal)**			
	2020	**2050**	**2020**	**2040**	**2015**	**2030**
Simulation: Weighted average decline in electricity/coal use in industry or commerce	21.9%	28.5%	19.5%	45.2%	8.0%	15.0%
Domestic production effects (activity output)						
Electricity supply	-7.7%	-10.0%			-1.5%	-2.7%
Coal supply			-12.2%	-29.0%		
Economy-wide production	0.2%	0.2%	0.2%	0.5%	0.02%	0.04%
Production prices (PPI)	-0.06%	-0.08%	-0.03%	-0.06%	0.00%	-0.01%
Changes in wages/employment and value added						
Skilled wages	0.5%	0.7%	0.5%	1.1%	0.2%	0.1%
Low-skilled employment	0.5%	0.6%	0.3%	0.8%	0.1%	0.2%
Gross Domestic Product (value added)	0.4%	0.5%	0.4%	0.9%	0.1%	0.1%
Changes in household expenditure/welfare						
Low income	0.3%	0.4%	0.3%	0.7%	0.1%	0.1%
Middle income	0.4%	0.5%	0.4%	0.8%	0.1%	0.1%
High income	0.3%	0.4%	0.4%	0.9%	0.1%	0.1%

Source: CGE model results

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[24] In simulations of this nature the GDP change should be understood as the comparative static GDP estimate, i.e. the percentage difference between simulated GDP and the base-level GDP, and not the GDP growth level.

In conclusion, energy efficiency gains modelled here generally have small but positive overall production effects in the economy. Output and employment losses in the coal mining and electricity generation sectors are generally offset by gains in other sectors that benefit from lower production costs, resulting in unambiguously positive but small employment effects. Household welfare effects are also small but positive, with the distribution of gains depending on the type of energy efficiency modelled; for example, electricity efficiency appears to benefit low and high income households least, while high income households gain most from thermal efficiency gains. These distributional effects, however, are too small to be overly concerned about the socio-economic implications. Of course, model results from the mining, industrial and commercial energy efficiency scenarios are not directly comparable given that the input parameters for each simulation as well as the production structures of these sectors differ significantly.

1.4.2 Structural Change Wedges[25]

1.4.2.1 Overview

In these scenarios the economic implications of a relative shift in energy supply away from carbon-based or emissions-intensive production processes towards cleaner, more environmentally friendly production processes are investigated. Three main mitigation scenarios are considered, namely a renewables intensive and a nuclear intensive scenario for electricity generation, and a biofuels scenario for liquid fuel supply. The results under each of these outcomes are compared against a reference case.

The study uses a SAM multiplier model[26] to analyse the structural change effects. The model produces results on sectoral output levels, employment and household incomes associated with the structural shifts in the composition of energy supply. The input-output table was adjusted to incorporate different production processes within the electricity (coal-fired plants, nuclear power stations, renewable energy and gas turbines) and petroleum (crude oil refineries, CTL plants, GTL plants and biofuels) sectors.[27]

1.4.2.2 Reference Case

The reference case itself, in this case ‘growth without constraints’, also assumes structural shifts in the output mix of electricity and petroleum over time. The MARKAL model results show the least cost optimisation energy output shares for the electricity and petroleum sectors. The shares by 2015, 2030 and 2050 are extracted and used to generate a counterfactual ‘path’ in the SAM multiplier model. This represents the reference case against which results under mitigation actions can be compared.[28]

1.4.2.3 Nuclear Intensive Scenario and Renewables Scenarios for the Electricity Sector

Under the nuclear intensive scenario there is a strong drive to increase the electricity output share from nuclear power. As shown in Figure 11 the electricity output share under the nuclear intensive scenario is no different from the reference case in 2015. Consequently no change from the reference case scenario is reported for this year. By 2030 the nuclear share rises rapidly to

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[25] A summary of results is supplied in this section. Please refer to the earlier SBT 5 Technical Document for further details.

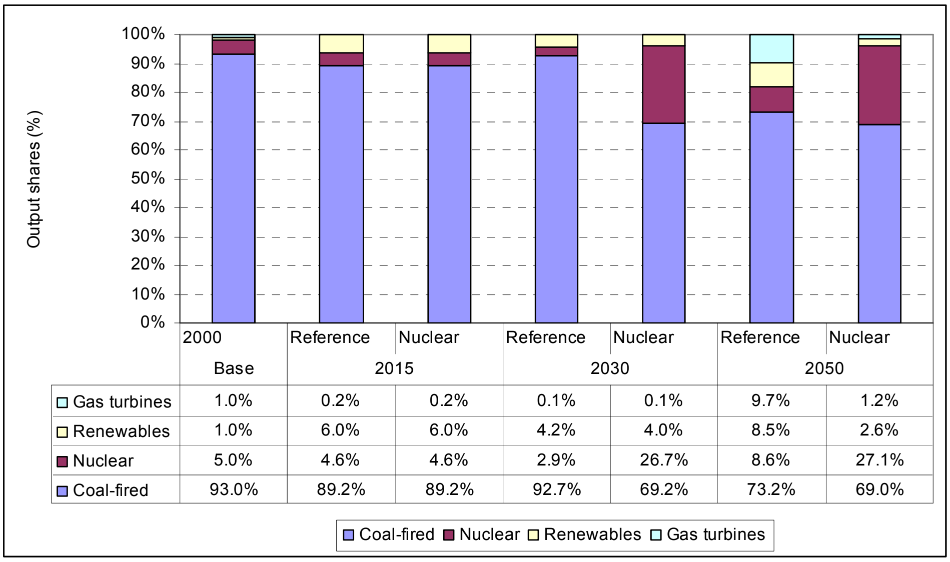
[26] This is similar to an input-output model, except that the SAM allows for so-called multi-product activities and also links information on factors of production (employment), households, government, savings and investments, as well as trade flows. See technical document from SBT 5 for more information about this type of modelling.

[27] This is a similar adjustment to the one explained in section 1.2.2.2 of this report.

[28] The structural shifts in output mix reported here are for individual wedges, and therefore differ from those used in the combined scenarios, Start Now*Start Now*, Scale Up*Scale Up* and Use the Market*Use the Market*.

27 per cent and remains roughly constant at this level through 2050. The reference case changes somewhat between 2030 and 2050.

Figure 11: Comparison of Output Shares under the Nuclear Intensive Scenario and Reference Case



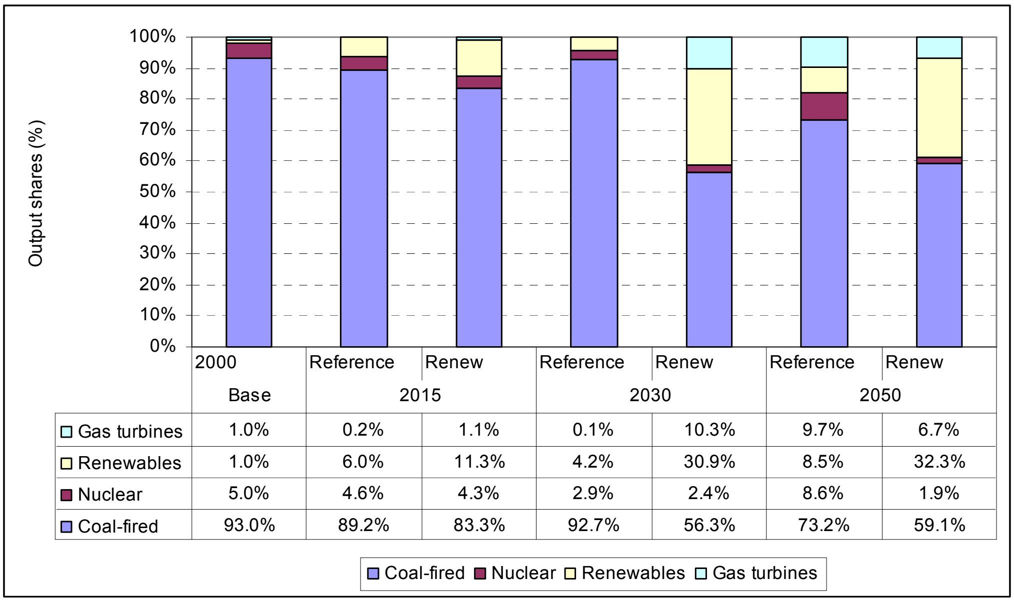
	2000	Reference	Nuclear	Reference	Nuclear	Reference	Nuclear
	Base	2015		2030		2050	
□ Gas turbines	1.0%	0.2%	0.2%	0.1%	0.1%	9.7%	1.2%
□ Renewables	1.0%	6.0%	6.0%	4.2%	4.0%	8.5%	2.6%
■ Nuclear	5.0%	4.6%	4.6%	2.9%	26.7%	8.6%	27.1%
□ Coal-fired	93.0%	89.2%	89.2%	92.7%	69.2%	73.2%	69.0%

Source: MARKAL model results for initial wedges.

Note: “Base” refers to the SAM multiplier model base for the year 2000. The scenario results are compared against the reference case.

Under the renewables scenario the renewables output share increases to 11.3, 30.9 and 32.3 per cent in 2015, 2030 and 2050, relative to the reference case shares of 6.0, 4.2 and 8.5 per cent (see Figure 12). As is the case with the nuclear scenario, the output shares under the renewables scenario remains fairly stable between 2030 and 2050, but since the output shares in the reference case do change, some differences between the renewables and reference cases will emerge in the results.

