Quantifying SD-PAMs: National energy models and international allocation models for climate change mitigation

SOUTH AFRICAN CASE STUDY

Harald Winkler, Andrew Marquard, Jonathan Manley, Stephen Davis, Ajay Trikam, Michel Den Elzen, Niklas Höhne and Jongikhaya Witi

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Contents

List of tables

List of figures

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Harald Winkler, Andrew Marquard, Jonathan Manley, Stephen Davis, Ajay Trikam are all from the Energy Research Centre, University of Cape Town, South Africa.

Michel Den Elzen works at the Netherlands Environmental Assessment Agency.

Jongikhaya Witi works at the Department of Environmental Affairs and Tourism, South Africa.

Niklas Höhne works at Ecofys in Cologne, Germany.

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1. Introduction: SD-PAMs, research objective and scope of work

1.1 The concept of SD-PAMs

Sustainable development policies and measures (SD-PAMs) are an approach to stimulating action on climate change mitigation in developing countries. Instead of starting from explicit climate targets, the approach deliberately sets out to start from development objectives. This strategic approach taps into the primary motivation for developing countries, namely development.

Defining more sustainable pathways to meet given development objectives has significant climate co-benefits. These co-benefits are by now broadly accepted (IPCC 2007, 2001b; Robinson *et al.* 2006; Winkler *et al.* 2006; Szklo *et al.* 2005; Munasinghe & Swart 2005; Baumert & Winkler 2005; Bradley *et al.* 2005; IISD 2005), the question is how to capture these benefits in the multi-lateral climate regime. A new strategic approach is needed, and SD-PAMs offers one possible approach. This approach provides a means to identify 'nationally appropriate mitigation actions by developing country Parties in the context of sustainable development, supported and enabled by technology, financing and capacity-building, in a measurable, reportable and verifiable manner' (UNFCCC 2007). Sustainable development is part of core balance between sub-paragraphs 1b(i) and 1b(ii), in that mitigation actions by developing countries are qualified as being 'in the context of sustainable development'.[1]

1.2 Research idea and objective: Linking national and international models

Energy is the sector contributing the most greenhouse gas (GHG) emissions in South Africa and internationally. Understanding the mitigation options in the energy sector is critical to any proposed solution to the challenge of climate change. However, much of the analysis supporting the international climate change (CC) negotiations under the UNFCCC is insufficiently rooted in analysis of energy development paths at the *national* level. Policy options at the national level need to be more fully understood, based on in-country analysis.

For South Africa, with its coal-dependent energy economy, defining CC mitigation paths that allow economic development to proceed in a sustainable manner is no trivial task. South Africa's past negotiating position has been to focus on 'no-regrets' measures and to stress that developing countries have no quantified emissions reduction commitments. As the discussion about the shape of the global climate change regime beyond Kyoto takes shape, the pressure on South Africa to engage proactively is increasing.

Without a clear understanding of the links between national energy planning and multi-lateral climate negotiations, negotiators do not have sufficient domestic buy-in to enable them to engage constructively in the multi-lateral negotiations. Analytically, this requires linking *national* energy models with *international* models considering the allocation of emissions allowances. We propose to develop a methodology to create such a linkage using South Africa as a test case to link a bottom up SD-PAMs analysis for South Africa with the /FAIR (Den Elzen & Lucas 2005) and Ecofys/ EVOC models (Höhne *et al.* 2008). This methodology is to be developed through a collaborative process between analysts from ERC, Netherlands Environmental Assessment Agency and Ecofys.

In linking national and international models, lessons will be learned about the methodological steps required, and some modifications to the FAIR and / or TIMER energy model will be made

1 The Bali Action Plan makes sustainable development policies key to the balance between adaptation (in 1e(iv)) and mitigation (b(ii), but that is not further investigated in this paper.

to include public domain energy data for South Africa. These lessons would allow replication of this approach in other countries in future work. We believe that this connection can make a contribution to the discussion around future mitigation commitments under the UNFCCC. It allows analysts in developing countries to conduct national analysis in different international emission allocation proposals and evaluate this in a consistent manner as an input to policy-making on climate change and sustainable development. The collaborative work will enable researchers in industrialised countries to better represent South Africa in their models. In this, they will be able to draw on the public-domain data provided, adjust it to the formats required by their models and discuss any queries with South African analysts.