Figure 12: Comparison of Output Shares under the Renewables Scenario and Reference Case



	2000	Reference	Renew	Reference	Renew	Reference	Renew
	Base	2015		2030		2050	
□ Gas turbines	1.0%	0.2%	1.1%	0.1%	10.3%	9.7%	6.7%
□ Renewables	1.0%	6.0%	11.3%	4.2%	30.9%	8.5%	32.3%
■ Nuclear	5.0%	4.6%	4.3%	2.9%	2.4%	8.6%	1.9%
■ Coal-fired	93.0%	89.2%	83.3%	92.7%	56.3%	73.2%	59.1%

Source: Earlier MARKAL model results

Note: "Base" refers to the SAM multiplier model base for the year 2000. The scenario results are compared against the reference case.

The percentage change in production under the nuclear intensive scenario compared against the reference case is shown in Table 4. As expected, the demand for coal and lignite products declines significantly (4.4 per cent) under this scenario in 2030, given the drop in electricity generated in coal-fired plants (-25.3 per cent). By 2050, however, under the reference case, output from nuclear energy also rises relative to electricity from coal-fired plants. Hence the change in coal output (relative to the reference case) is lower at this point. The reference case also envisages a sharp increase in electricity output from renewable sources and gas, hence under the nuclear scenario, which does not rely on these energy sources, comparative output levels are much lower.

Under the renewables scenario we notice declines in output from coal mining due to the decline in electricity from coal-fired plants. We also note a decline in nuclear output, which is an important future electricity source in the reference case. Here it is replaced by electricity from renewable sources. The large percentage increase in output from renewables is indicative of the small base from which it grows.

Table 4: Production Levels under the Nuclear/Renewables Scenario Compared Against the Reference Case

	Nuclear intensive scenario			Renewables intensive scenario		
	2015	2030	2050	2015	2030	2050
Coal and lignite	0.0%	-4.4%	-0.8%	-1.1%	-6.9%	-2.9%
Crude oil and other mining	0.0%	0.1%	0.0%	0.0%	0.1%	0.0%
Petroleum	0.0%	0.9%	0.7%	0.0%	0.1%	-0.3%
Electricity: Coal-fired	0.0%	-25.3%	-6.0%	-6.6%	-38.8%	-19.1%
Electricity: Nuclear	0.0%	816.9%	214.9%	-5.0%	-17.4%	-78.4%
Electricity: Renewable sources	0.0%	-5.9%	-68.9%	86.9%	636.3%	281.6%
Electricity: Gas turbines	0.0%	-0.6%	-87.4%	524.6%	7047.7%	-30.8%
Total activity output	***0.0%***	***0.0%***	***0.0%***	***0.0%***	***0.0%***	***0.0%***

Source: SAM multiplier model results

Despite output levels remaining stable, small employment effects can be observed when comparing the nuclear scenario against the reference case. Output-employment ratios and skills intensities in nuclear power plants are different from those of other electricity generation processes.[29] Hence we expect to see some relative shifts in employment levels and/or skills distributions. Figure 13 shows the percentage changes in employment under the nuclear scenario compared to the reference case, disaggregated by skill. Given lower output employment ratios in nuclear power plants all skill classes experience negative employment effects relative to the reference case. However, high-skilled workers are likely to be less affected, with employment dropping by only 0.02 per cent compared to the reference case, compared to 0.08 per cent for low-skilled workers by 2050.[30]

Figure 13 also shows the changes in per capita income levels. Given the small overall employment changes relative to the reference case, income changes are small, yet negative across all household types. Given the skills changes under the nuclear scenario and the fact that low-skilled workers are typically attached to lower income households, poorer households are likely to be disadvantaged more.

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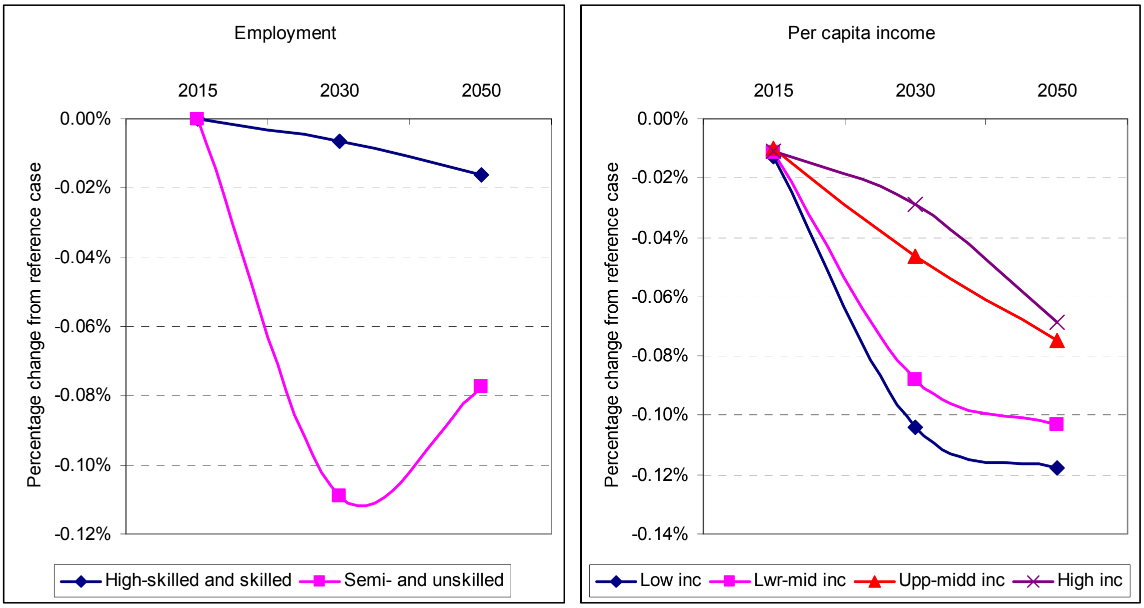
[29] Information on labour intensity or 'jobs per megawatt installed capacity' (operational multipliers only) is obtained from a report by AGAMA (2003), which draws on Eskom employment figures in various plants in 2003. In particular, the study finds that there are on average 0.93 jobs/MW in coal-fired plants, 0.54 jobs/MW in nuclear plants, 1 job/MW in renewable energy (average of hydro, pumped storage and solar energy) and 0.13 jobs/MW in gas turbines. Data on the skills composition within these sub-industries was not readily available, and hence assumptions had to be made. For coal the assumed skilled to unskilled ratio is 41:59, for nuclear 74:26, for renewables 50:50 and for gas 43:57.

[30] In an input-output model prices (and hence wages) are considered fixed, hence in contrast to the CGE model we interpret a change in the value added of labour as a change in employment, irrespective of the skill level. Therefore, the assumption that excess production capacity exists also extends to the labour market.

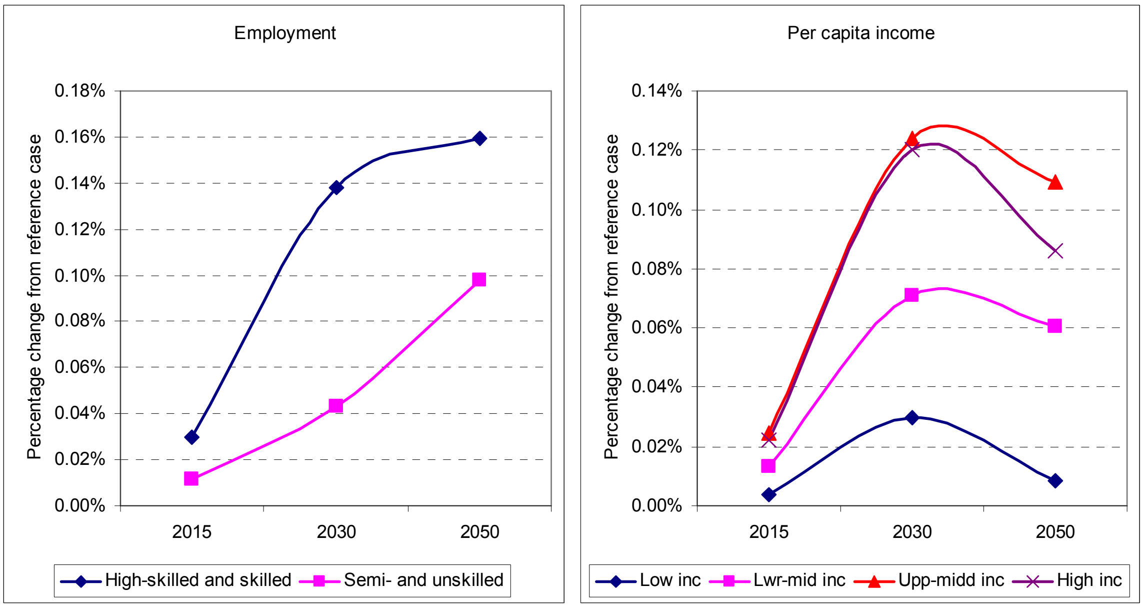
Figure 13: Employment Effects and Per Capita Incomes under the Nuclear Scenario Compared Against the Reference Case (GWC)



Source: SAM multiplier model results

Small employment effects can also be observed when comparing the renewables scenario against the reference case. As before, results observed are of course sensitive to the assumed output-employment ratios (relatively high for renewables) and skills intensities (lower skills intensity than, for example, nuclear power, but higher than coal) (see footnote 29). Figure 14 shows the percentage changes in employment under the renewables scenario compared to the reference case, disaggregated by skill. Employment levels rise marginally relative to the reference case, with high-skilled workers likely to gain relatively more. As far as per capita incomes are concerned all household groups gain. However, in terms of the distributional effects we again notice that high-income households gain relatively more, thus leading to increased inequality. These changes are, however, very small, with changes below 0.12 per cent unlikely to have any significant effect on an inequality measure such as the Gini coefficient.

Figure 14: Employment Effects and Per Capita Incomes under the Renewables Scenario Compared Against the Reference Case (GWC)

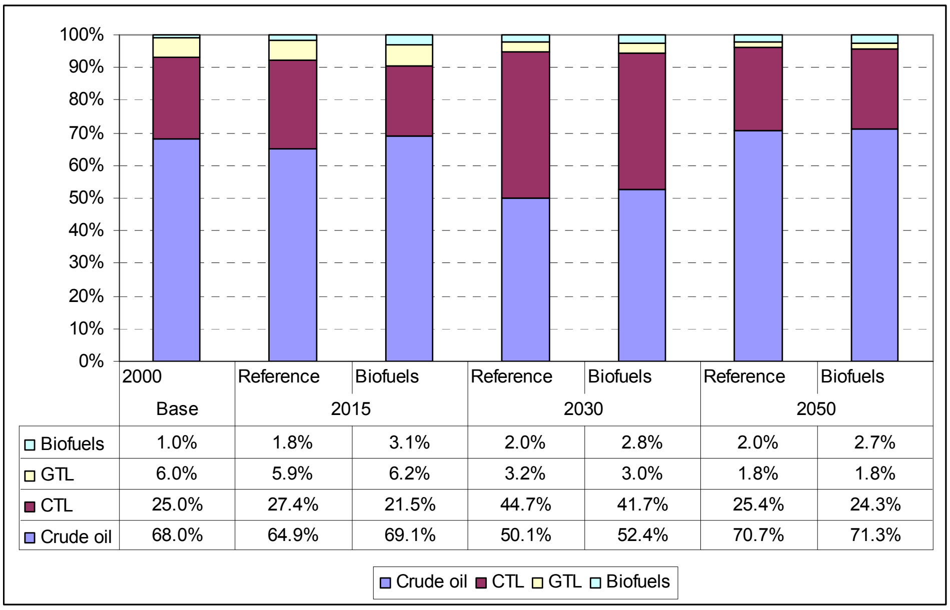


Source: SAM multiplier model results

1.4.2.4 Biofuels Scenario for the Petroleum Sector

The biofuels scenario is preliminarily modelled here as an alternative to the reference case rather than a mitigation action. As such it differs very little from the reference case (see Figure 15). The reference case considers, relative to the model base, an initial quadrupling of the production capacity of CTL refineries. This becomes most visible by 2030. In the subsequent period the output share of CTL declines again as an increased dependence on crude oil develops.

Figure 15: Comparison of Output Shares under the Biofuels Scenario and Reference Case



	2000	Reference	Biofuels	Reference	Biofuels	Reference	Biofuels
	Base	2015		2030		2050	
□ Biofuels	1.0%	1.8%	3.1%	2.0%	2.8%	2.0%	2.7%
□ GTL	6.0%	5.9%	6.2%	3.2%	3.0%	1.8%	1.8%
■ CTL	25.0%	27.4%	21.5%	44.7%	41.7%	25.4%	24.3%
□ Crude oil	68.0%	64.9%	69.1%	50.1%	52.4%	70.7%	71.3%

Note: “Base” refers to the SAM multiplier model base for the year 2000. The scenario results are compared against the reference case.

In the biofuels scenario a slightly greater reliance on biofuels is modelled, but given the small overall contribution of biofuels, even a large increase in biofuels output will do little to alter production and employment at a national level in any significant way. As shown in Table 5 below, a visible effect under the biofuels scenario is an increase in agricultural output relative to the reference case. This comes at the expense of coal mining output. The scenario also allows for slightly higher output from crude oil refineries. Consequently, CTL is the main liquid fuel source being replaced by biofuels, which also explains the decline in coal production levels.

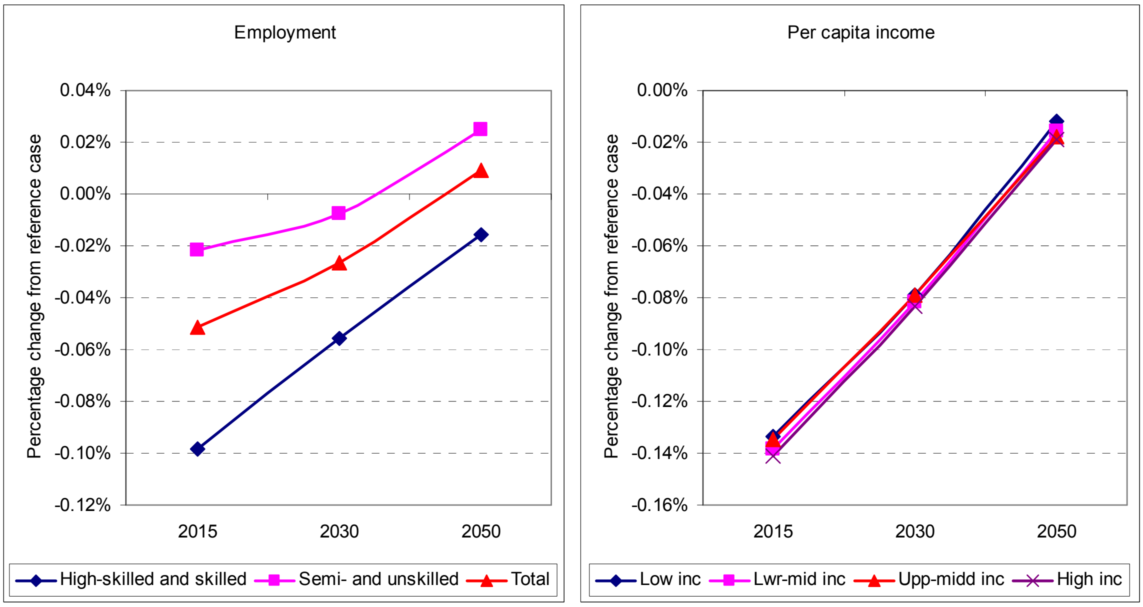
Table 5: Production Levels under the Biofuels Scenario Compared Against the Reference Case

	2015	2030	2050
Agric forestry & fish	0.5%	0.4%	0.3%
Coal and lignite	-4.8%	-2.2%	-0.9%
Crude oil and other mining	0.4%	0.0%	0.0%
Crude oil refineries	5.9%	4.4%	0.6%
Coal to liquids	-21.8%	-6.9%	-4.6%
Gas to liquids	5.5%	-6.9%	-4.6%
Biofuels	68.9%	41.8%	35.1%
Total activity output	***-0.1%***	***-0.1%***	***0.0%***

Source: SAM multiplier model results

Employment is slightly lower under the biofuels scenario than under the reference case. This may seem surprising, given the high labour intensity of the agricultural sector. However, coal that is displaced is equally labour intensive, while the biofuels scenario in particular assumes a greater crude oil share. Since crude oil is largely imported, an increase in demand for crude oil implies that more funds leave South Africa to pay for imports. Only by 2050 does the biofuels scenario lead to positive employment effects, with low-skilled workers being the main beneficiaries here. However, income levels remain negative compared to those under the reference case, even in 2050, despite positive employment. This suggests that the household income gains associated with employment gains among low-skilled workers in 2050 is more than offset by income losses associated with job losses among high skilled workers. This is true across all household groups, with virtually no distributional effects discernible, as shown in Figure 16.

Figure 16: Employment Effects and Per Capita Incomes under the Biofuels Scenario Compared Against the Reference Case



Source: SAM multiplier model results

1.4.3 The Economic Impact of a CO_2 Emissions Tax

1.4.3.1 Overview

Taxes are ultimately distortionary since they cause a reallocation of resources away from the so-called Pareto efficient allocation. Consequently, in a CGE model, which is based on neoclassical microeconomic principles, we often expect to see welfare losses arising from taxes. However, depending on how revenue from taxes is used, some of these welfare losses may be mitigated. The aim of this analysis is twofold: firstly, to determine the economic effects of various levels of CO_2 taxes in terms of GDP, employment and welfare; and, secondly, to consider which revenue recycling scheme would ultimately cause a CO_2 tax to be the least distortionary, given various modelling assumptions. In doing so the analysis may shed some light on changes in the energy output mix that may arise in response to the implementation of a CO_2 tax. The analysis may also assist policymakers in deciding on an appropriate level of a CO_2 tax.

The analysis here converts a given level of a CO_2 tax to a comparative tax on coal, crude oil or natural gas used as intermediate inputs in production processes. Table 6 shows the various CO_2 tax levels which we model, expressed as a Rand value per ton of CO_2 emitted, while the three rows directly below show the associated taxes on coal, crude oil and natural gas. Given the high emissions associated with coal use, the implied tax rates on coal are extremely high; for example, coal prices are likely to rise 25 times if the CO_2 tax were R1000. At present levels of between R250 and R750 are being considered in the *Use the Market* scenario. The table is useful for putting into perspective the kind of economic shock that the implementation of CO_2 taxes at these levels implies.