1.3 Scope of work

The scope of work for this projected focused on strengthening existing capacity in developing countries to analyse the co-benefits of SD-PAMs. It included the following elements:

1. Identifying major policies in South Africa
2. Quantifying the sustainable development benefits of each policy
3. Quantifying the energy and / or GHG implications of each policy
4. Using tools of national energy modeling to analyse the implications for national GHG emissions trajectories
5. Learning the use of international emission allocation models (FAIR and EVOC) to understand the contribution of SD-PAMs
6. Collaborative analysis of national policies in international context
7. Writing up case study

The present report addresses this scope of work.

2. Case study of quantifying SD-PAMs in South Africa

2.1 Identified policies, sustainable development benefits and energy GHG implications

Having considered the concept of SD-PAMs (section 1.1), specific policies and measures that promote local sustainable development were identified. A sustainable development policy that has low impact on the local environment, promotes access and favours an equitable allocation of wealth and resources represents a major challenge.

A short overview of the policies in the residential demand and electricity supply sector is provided in Table 1. Alost 80% of South Africa's GHG emissions are from energy supply and use (RSA 2004), and the SD-PAMs are analysed using the Markal energy modeling system for national-level analysis.

Several of the SD-PAMs focus on energy efficiency, across the industrial, commercial and residential sectors. The specific measures modelled are specified in section 2.2.5 below.

Renewable energy technologies for electricity generation are another SD-PAM analysed. The other two options examined are imported hydro-electricity, or increased use of gas, which would also have to come from outside of the country.

Transport is a fast-growing sector of emissions internationally and in South Africa. SD-PAMs could contribute by increasing mobility, providing savings on fuel costs to consumers and reducing GHG emissions. The policies and measures considered here start with efficiency again, improving the efficiency of light vehicles, which could be done through hence fuel economy standards. Two vehicle technologies considered are greater shares of hybrid vehicles, and electric vehicles. In the latter case, the fuel mix of the electricity grid is important for the overall effect, although emission reductions can be achieved on greater efficiency of electric vehicles alone (EPRI & NRDC 2007). Shifts from private to public transport for passengers is an important measure to relieve congestion, improve mobility and reduce energy use per passenger-km. And finally, an increased share of bio-fuels (which is part of the Accelerated and Shared Growth Initiative of South Africa (AsgiSA 2006)), is considered.

The identified SD-PAMs are more fully described in Table 1, and the results, focusing on emission reductions and mitigation costs, are reported in section 2.2.5.

Table 1: South African SD-PAMs, sustainable development benefits, energy and GHG implications

Policy – name	*Policy – short description*	*Local SD benefits*	*Energy implications*	*GHG implications, from existing studies*
Industrial energy efficiency	Through various of measures, the energy efficiency in industry is improved. Measures include improving boiler efficiency, decreasing coal dependency, improving motor efficiency and introducing variable speed drives.	Lowers the demand for extra generating capacity, improve industrial competitiveness, improved industrial efficiency	15% savings against baseline projection, improvement by 2015. extended up to 2030.	Emission reduction of 45Mt CO_2 in 2030. Cumulative emission reductions of 486Mt CO_2 for 2001-2030 from non-electricity energy carriers (Haw, Hughes 2007).
Renew-able energy generation	The use of renewable energy is strongly advocated and targets are set for renewable energy.	Decreases CO_2 per capita, increased investment in renewable options and strengthens energy security, less local pollution, lower fuel costs	RE to contribute 27% by 2030. 10000GWh (36PJ) from RE by 2013.	180Mt CO_2-eq over 25 years 2001-2025 (Winkler et al. 2006)
Improve light vehicle efficiency	Standards and targets are set for light vehicle fuel economy.	Improves local air pollution, slows growth in demand for petrol, reduce fuel imports, increase fuel exports.	An improvement of 1.2% is made per year on light vehicle economy, as opposed to a 0.4% increase in the base case.	33Mt CO_2 can be saved in 2030.
Transport mode shift	Shift passenger transport away from personal vehicles to public transport	Improves local air pollution, slows growth in demand for diesel and petrol, reduce fuel import, increase exports, significant improvements in traffic	Public transports share of passenger km's increases from 50% in 2001. Increase by 0.5% per year to 65% in 2030.	35Mt CO_2 saved in 2030.
Hybrid Vehicles	The share of hybrid vehicles on the roads is gradually increased	Reduces local air pollution, slows growth in demand for diesel and petrol, lowers fuel imports	Hybrid vehicles will account for 7% of private passenger kilometres by 2015 and 40% of private passenger km's by 2030. Ratio of public to private kilometres = 50% for whole scenario.	13Mt CO_2-eq reduction in 2030.
Commer-cial Energy Efficiency	Energy efficiency measures are implemented in commercial and public buildings and public awareness is promoted. The main areas for improvement, are lighting, thermal design and HVAC systems.	Reduces pollution, slows growth in energy demand, reduces urgency for increased capacity, raises public awareness, and promotes job creation.	A final energy demand decrease of 15% by 2015 compared to the baseline is targeted for commercial energy. Final energy demand decreases by 30% in 2030 compared to the baseline.	1.5Mt CO_2 reduction made in 2030, cumulative reduction of 19Mt CO_2 reduction (2001-2030). These emissions are from non-electricity energy carriers.