Table 6: Energy Use Tax Equivalent of Rand per Ton CO_2 Taxes

Rand / ton tax		R 25	R 50	R 75	R 100	R 200	R 300	R 400	R 600	R 800	R 1,000
Equivalent tax on energy inputs	Coal	59.4%	118.8%	178.2%	237.6%	475.2%	712.8%	950.5%	1425.7%	1900.9%	2376.1%
	Crude	2.8%	5.6%	8.4%	11.2%	22.4%	33.5%	44.7%	67.1%	89.4%	111.8%
	Gas	0.1%	0.2%	0.3%	0.4%	0.8%	1.2%	1.6%	2.5%	3.3%	4.1%

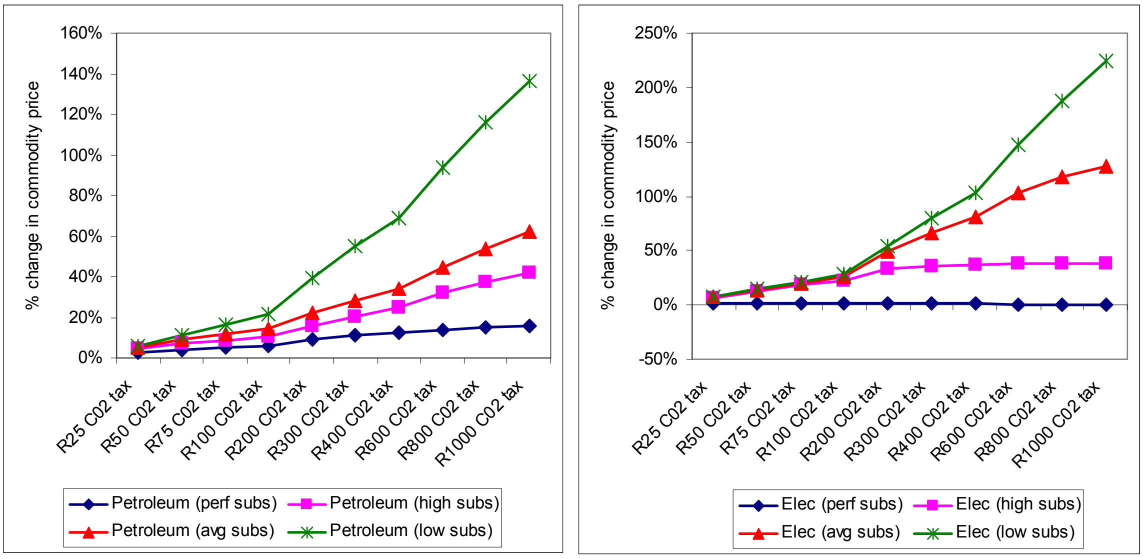
Source: Author's calculations based on South African SAM (2000) and information supplied by Andrew Marquard, Energy Research Centre.

1.4.3.2 Prices, Output and Employment

The aim of an emissions tax is to reduce emissions through incentivising producers to switch away from processes associated with high levels of emissions. The economic welfare losses of rising energy prices therefore have to be weighed against the social welfare gains of reduced emissions. These social welfare gains are not measured in standard CGE models; what we are concerned about here are only the pure economic effects.

As coal, crude oil and natural gas prices rise we expect to see production costs of producers to increase. Ultimately the impact on the energy prices faced by consumers depends on a number of factors. The extent to which highly taxed commodities (coal, crude oil and gas) are still used in the supply of electricity and petroleum products is an important factor, as are production costs in the alternative energy supply sectors (e.g. non-carbon-based) that expand as a result of the CO_2 tax. There are also, of course, costs involved in switching. In the CGE model the cost of switching is influenced by the degree of substitutability allowed for in the commodity aggregation function. To illustrate this effects, we consider low (0.5), average (4) and high (10) elasticities of substitution, as well as a special case with perfect substitution (infinite). Figure 17 shows how these various substitution possibilities impact on energy consumer prices (petroleum and electricity). The easier it is to substitute, the lower the price impact will be. All subsequent simulations were done using the more moderate 'average subsidy', also used in the modelling of the various mitigation scenarios.

Figure 17: CO_2 Tax Simulations: Impact of Different Substitution Possibilities on Energy Prices



Source: CGE model results

Revenue from a CO_2 tax can be used in a variety of ways by government. As a base scenario we assume government simply uses the additional revenue to reduce its deficit. This increases savings in the economy, which then under the savings-investment balance implies that investments will go up. We call this the 'non-neutral' scenario. Later we compare results under various revenue neutral scenario, whereby additional revenue is recycled in the form of production subsidies for nuclear/renewable energy and biofuels, or in the form of food subsidies, general VAT subsidies or income tax subsidies. We also consider an option whereby additional revenue is passed on to poorer households in the form of increased welfare transfers.

Table 7 shows the percentage changes in production levels in various industries under the 'non-neutral' scenario, i.e. additional revenue generated by the tax is added to government revenue, which eventually makes its way to the pool of savings via the budget surplus. The table clearly shows the extent to which substitution takes place, particularly in the electricity sector. Looking at the petroleum sector, we note that output from CTL plants is virtually wiped out once the tax reaches R600 and beyond. At this level output from coal-fired electricity plants is down by two-thirds. While a reduction in coal use would, of course, ultimately be the aim of a mitigation action such as this, we also note that overall production levels in other sectors decline as a result of the CO_2 tax. This is due to indirect increases in transformed energy prices (electricity and petroleum) and direct increases in primary energy prices (coal, crude oil and gas).

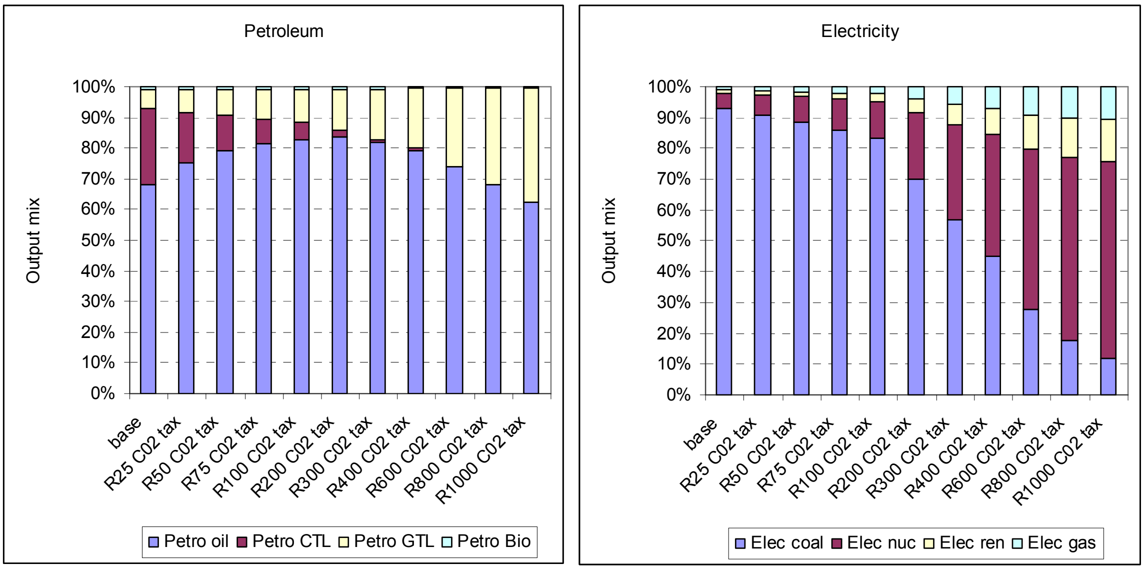
Table 7: CO_2 Tax Simulations: Percentage Change in Output Levels (Selected Sectors)

	R25 C02 tax	R75 C02 tax	R100 C02 tax	R200 C02 tax	R300 C02 tax	R600 C02 tax	R1000 C02 tax
Agriculture	0.0%	-0.2%	-0.3%	-0.7%	-1.3%	-2.8%	-4.6%
Coal and lignite	-11.7%	-23.9%	-27.5%	-35.9%	-40.6%	-48.5%	-53.2%
Petroleum: Crude oil refineries	6.0%	11.3%	12.1%	10.8%	7.0%	-6.0%	-20.9%
Petroleum: CTL	-36.9%	-70.2%	-78.2%	-91.9%	-96.0%	-98.9%	-99.6%
Petroleum: GTL	17.3%	45.8%	58.3%	103.0%	144.6%	267.2%	431.4%
Petroleum: Biofuels	-0.4%	-6.2%	-9.9%	-24.6%	-36.1%	-56.4%	-69.0%
Electricity: Coal-fired	-4.1%	-11.6%	-15.2%	-28.3%	-39.8%	-64.7%	-81.7%
Electricity: Nuclear	26.9%	91.4%	128.7%	305.6%	510.9%	1126.1%	1717.9%
Electricity: Renewables	28.8%	97.2%	136.5%	322.6%	538.6%	1193.5%	1842.2%
Electricity: Gas turbines	27.2%	90.6%	126.3%	289.9%	471.1%	975.6%	1410.1%
Other sectors	0.0%	-0.2%	-0.3%	-1.0%	-1.6%	-3.6%	-5.7%
Total	**-0.3%**	**-0.8%**	**-1.0%**	**-1.8%**	**-2.4%**	**-4.1%**	**-5.7%**

Source: CGE model results

The shift in output mix in electricity and petroleum looks very different from the output mix predicted by the MARKAL model for the *Use the Market* scenario (see Figure 18). Of course, the CGE model does not take into account emissions constraints. However, this explains why the CGE model results from the *Use the Market* scenario showed such large negative effects, as the output mix imposed was not the optimal one (from an economic point of view) under the conditions.

Figure 18: CO_2 Tax Simulations: CGE Model Predicted Shifts Output Mix

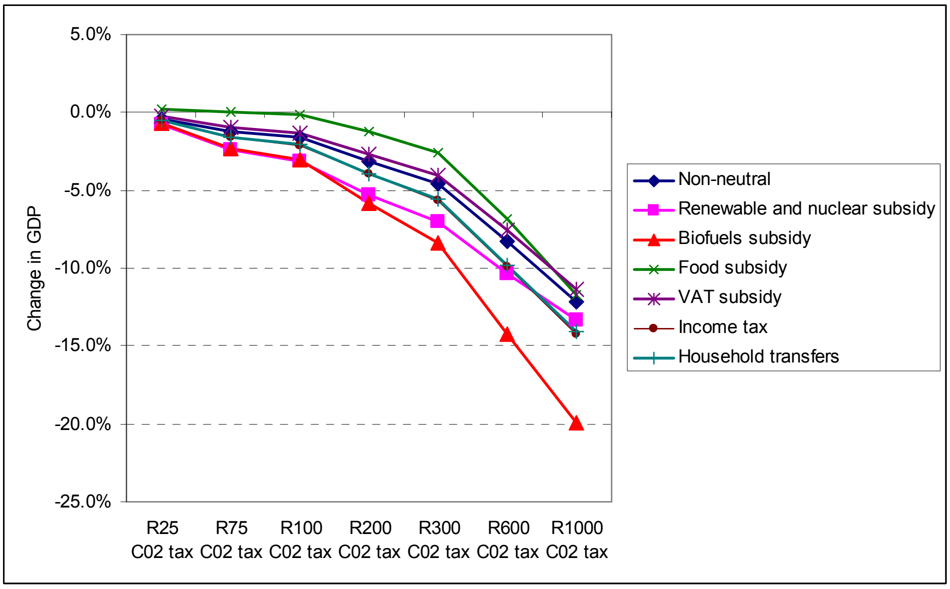


Source: CGE model results

Declining production levels already give an indication that GDP is likely to decline as a result of the CO_2 tax. As noted, in addition to the non-neutral scenario, we also consider various revenue recycling options. In Figure 19 we compare the GDP effects under a variety of these closures, namely a renewables and nuclear subsidy, a biofuels subsidy, a food subsidy, a general VAT subsidy, an income tax subsidy and a general increase in welfare transfers. Under the non-neutral scenario GDP declines from about 0.5 per cent for a R25 CO_2 tax, increasing to 13.9 per cent for a R1000 tax. At the proposed tax of R250 per ton of CO_2 GDP is likely to decline by about 5 per cent. Of all the alternative revenue recycling options the food subsidy appears to be the best option, while the two production subsidies yield the worst results. In fact, at low levels of taxation the food subsidy may actually cause GDP to increase marginally. This result is consistent with Van Heerden et al.'s (2006) results for a R35/ton CO_2 tax.[31]

The actual amount recycled under each scenario is not exactly the same, hence the scenarios are not directly comparable. It may well be that in the absence of a CO_2 tax that an income tax subsidy, for example, may have a more favourable outcome than a food subsidy.

Figure 19: CO_2 Tax Simulations: GDP Effects Under Alternative Revenue Recycling Options



Source: CGE model results

Production subsidies should not be summarily dismissed because they fail to reduce the negative impact of a CO_2 tax on GDP. If the aim is to mitigate the rise in energy prices they can be very successful. Figure 7 shows the rise in energy prices (electricity and petroleum) with and without nuclear/renewables or biofuels production subsidies. However, ultimately, because GDP declines more when a production subsidy is introduced suggests that the subsidisation of a less efficient production process is not an economically sensible option.

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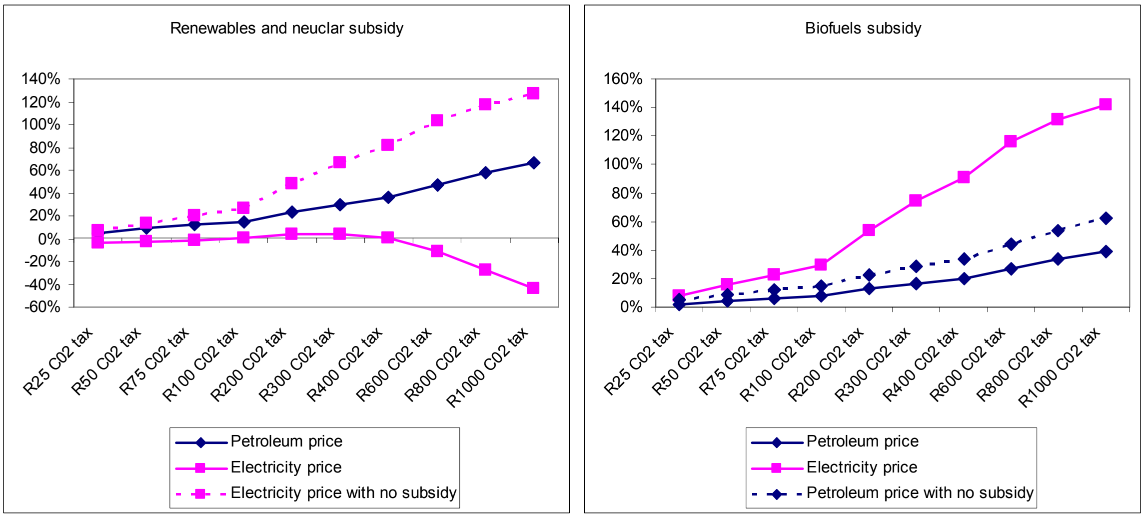
[31] Van Heerden et al. (2006) only consider a R35 tax, hence it is not possible to say whether our results are consistent at all levels of taxation.

Figure 20: CO$_2$ Tax Simulations: Impact of Renewables/Nuclear and Biofuels Production Subsidies on Energy Prices



Source: CGE model results

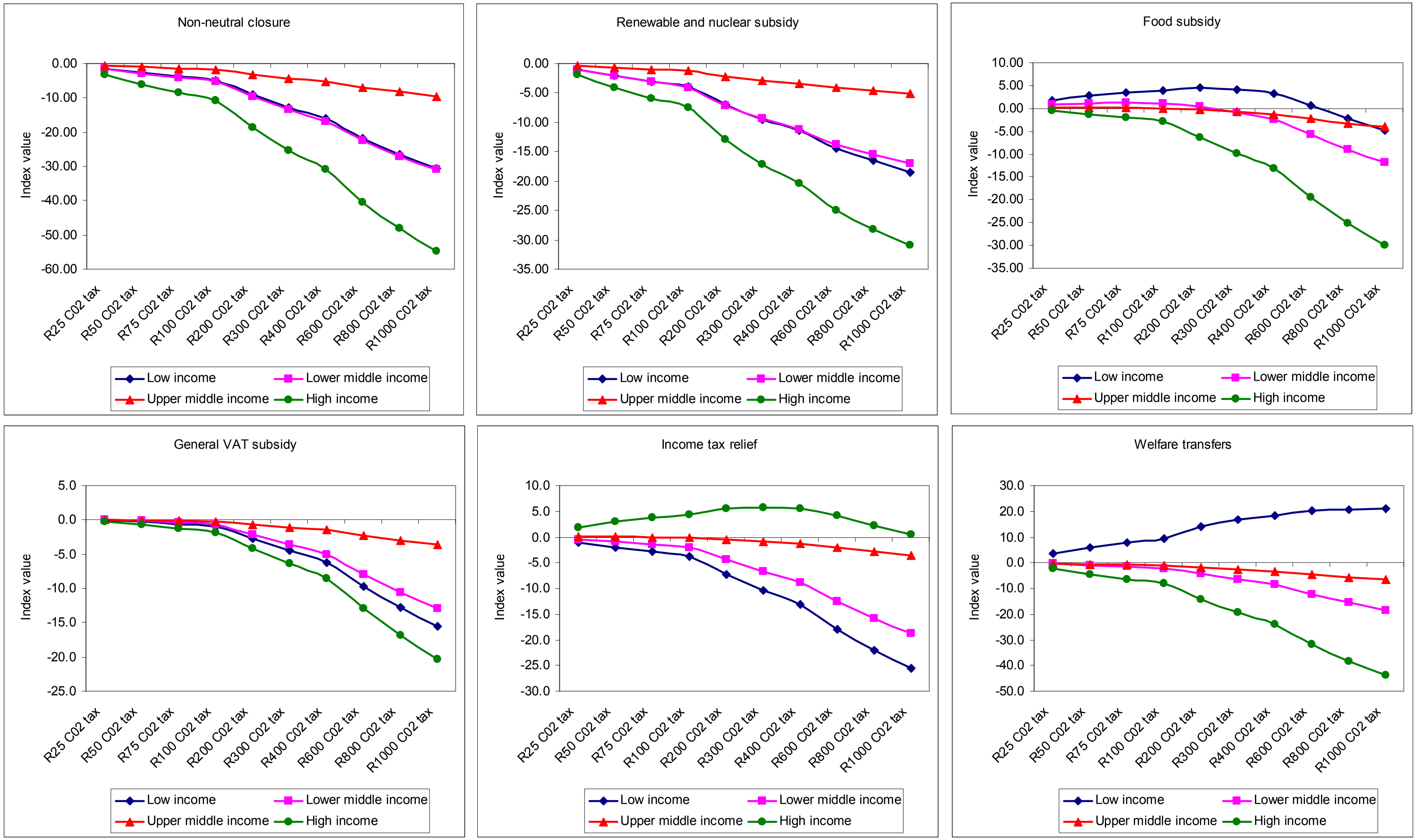
Next, we turn to employment effects. The CO$_2$ tax generally has a negative employment impact, especially at high levels of taxation. At the lower levels some of the revenue recycling schemes, in particular the biofuels subsidy, the food subsidy and the general VAT subsidy have a positive effect on employment . In the case of the biofuels and food subsidies, for example, demand for food and agricultural output increases. Both these sectors are characterised by fairly high labour intensities, hence the positive employment effect. However, at higher levels of taxation employment effects become negative, as the effect of high energy prices overwhelm any employment gains associated with the targeted revenue recycling schemes.