Policy – name	*Policy – short description*	*Local SD benefits*	*Energy implications*	*GHG implications, from existing studies*
Residen-tial Energy Efficiency	Various measures are implemented to improve residential energy efficiency.The main areas are lighting, water heating (SWH) and cooking.	energy poverty alleviation, decreases localised air pollution (total suspended particulate solids) through reduced use of coal, improves health.	Final energy demand decrease of 10% by 2015 for residential energy. 32PJ by 2030 (Haw, Hughes 2007). 20%-60% of rich households have SWH by 2030, 10-50% of poor households have SWH.	Final energy demand decrease of 10% for residential energy. 8.13PJ by 2025 (Winkler et al. 2006) and 32PJ by 2030 (Haw, Hughes 2007).
Imported hydro	The amount of imported hydro-electricity is significantly increased over the base case	reduces local air pollution and lowers the need for more domestic power generating capacity, improves energy mix.	Increases share of imported hydro from 9.2TWh per year in the base year to 17TWh in the policy case.	167Mt CO_2 avoided. Possible increase in methane emissions.
Biodiesel / biofuels	Biodiesel is used to supply more of the transport needs.	Job creation, and increase in fuel specific agriculture, small reduction in local pollutants, less imported crude oil, promotes job creation and economic growth.	8% petrol, from bioethanal, 8% of diesel is from biodiesel.	5Mt CO_2-eq/annum emission reduction by 2025, cumulative savings are 31Mt CO_2 for the period
Imported gas & increased CCGT	In this policy scenario, a stronger emphasis is put on imported gas and gas generation. Three combined cycle gas turbines (CCGT) of 1950MW each are built.	Lowers demand for coal generating capacity, and lowers air pollution.	By 2015 build 1, 2020, build another, 2025 build another.	199Mt CO_2e saved
Electric vehicles	More uptake of pure electric vehicles. It is a requirement for renewable electricity to contribute towards this increase in demand, off-setting the potential increased fossil-fuel requirements.	significantly reduces local air pollution, decrease import of crude oil, increases petrol exports as diesel makes up bigger share.	Increased renewable electricity generating capacity is required. By 2030 - 60% of private passenger km's.	90 Mt CO_2 is saved in 2030 with an increased share of renewables of 27% by 2030.

2.2 National energy modeling to analyse the implications for national GHG emissions trajectories

National energy modeling using Markal is technology-rich and data-intensive. Not all individual data inputs can be reported. However, major drivers are reported, notably growth in population and the economy (the latter measured by GDP), as well as assumed prices of energy into the future. Assumptions have been updated compared to previous studies.

The GDP projections have been significantly updated. Some of the key previous studies (NER 2004; Winkler 2006) had central GDP growth rate estimates of 2.8% per year. The South African government has set targets of GDP growth rates between 3% to 6%, and growth has reached these levels in recent years. The GDP projections have been adjusted to be within this range, rising to 6% and then declining in the longer term. Assumptions about energy prices have been updated

2.2.1 Methodology for national energy modeling and mitigation costing

Energy models allow the construction of policy cases in a quantified way. The implications of policy interventions can be tested. Developing more than one policy case allows comparisons of alternative development paths. In keeping with the methodology, the policy cases will have in common some development objectives (e.g. increasing access to energy services, or supplying electricity demand), but they differ in the way they reach the objective.

The national energy modeling used for this study is the Markal framework, which has been used in previous work by ERC (Hughes & Haw 2007; Winkler 2006; Howells & Solomon 2002), including work in preparation for the Department of Minerals and Energy's integrated energy plan (DME 2003).

Markal has an objective function to minimize the cost of the energy system (Loulou et al 2004). Sectoral demand projections are entered into the model along with an array of supply-side options that can meet the demands. Estimates of demand, existing technology stocks, and information on technology choices that can be used to meet demand are input by the user. With a demand projection based on GDP and population growth (developed in LEAP in this case), Markal computes least-cost energy balances at all levels of the energy system. The model aims to supply energy services at a minimum global cost by simultaneously making decisions about capital investment in equipment, operating costs and primary energy supply. By taking all these factors into account, Markal is a vertically integrated representation of the entire energy system.