Table 8: CO_2 Tax Simulations: Employment and Wage Changes

		R25 C02 tax	R75 C02 tax	R100 C02 tax	R200 C02 tax	R300 C02 tax	R600 C02 tax	R1000 C02 tax
Non-neutral closure								
Employment changes	Semi-skilled	-0.4%	-1.4%	-2.0%	-4.4%	-6.6%	-12.2%	-17.4%
	Unskilled	-1.1%	-3.0%	-3.8%	-6.8%	-9.4%	-15.8%	-22.0%
Wage changes	High-skilled	-1.6%	-4.4%	-5.6%	-9.8%	-13.4%	-21.7%	-29.5%
	Skilled	-1.5%	-4.1%	-5.2%	-9.1%	-12.5%	-20.6%	-28.2%
Neutral - subsidise renewables and nuclear								
Employment changes	Semi-skilled	-0.4%	-1.6%	-2.2%	-4.1%	-5.5%	-7.7%	-8.5%
	Unskilled	-1.0%	-2.8%	-3.6%	-6.2%	-8.2%	-12.4%	-16.1%
Wage changes	High-skilled	-1.0%	-3.2%	-4.1%	-7.2%	-9.6%	-14.4%	-18.6%
	Skilled	-1.3%	-3.7%	-4.7%	-8.1%	-10.7%	-16.0%	-20.7%
Neutral - subsidise biofuels								
Employment changes	Semi-skilled	0.0%	-0.7%	-1.2%	-3.2%	-5.2%	-10.1%	-14.7%
	Unskilled	0.4%	0.5%	0.4%	-0.1%	-0.9%	-4.0%	-7.8%
Wage changes	High-skilled	-1.2%	-3.6%	-4.7%	-8.8%	-12.3%	-20.7%	-28.7%
	Skilled	-1.0%	-3.1%	-4.1%	-7.8%	-11.2%	-19.3%	-27.2%
Neutral - food subsidy								
Employment changes	Semi-skilled	0.5%	0.6%	0.4%	-0.9%	-2.5%	-7.4%	-12.5%
	Unskilled	0.5%	0.8%	0.8%	0.4%	-0.5%	-4.1%	-8.7%
Wage changes	High-skilled	0.3%	0.2%	-0.1%	-1.5%	-3.3%	-9.1%	-15.9%
	Skilled	0.4%	0.4%	0.3%	-0.8%	-2.4%	-7.9%	-14.3%
Neutral - general VAT subsidy								
Employment changes	Semi-skilled	0.1%	-0.3%	-0.6%	-2.0%	-3.5%	-7.5%	-11.4%
	Unskilled	0.1%	-0.2%	-0.4%	-1.2%	-2.2%	-5.4%	-9.2%
Wage changes	High-skilled	0.0%	-0.5%	-0.8%	-2.2%	-3.6%	-7.9%	-12.7%
	Skilled	0.0%	-0.4%	-0.6%	-1.8%	-3.1%	-7.3%	-12.2%
Neutral - income tax relief								
Employment changes	Semi-skilled	-1.2%	-3.5%	-4.5%	-8.4%	-11.6%	-18.8%	-25.1%
	Unskilled	-1.0%	-2.6%	-3.4%	-6.2%	-8.6%	-14.5%	-20.3%
Wage changes	High-skilled	-1.3%	-3.7%	-4.7%	-8.4%	-11.5%	-19.0%	-26.1%
	Skilled	-1.4%	-3.6%	-4.7%	-8.3%	-11.4%	-18.9%	-26.1%
Neutral - welfare transfers								
Employment changes	Semi-skilled	-1.1%	-3.2%	-4.2%	-7.8%	-10.9%	-17.9%	-24.0%
	Unskilled	-1.0%	-2.6%	-3.4%	-6.2%	-8.6%	-14.5%	-20.3%
Wage changes	High-skilled	-1.4%	-3.9%	-5.0%	-8.8%	-12.1%	-19.8%	-27.0%
	Skilled	-1.4%	-3.7%	-4.7%	-8.3%	-11.5%	-19.0%	-26.3%

Finally, we consider some of the welfare effects. Figure 21 shows the results under all the different revenue recycling options. None of the outcomes are necessarily surprising. The food subsidy benefits low-income households most, given the share of poor households' budget spent on food. Similarly, the welfare transfer scenario also benefits the poor, given that welfare transfers are means tested and targeted at poor people. In contrast, an income tax relief programme benefits mostly high income households, given that they contribute the bulk of income taxes in South Africa.

Figure 21: CO_2 Tax Simulations: Welfare Effects Under Alternative Revenue Recycling Options



1.4.3.3 Concluding Remarks

This section briefly reviewed some of the price, production, employment, GDP, savings, investments and welfare effects of a proposed tax on CO_2 emissions. The analysis can be used to determine a suitable level of taxation that would bring about a positive social outcome as far as emissions reductions are concerned without causing too much harm to the economy at large.

It was shown that any level of taxation induces switching away from CTL and coal-fired electricity plants. Although switching comes with a cost, increasing tax levels act as incentives to switch further away from coal-based processes, which is a desirable outcome from a mitigation point of view. It is clear, however, given the modelling assumptions, that at levels beyond R75 per ton of CO_2, and despite using the most efficient of the revenue recycling options available, the economic impact will be negative. At high levels of taxation, therefore, overall economic activity (production) and employment levels are likely to decline. GDP may fall by anything between 2 and 7 per cent for a R250 tax, and by between 9 and 17 per cent as the tax reaches R750 per ton of CO_2. It is for policymakers to decide what level of GDP decline is deemed acceptable given the associated mitigation reductions of the tax instrument.

1.5 Additional Tables and Figures

Table 9: Accounts in the SAM

SAM Code	Description	SAM Code	Description
Commodities		**Activities**	
cagfield	Agric field crops & forestry	aagric	Agric forestry & fish
caghort	Agric horticulture	acoal	Coal and lignite
caglive	Agric livestock fishing	agold	Gold and uranium ore
ccoal	Coal and lignite products	aomin	Crude oil and other mining
cgold	Gold and uranium ore product	afood	Food products
ccroil	Crude oil products	abev	Beverages and tobacco
comin	Other mining products	atext	Textiles
cfood	Food products	alwpap	Leather Wood and Paper
cbevs	Beverages and tobacco	apetro	Petroleum
ctext	Textile products	afert	Fertilisers
clwpap	Leather wood and paper products	apest	Pesticides
cpetro	Petroleum products	apharm	Pharmaceuticals
cfert	Fertilisers	aochem	Other Chemicals
cpcides	Pesticides	anonmet	Non metallics
cpharm	Pharmaceutical products	ametals	Metals
ochem	All other chemical products	amach	Machinery
cnonmet	Non metalic products	avehic	Vehicles
cmetprod	Metal products	aomanu	Other manufacturing
cmach	Machinery	aelec	Electricity
cvehic	Vehicles	awater	Water
comanu	Other manufacturing	aconst	Construction and Building
celec	Electricity	atrad	Trade and transposrt services
cwater	Water	aoserv	Other services
cconst	Construction and building		
ctraserv	Trade and transport services		
coserv	Other services		
Disaggregation of Petroleum and Electricity Activities			
apet_oil	Petroleum Crude oil based	aelec_coal	Electricity Coal based
apet_ctl	Petroleum Coal to liquids	aelec_nuclear	Electricity Nuclear
apet_gtl	Petroleum Gas to liquids	aelec_renew	Electricity Hydro & Renewables
apet_bio	Petroleum Biofuels	aelec_gas	Electricity Gas turbines
Factors of production		**Households**	
fgos	Gross operating surplus	hhlow	Low income households
fland	Land	hhlowmid	Lower middle income households
fhskil	High-skilled labour	hhuppmid	Upper middle income households
fskil	Skilled labour	hhhigh	High income households
fsskil	Semi-skilled labour		
fuskil	Unskilled labour		