In Markal the energy system is represented by a set of energy carriers that link primary energy resources through transmission, transport modes and transformation to final energy demand technologies. A simplified figure of the electricity Reference Energy System (RES) in South Africa is shown in Figure 1. Fuels from refineries or mines, in the case of coal, flow along fuel paths to meet specific demands.

The identified SD-PAMs are implemented in the Markal modeling framework, as described more fully below. This provides the data for mitigation costing. The methodology for mitigation costing takes the difference in the levelised life cycle costs of the mitigation option and the baseline option, and divides it by the emission reductions, which are the difference in emissions in the baseline minus the mitigation case. The mitigation cost methodology is described more fully in Appendix 0.

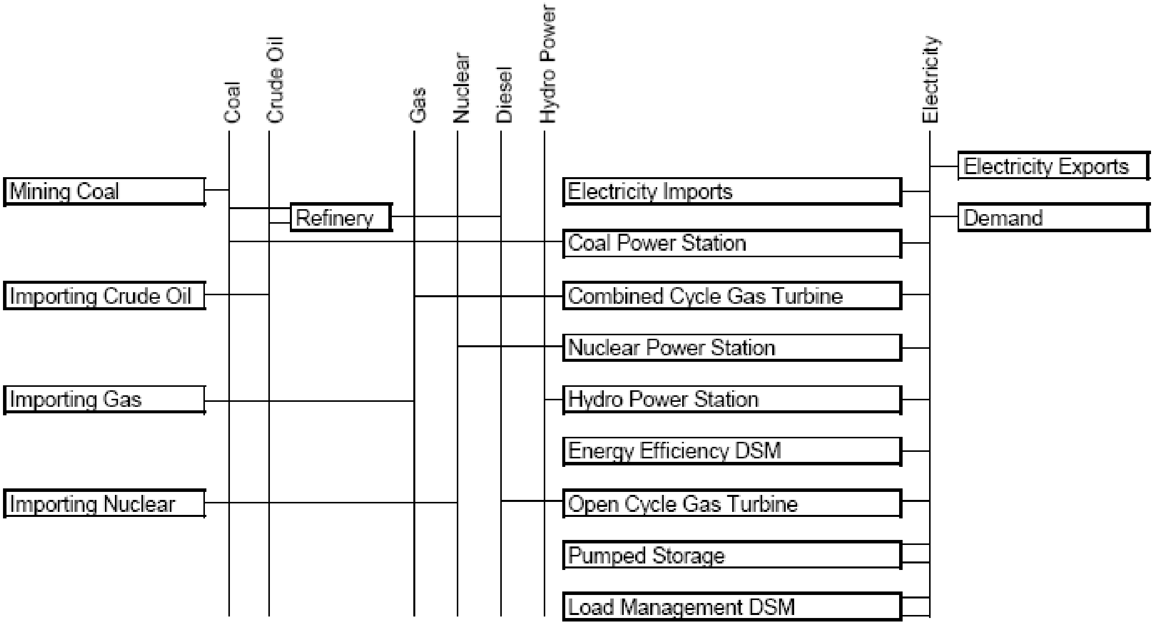


Figure 1: Simplified RES for the electricity sector of South Africa
Source: Schultz (2003)

2.2.2 Major drivers

2.2.2.1 Population growth

Population projections are a topic of much debate in South Africa given the high rate of HIV infection and how this will impact the growth of the population. Many believe that the population will level off and even decline in the future. No model can perfectly simulate this population growth as there are too many unknown variables. Nevertheless, a study by Professor Dorrington of the University of Cape Town Commerce Faculty for the Actuarial Society of South Africa is well respected for its population projections with the influence of HIV/AIDS (ASSA 2003). This is the model used for this study. Figure 2 shows the simulated population growth over the study period.

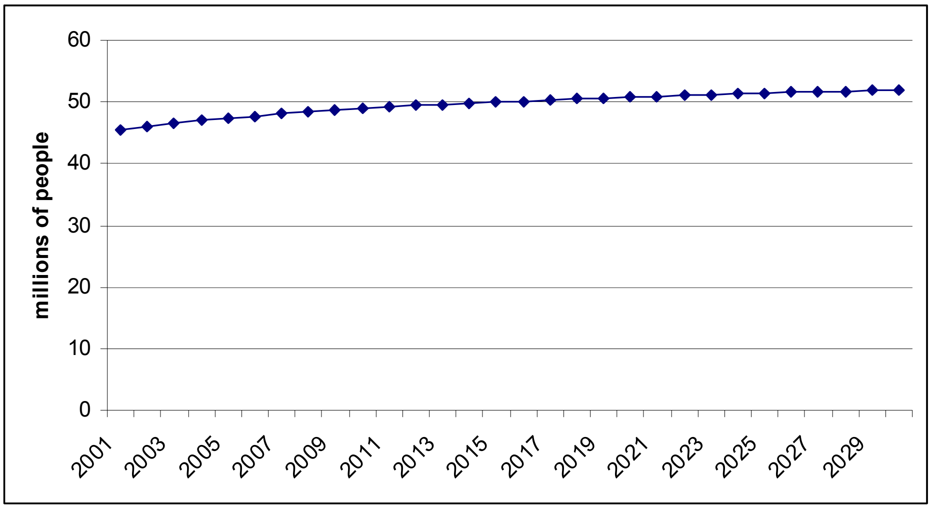


Figure 2: Population projections
Source: based on ASSA (2003)

2.2.2.2 Economic growth measured by GDP

Over the past 12 years, GDP growth in South Africa has fluctuated between 0.5% and 5% but has shown as positive trend. Targets for GDP growth rates have been set as part of the Accelerated and Shared Growth Initiative for South Africa (AsgiSA 2006; National Treasury 2005).

The literature on GDP growth rates has been assessed *inter alia* by the IPCC (IPCC 2000). The world has witnessed high periodic economic growth in many countries. A per capita GDP growth rate of 3.5% per annum were, for instance, achieved in Western Europe between 1950 and 1980. Similarly, high per capita GDP growth rates were achieved in the developing economies of Asia. Per capita GDP growth rates of individual countries have even been higher – 8 % per annum in Japan over the period 1950-1973, 7 % in Korea between 1965 and 1992, and 6.5 % per year in China since 1980 (IPCC 2000). Based on such analysis, suggested that South Africa might be considered to be in an acceleration phase (stage 5). This would be consistent with AsgiSA targets of economic growth increasing from recently relatively low values around 2.5%. In the long-term, GDP growth rates might settle around 3%, consistent with the IPCC's recommendation for discount rates of 3% to be applied for long-term, inter-generational studies (IPCC 2001a: 467).

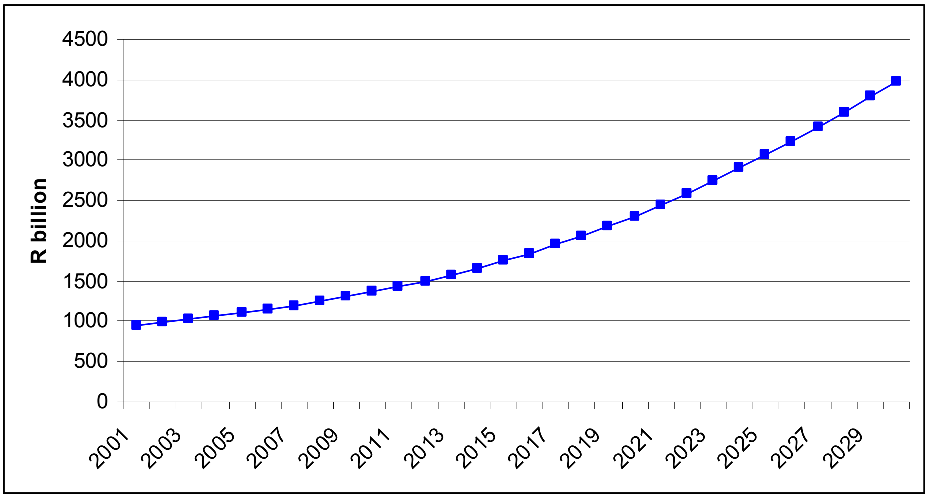


Figure 3: GDP projections
Source: based on Vessia (2006)

The projections used here (following earlier work (Vessia 2006)), assume that current growth trend extends to 2015 and 2016 in which the peak growth at 5.24% is reached, after which growth decreases to a more stable lower level of approximately 2% annual growth.

2.2.2.3 Assumed future energy prices

The following prices are specified as inputs over the modelling period in the Markal model:

1. The crude oil price – this is an international price, since almost all oil is imported in South Africa.
2. Liquid fuels product import and export prices, which are derived from the above using historical data.
3. Coal prices – prices for coal for domestic consumption are considerably lower in South Africa than international coal prices, since most domestic production for thermal applications is very low-grade coal which does not have alternative uses.
4. A price for nuclear fuel, which is imported (even though South Africa is a uranium producer, no enrichment or fuel fabrication takes place in the country).