Table 10: Disaggregated Petroleum and Electricity SAM Accounts

	Petroleum					Electricity				
	Original Petroleum Activity in SAM	**Crude oil**	**CTL**	**GTL**	**Biofuels**	**Original Electricity Activity in SAM**	**Coal-fired**	**Nuclear**	**Renew-ables**	**Gas turbines**
Agric field crops & forestry	350.72	0.04	0.12	0.03	350.54	15.11	13.86	0.84	0.19	0.23
Agric horticulture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agric livestock fishing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coal and lignite products	5,198.57	0.35	5,155.23	0.27	42.72	4,467.72	4,463.80	1.12	1.26	1.53
Gold and uranium ore product	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crude oil products	24,306.48	24,296.70	2.86	0.77	6.16	0.00	0.00	0.00	0.00	0.00
Other mining products	2,706.07	1.29	3.68	2,669.43	31.67	4.33	0.43	0.48	0.55	2.86
Food products	1.53	0.88	0.63	0.01	0.00	49.80	45.68	2.76	0.62	0.75
Beverages and tobacco	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Textile products	0.00	0.00	0.00	0.00	0.00	19.56	17.94	1.08	0.24	0.30
Leather wood and paper products	92.35	53.37	38.17	0.61	0.20	105.18	96.46	5.82	1.31	1.59
Petroleum products	4,100.44	1,593.86	2,453.00	39.49	14.09	199.56	0.85	191.09	1.07	6.54
Fertilisers and pesticides	0.00	0.00	0.00	0.00	0.00	12.64	11.59	0.70	0.16	0.19
Pharmaceuticals and other chemicals	1,793.20	1,036.28	741.16	11.93	3.83	102.39	93.91	5.67	1.27	1.55
Non metalic products	299.74	173.22	123.89	1.99	0.64	54.50	49.98	3.02	0.68	0.82
Metal products	246.94	142.70	102.06	1.64	0.53	411.80	377.66	22.79	5.13	6.22
Machinery	892.77	515.92	369.00	5.94	1.91	427.23	391.81	23.64	5.32	6.46
Vehicles	90.64	52.38	37.46	0.60	0.19	158.53	145.39	8.77	1.97	2.40
Other manufacturing	44.28	25.59	18.30	0.29	0.09	1,981.02	1,816.78	109.63	24.67	29.94
Electricity	825.03	476.78	341.00	5.49	1.76	1,911.61	1,753.13	105.79	23.80	28.89
Water	208.08	120.25	86.00	1.38	0.44	149.12	136.76	8.25	1.86	2.25
Construction and building	0.00	0.00	0.00	0.00	0.00	2,462.63	2,258.47	136.29	30.66	37.21
Trade and transport services	2,961.21	1,711.26	1,223.92	19.70	6.33	633.32	580.81	35.05	7.89	9.57
Other services	2,111.35	1,220.13	872.66	14.05	4.51	1,722.59	1,579.78	95.33	21.45	26.03
Gross operating surplus	8,895.22	6,037.16	2,228.99	537.22	91.85	14,197.85	13,187.90	727.86	124.11	157.97
Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
High-skilled labour	1,812.37	1,248.95	445.33	107.33	10.77	1,849.04	1,677.36	123.29	44.41	3.99
Skilled labour	452.40	344.91	84.23	20.30	2.96	598.37	566.58	20.73	10.15	0.91
Semi-skilled labour	846.76	560.01	223.11	53.77	9.87	1,312.60	1,274.79	18.02	18.32	1.47
Unskilled labour	47.66	20.48	20.38	4.91	1.89	173.99	167.63	2.67	3.44	0.25
Production rebates	-491.39	-333.51	-123.13	-29.68	-5.07	-33.22	-30.85	-1.70	-0.29	-0.37
Production taxes	106.36	72.18	26.65	6.42	1.10	293.43	272.56	15.04	2.57	3.26
Production subsidies	-3.80	-2.58	-0.95	-0.23	-0.04	-5.39	-5.00	-0.28	-0.05	-0.06
TOTAL	57,894.98	39,368.59	14,473.75	3,473.70	578.95	33,275.30	30,946.03	1,663.77	332.75	332.75

Note: Figures and millions of Rands, year 2000 prices.

Source: Control totals from SAM (2000); disaggregation based on author’s calculations.

Table 11: Industry-level Employment Levels by Skill

	High-skilled labour	**Skilled labour**	**Semi-skilled labour**	**Unskilled labour**	***Total***
Agric forestry & fish	26,286	20,963	399,864	545,856	*992,969*
Coal and lignite	6,091	2,580	41,269	5,762	*55,702*
Gold and uranium ore	23,178	31,269	230,744	28,181	*313,372*
Crude oil and other mining	9,238	16,541	93,869	28,398	*148,046*
Food products	25,274	25,363	107,176	61,288	*219,101*
Beverages and tobacco	10,152	15,124	33,322	10,895	*69,493*
Textiles	21,720	32,823	245,570	28,896	*329,009*
Leather Wood and Paper	26,087	24,546	134,899	36,034	*221,566*
Petroleum: Crude oil based	3,634	4,868	5,922	339	*14,763*
Petroleum: Coal to liquids	1,357	1,245	2,472	353	*5,428*
Petroleum: Gas to liquids	326	299	593	85	*1,303*
Petroleum: Biofuels	33	43	109	33	*217*
Fertilisers and pesticides	1,187	630	1,479	910	*4,206*
Pharmaceuticals and other chemicals	15,743	7,836	21,352	9,341	*54,272*
Non-metals	16,194	9,464	90,147	28,047	*143,852*
Metals	27,405	12,301	154,328	21,768	*215,802*
Machinery	13,095	7,443	26,863	8,873	*56,274*
Vehicles	13,674	8,673	44,806	9,517	*76,670*
Other manufacturing	18,703	12,373	60,513	27,108	*118,697*
Electricity: Coal based	11,498	8,499	21,997	7,999	*49,993*
Electricity: Nuclear	836	307	307	126	*1,577*
Electricity: Hydroelectricity & Renewables	349	175	363	188	*1,075*
Electricity: Gas turbines	25	12	23	11	*71*
Water	5,057	4,092	13,655	2,945	*25,749*
Construction and Building	21,972	18,631	473,904	117,962	*632,469*
Trade and transport services	371,009	1,062,879	749,030	609,437	*2,792,355*
Other services	1,208,900	1,092,047	442,353	1,769,222	*4,512,522*
Total	*1,879,022*	*2,421,027*	*3,396,929*	*3,359,573*	*11,056,551*

Table 12: Simulation Parameters for Combined Scenarios: Structural Shifts in Energy Output Mix

Reference Case - GWC								
	base	simref05	simref10	simref15	simref20	simref30	simref40	simref50
aelec_coal	92.9%	93.9%	94.6%	94.7%	92.2%	83.4%	81.6%	81.3%
aelec_nuclear	5.1%	5.9%	5.2%	4.9%	6.4%	7.8%	12.1%	14.0%
aelec_renew	0.9%	0.01%	0.01%	0.2%	1.1%	8.6%	6.2%	3.7%
aelec_gas	1.1%	0.2%	0.2%	0.3%	0.3%	0.2%	0.1%	1.0%
	base	simref05	simref10	simref15	simref20	simref30	simref40	simref50
apet_oil	67.9%	69.5%	70.9%	69.4%	66.8%	68.2%	71.3%	76.6%
apet_ctl	25.1%	23.7%	22.0%	23.2%	26.4%	26.6%	24.4%	19.5%
apet_gtl	6.0%	6.8%	6.3%	5.7%	4.9%	3.2%	2.3%	1.8%
apet_bio	1.0%	0.04%	0.8%	1.7%	1.9%	1.9%	2.0%	2.0%
Mitigation - *Start Now* (initial wedges)								
	base	simshd05	simshd10	simshd15	simshd20	simshd30	simshd40	simshd50
aelec_coal	92.9%	93.9%	94.0%	87.3%	73.5%	51.3%	47.6%	45.7%
aelec_nuclear	5.1%	5.9%	5.4%	7.5%	13.5%	24.2%	26.2%	26.6%
aelec_renew	0.9%	0.2%	0.6%	5.2%	12.8%	23.7%	26.0%	27.7%
aelec_gas	1.1%	0.01%	0.01%	0.01%	0.27%	0.8%	0.2%	0.1%
	base	simshd05	simshd10	simshd15	simshd20	simshd30	simshd40	simshd50
apet_oil	67.9%	69.5%	69.9%	66.5%	61.3%	57.6%	60.1%	65.8%
apet_ctl	25.1%	23.6%	22.4%	24.6%	29.9%	34.7%	33.2%	28.0%
apet_gtl	6.0%	6.8%	6.4%	6.0%	5.5%	4.2%	3.2%	2.6%
apet_bio	1.0%	0.1%	1.3%	2.8%	3.3%	3.6%	3.5%	3.6%
Mitigation - *Scale Up* (extended wedges)								
	base	simcan05	simcan10	simcan15	simcan20	simcan30	simcan40	simcan50
aelec_coal	92.9%	93.9%	93.0%	86.3%	73.8%	51.4%	31.8%	17.2%
aelec_nuclear	5.1%	5.9%	5.4%	7.5%	13.4%	24.5%	34.3%	41.5%
aelec_renew	0.9%	0.2%	1.6%	6.2%	12.8%	24.1%	33.9%	41.3%
aelec_gas	1.1%	0.01%	0.01%	0.01%	0.01%	0.02%	0.01%	0.01%
	base	simcan05	simcan10	simcan15	simcan20	simcan30	simcan40	simcan50
apet_oil	67.9%	69.4%	69.8%	67.5%	64.4%	64.3%	63.8%	70.5%
apet_ctl	25.1%	23.6%	22.3%	23.4%	26.9%	28.3%	29.4%	23.7%
apet_gtl	6.0%	6.8%	6.4%	5.8%	5.0%	3.4%	2.8%	2.2%
apet_bio	1.0%	0.1%	1.5%	3.3%	3.8%	4.0%	3.9%	3.6%
Mitigation - *Use the Market* (economic instruments)								
	base	simcld05	simcld10	simcld15	simcld20	simcld30	simcld40	simcld50
aelec_coal	92.9%	94.0%	90.8%	63.7%	22.0%	2.0%	0.0%	0.0%
aelec_nuclear	5.1%	5.7%	5.4%	18.1%	43.9%	44.9%	27.4%	25.6%
aelec_renew	0.9%	0.3%	3.9%	18.2%	34.1%	53.1%	72.6%	74.4%
aelec_gas	1.1%	0.01%	0.01%	0.01%	0.01%	0.00%	0.00%	0.02%
	base	simcld05	simcld10	simcld15	simcld20	simcld30	simcld40	simcld50
apet_oil	67.9%	72.3%	72.5%	72.1%	81.1%	94.5%	95.6%	96.1%
apet_ctl	25.1%	24.0%	21.7%	20.5%	12.2%	0.2%	0.0%	0.0%
apet_gtl	6.0%	3.7%	5.1%	5.8%	5.0%	3.7%	2.8%	2.3%
apet_bio	1.0%	0.0%	0.7%	1.6%	1.7%	1.6%	1.6%	1.6%

Note: In the results section we only report on results up to 2015, i.e. simshd15, simcan15 and simcld15.