For the purposes of the comparison modelling, the crude oil price was assumed to be $55 per barrel in 2001, escalating to $100 per barrel by 2010, and escalating further at a slower rate to $150 by 2030. Import and export liquid fuels prices escalated in proportion. Coal prices ranged from R56/ton to R118/ton in 2001 (R56 for current contracts supplying electric power plants, R71 for new contracts for electricity, R92 for coal to liquids, and R118 for industrial and other uses), and were assumed to increase at half the rate at which the crude oil price increased. The nuclear fuel price begins in 2001 at R2.5 per GJ, and increases at half the rate of crude oil.

2.2.3 **Reference case**

The key drivers for energy demand are economic growth, population and technological changes. In other words, the key drivers outlined in section 2.2.2 above are implemented in the modeling framework to provide a modeling reference case, against which mitigation options ('scenarios' in Markal) are assessed.

The reference case is effectively a simulation of the development of the energy system into the future, and is very tightly constrained to represent a 'business as usual' scenario, generally continuing existing development trends. For instance, energy efficiency is only increased in line with historical trends. In the case of climate change, constraints can be changed to develop different mitigation scenarios (for instance, requiring a minimum or absolute percentage of climate-friendly technologies, assuming a significant increase in energy efficiency, or placing a limit on emissions); the model then optimises the energy system within the parameters of these new constraints. It is then possible to compare the mitigation scenario in question to the reference scenario in terms of total system cost, and in terms of other factors such as CO_2 emissions.

Energy models, including Markal, have various limitations which need to be considered when interpreting outputs. First, the structure of the energy system remains static over the modelling period. Second, Markal and other models simulate decision-making in a relatively simple way (usually using only a few quantitative criteria). Results are driven by the objective function – minimising costs. More complex criteria (such as public resistance to nuclear power) can be approximated roughly by imposing constraints (for instance, a limit to investment in nuclear power plants). Third, a specific failing of Markal is its inability to account satisfactorily for peak load in the electricity sector, since although the model distinguishes between day and night (and summer, winter and intermediate periods), it does not make finer time distinctions. Thus, the model has a tendency to generate less electricity from peak-load plant than would be the case in a real electricity system. Fourth, major drivers of energy demand, such as GDP and population, are not explicitly represented within Markal. Energy demands and projections are calculated outside of the model.

The energy model is based on energy demand from key economic sectors. The sectors in this study were agriculture, commercial, industry, residential and transport. The structure and major assumptions for the reference case of each of the following sectors is given below.

2.2.4 Consistency with SA projections with projections used in global models

The populations projections used for the Markal energy modeling and the FAIR 2.2 model (version 2.2 is described in den Elzen *et al.* (2008), and includes 26 world regions including the country South-Africa) differ somewhat. However, on a scale set to zero at origin of the y-axis, the difference appears to be within acceptable limits. The remaining difference may be due to different assumptions about mortality or other issues. The population projections for the national energy modeling work are drawn from a highly respected source, that is based in actuarial science, i.e. risk-analysis background (ASSA 2003).

The GDP projections used in the two models appear to differ substantially. Certainly projections from different sources may differ, but the reasons are not readily apparent. However, projections should be parameterized against well-known numbers. Data from the South African Reserve Bank's *Quarterly Bulletins* and other publications provide a reliable and authoritative source for GDP by various measures. According to SARB, gross domestic product at market prices in 2000 was R 922 148 million, or R 922.1 billion (SARB 2005a). Table 2 provides a time-series for the last ten years of GDP reported.

Table 2: South African gross domestic product at market prices

Source: (SARB 2005b)

Year	*GDP (R million, at current prices)*
1994	482 120
1995	548 100
1996	617 954
1997	685 730
1998	742 424
1999	813 683
2000	922 148
2001	1 020 007
2002	1 164 945
2003	1 251 468
2004	1 374 476

The FAIR 2.2 model uses for the population projection, the UN medium scenario for the country South-Africa (UN, 2004), as part of the overall ADAM reference scenario (van Vuuren *et al.* 2008 (in preparation)), which is an elaboration of the World Energy Technology Outlook (WETO) reference scenario (DG-Research 2007) (see Table 3).