Source: MARKAL model results

Table 13: Simulation Parameters for Combined Scenarios: Energy Efficiency

Start Now

	Electricity							Coal							Petroleum						
	2005	**2010**	**2015**	**2020**	**2030**	**2040**	**2050**	**2005**	**2010**	**2015**	**2020**	**2030**	**2040**	**2050**	**2005**	**2010**	**2015**	**2020**	**2030**	**2040**	**2050**
Mining	0.0%	-5.7%	-23.7%	-23.8%	-23.7%	-26.3%	-29.8%	0.0%	0.0%	0.0%	0.0%	0.0%	-2.4%	-4.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Industry	0.0%	-1.4%	-8.0%	-8.2%	-7.2%	-7.9%	-7.5%	0.0%	0.0%	-16.2%	-19.7%	-26.0%	-41.9%	-33.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Commerce	-0.4%	-3.5%	-8.5%	-12.0%	-15.6%	-15.9%	-16.6%	-0.3%	-6.1%	-16.8%	-24.7%	-36.0%	-37.7%	-39.7%	0.0%	0.1%	0.3%	0.5%	0.7%	0.7%	0.9%
Transport	9.5%	30.1%	36.4%	38.1%	43.3%	43.3%	42.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-3.7%	-12.5%	-16.6%	-17.7%	-19.9%	-22.6%	-25.1%
Int input	**1.8%**	**2.2%**	**-2.6%**	**-2.7%**	**-1.6%**	**-2.4%**	**-3.0%**	**0.0%**	**-0.1%**	**-11.1%**	**-13.5%**	**-17.8%**	**-28.6%**	**-23.1%**	**-8.0%**	**-11.4%**	**-13.0%**	**-13.4%**	**-14.3%**	**-15.3%**	**-16.3%**
Tot supply	**1.1%**	**1.4%**	**-1.6%**	**-1.7%**	**-1.0%**	**-1.4%**	**-1.8%**	**0.0%**	**0.0%**	**-7.1%**	**-8.7%**	**-11.5%**	**-18.4%**	**-14.8%**	**-4.3%**	**-6.2%**	**-7.1%**	**-7.3%**	**-7.7%**	**-8.3%**	**-8.8%**

Scale Up

	Electricity							Coal							Petroleum						
	2005	**2010**	**2015**	**2020**	**2030**	**2040**	**2050**	**2005**	**2010**	**2015**	**2020**	**2030**	**2040**	**2050**	**2005**	**2010**	**2015**	**2020**	**2030**	**2040**	**2050**
Mining	0.0%	-5.7%	-23.7%	-23.8%	-23.7%	-26.3%	-29.8%	0.0%	0.0%	0.0%	0.0%	0.0%	-2.4%	-4.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Industry	0.0%	-1.3%	-8.0%	-8.2%	-7.2%	-7.9%	-7.5%	0.0%	0.0%	-16.2%	-19.7%	-26.0%	-41.9%	-33.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Commerce	-0.4%	-3.5%	-8.5%	-12.0%	-15.6%	-15.9%	-16.6%	-0.3%	-6.1%	-16.8%	-24.7%	-36.0%	-37.7%	-39.7%	0.0%	0.1%	0.3%	0.5%	0.7%	0.8%	0.9%
Transport	0.2%	3.5%	7.6%	7.2%	7.2%	35.1%	51.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	-1.1%	-2.2%	-1.5%	-1.2%	-10.1%	-15.4%
Int input	**0.0%**	**-1.1%**	**-6.4%**	**-6.9%**	**-6.8%**	**-2.1%**	**0.6%**	**0.0%**	**-0.1%**	**-11.1%**	**-13.5%**	**-17.8%**	**-28.6%**	**-23.1%**	**-6.5%**	**-6.9%**	**-7.4%**	**-7.0%**	**-6.9%**	**-10.4%**	**-12.5%**
Tot supply	**0.0%**	**-0.7%**	**-3.9%**	**-4.2%**	**-4.2%**	**-1.3%**	**0.4%**	**0.0%**	**0.0%**	**-7.1%**	**-8.7%**	**-11.5%**	**-18.4%**	**-14.8%**	**-3.5%**	**-3.8%**	**-4.0%**	**-3.8%**	**-3.7%**	**-5.6%**	**-6.8%**

Use the Market

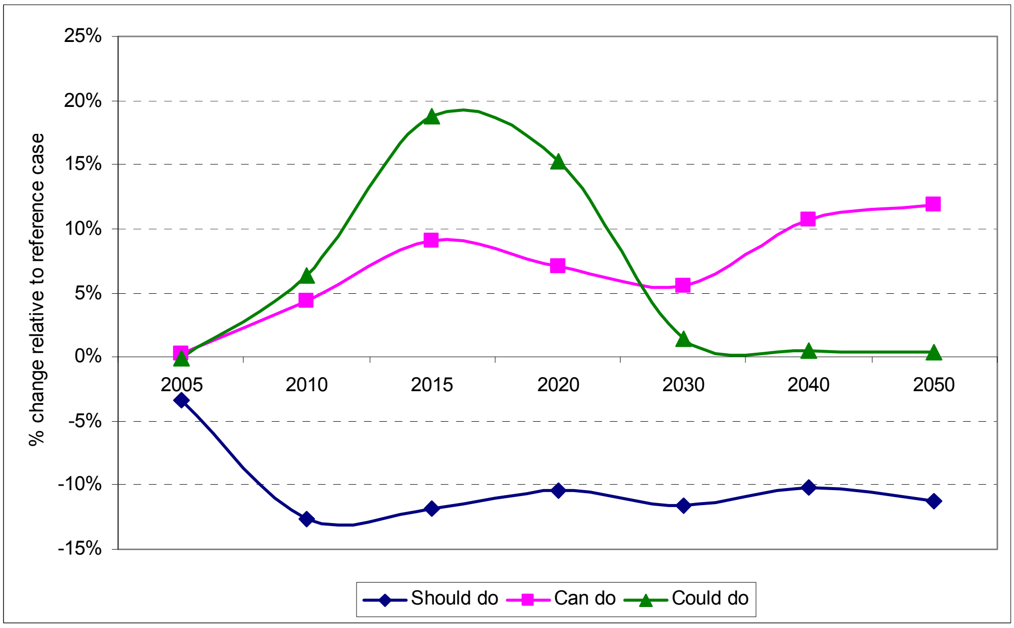
	Electricity							Coal						
	2005	**2010**	**2015**	**2020**	**2030**	**2040**	**2050**	**2005**	**2010**	**2015**	**2020**	**2030**	**2040**	**2050**
Mining	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-66.5%
Industry	0.0%	-1.3%	-8.0%	-8.2%	-7.2%	-7.9%	-7.5%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%	-45.2%
Commerce	-0.4%	-3.6%	-8.7%	-12.3%	-15.5%	-14.8%	-15.0%	-0.1%	-1.2%	-2.7%	-8.8%	-35.7%	-44.2%	-45.5%
Transport	0.1%	3.1%	11.3%	25.9%	60.5%	70.3%	77.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Int input	**0.0%**	**-0.3%**	**-1.9%**	**0.5%**	**7.3%**	**9.0%**	**10.5%**	**0.0%**	**0.0%**	**0.0%**	**-0.1%**	**-0.3%**	**-0.5%**	**-31.9%**
Tot supply	**0.0%**	**-0.2%**	**-1.2%**	**0.3%**	**4.5%**	**5.5%**	**6.4%**	**0.0%**	**0.0%**	**0.0%**	**-0.1%**	**-0.2%**	**-0.3%**	**-20.5%**

	Petroleum							Gas switching						
	2005	**2010**	**2015**	**2020**	**2030**	**2040**	**2050**	**2005**	**2010**	**2015**	**2020**	**2030**	**2040**	**2050**
Mining	179.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	-0.1%	1760.5%
Industry	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.2%	1075.2%
Commerce	0.0%	-0.1%	-0.3%	-0.4%	-0.4%	-0.5%	-0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Transport	-0.1%	-1.0%	-3.7%	-8.2%	-17.9%	-20.9%	-23.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Int input	**-0.1%**	**-6.9%**	**-8.0%**	**-9.8%**	**-13.6%**	**-14.8%**	**-15.8%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**3.7%**	**966.6%**
Tot supply	**0.0%**	**-3.8%**	**-4.3%**	**-5.3%**	**-7.4%**	**-8.0%**	**-8.6%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**1.3%**	**342.8%**

Note: In the results section we only report on results up to 2015, i.e. simshd15, simcan15 and simcld15.

Source: MARKAL model results

Figure 22: Simulation Parameters for Combined Scenarios: Investment Costs



Source: MARKAL model results

Table 14: Simulation Parameters for Combined Scenarios: CO2 Emissions Taxes

Year	Tax: Rands per ton of CO_2	Effective tax on crude oil	Effective tax on other mining commodities (gas)	Effective tax on coal
2005	R 0	0.0%	0.0%	0.0%
2010	R 279	31.2%	1.2%	663.9%
2015	R 353	39.5%	1.5%	838.5%
2020	R 427	47.7%	1.8%	1013.4%
2030	R 574	64.1%	2.4%	1362.7%
2040	R 721	80.6%	3.0%	1712.0%
2050	R 750	83.8%	3.1%	1781.9%

Source: MARKAL model results

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