Table 3: Population, GDP per capita and GDP for 1990, 2000 and 2020 for the ADAM baseline for South-Africa used in the FAIR 2.2 model

Source: Van Vuuren et al. *(in preparation 2008).*

Population (million inhabitants)			*GDP (MER) per capita Using rate of 6 Rand for 2000US$. (2000US$ per capita)*			*GDP (2000US$)*		
2000	*2020*	*2030*	*2000*	*2020*	*2030*	*2000*	*2020*	*2030*
46	48.1	48.5	3 974	4 796	5 425	181	231	263
			2000 Rand per capita			2000 Rand		
			31 797	38 365	43 400	1 088	1 384	1575

Economic growth projections of the FAIR model are based on the ADAM scenario, i.e. a scenario of Barkers' economic model, and a downscaling of the GDP for the region South-Africa to the country South-Africa (Van Vuuren *et al.* 2007). This scenario is an update compared to the projections used for the WETO (2004) scenario that accounts for higher oil prices (DG-Research 2007).

The 2000 numbers differ slightly, but more important is the difference in the 2020 projection, as will be explained in much detail in Section 3.1.1, and briefly here. In the SARB projection the average growth between 2000-2020 can be calculated as approximatley 3% /year, and the total GDP is about 2000 Rand in 2020, whereas in the FAIR model we see an average growth of 1.2%/yr, and total GDP is about R1400 billion Rand, in other words significant differences. Ecofys' EVOC model, following the IMAGE SRES scenarios, shows similar trends.

The GDP growth difference of about 1.8%/year in 2020 can be explained for 0.4%/year by the growth difference for the population, and the remainder in the per capita income growth difference.

Apparently the FAIR and EVOC models uses more pessimistic assumptions on both the population and GDP growth, based on international statistics. The Markal modeling uses national statistics, in which national researchers in this instance have high confidence. Nonethelss, there is no ‘right’ or ‘wrong’ projection, the key point is to be clear which projections are being used.

2.2.5 Updated results from national modeling

Several of the SD-PAMs focus on energy efficiency, across the industrial, commercial and residential sectors. Industrial efficiency focuses on measures such as improved boiler efficiency, improved motors, variable speed drives and reduced direct use of coal by industry. In commercial buildings, much potential lies in lighting, thermal design and HVAC systems – but behavioural changes due to increased awareness are a critical component too. For households, lighting and cooking can be shifted to more efficient means, saving money for households, reducing energy use and with the co-benefit of avoided GHG emissions. Solar water heating, which can be seen as efficiency and / or renewable energy, is also included here.

The study implemented the SD-PAMs (identified in 2.1) in a national energy modeling framework, the methodology for which was elaborated in section 2.2. The SD-PAMs broadly focus on energy efficiency, some alternative options for electricity generation, and options for transport. This set of SD-PAMs addresses most of the major emission sources (with a focus on industry in the efficiency component), with the exception of liquid fuel supply. Addressing the challenge of replacing liquid fuel from imported crude and domestic coal-to-liquid (a highly emissions-intensive process) requires further detailed study.

Sketching a policy case of sustainable development should not suggest that this is easy to achieve. The challenge of building new power stations present a major opportunity to choose cleaner technologies, but significant resources and effort are required to make such major changes. But the analysis conducted here does give a good indication of the emission reductions and mitigation costs.

2.2.5.1 Industrial energy efficiency

- Through a variety of measures, the energy efficiency in industry is improved by 15% by 2015 and extended to 2030. Measures include improving boiler efficiency, decreasing coal dependency, improving motor efficiency and installing variable speed drives.
- The sustainable development benefits of greater industrial efficiency are multiple. Firms would save energy bills and improve their competitive advantage. Given that industrial demand for electricity is about 38% of the total, saving electricity would assist in relieving the current electricity shortage. Continued into the future, it can avoid or delay the need to build another power station. The fuel savings are quantified in the following figures.

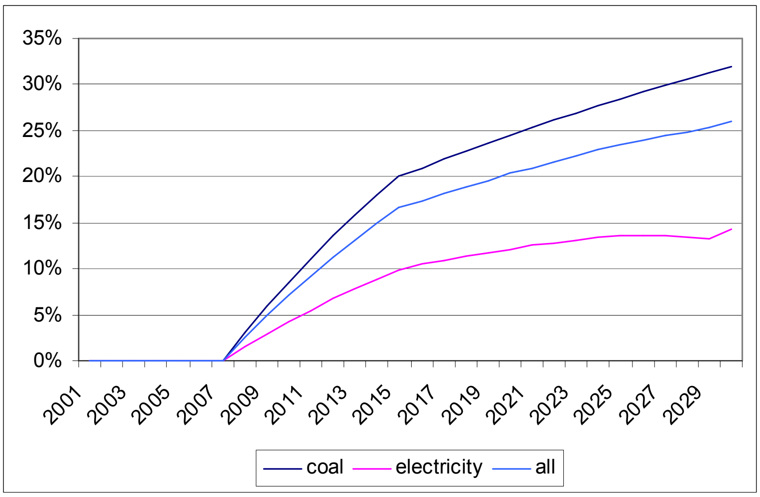


Figure 4: Savings of coal and electricity with greater efficiency in industry, in percentage terms

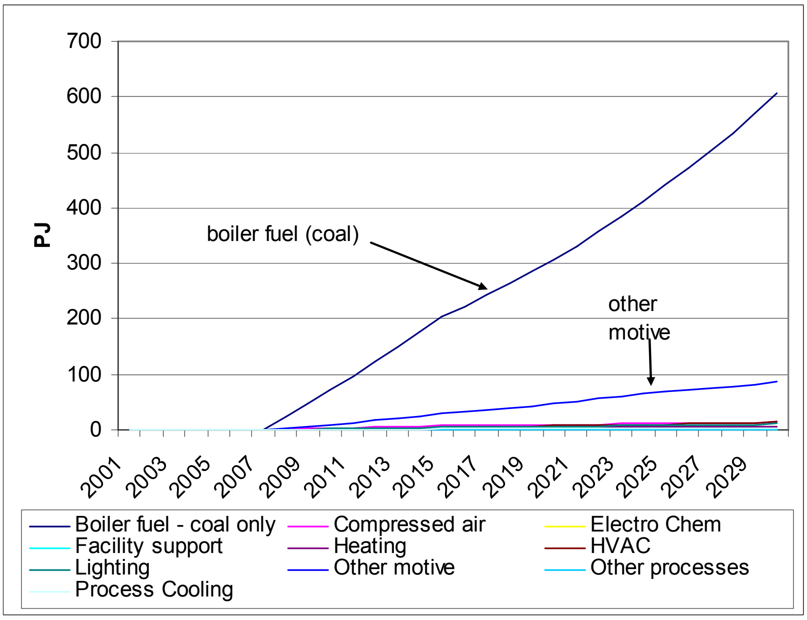


Figure 5: Annual energy savings by end-use technology

- The energy saved in the industrial sector is mainly in the form of electricity and coal. Figure 4 shows the savings both in absolute numbers, but also percentage terms to give a sense of the scale. The source of these savings, by the technology which deliver them, is shown Figure 5.
- Emission reductions 1231Mt CO_2-eq (relative to baseline) up to 2030.
- Mitigation savings, R95 / t CO_2-eq, or 10t CO_2-eq saving for every R1000 spent.
- Industrial energy efficiency has the ability to mitigate the most CO_2 out of the scenarios examined. Due to inefficiencies in the industrial sector, mitigation efforts are a 'Net negative cost option'.
- Industrial energy efficiency also has advantages for the local environment. Figure 6 shows that NO_x emissions, that are contribute to health problems, surface ozone and acid rain, can be reduced significantly. In 2030, the NO_x reductions are 269 000 tons.

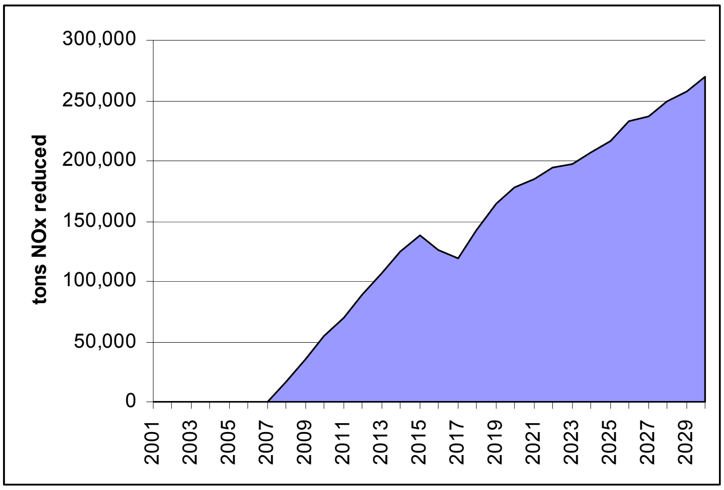


Figure 6: Reduction of NO_x emissions with industrial energy efficiency

2.2.5.2 *Commercial energy efficiency*

- Energy efficiency measures are implemented in commercial and public buildings and public awareness is promoted. The main areas for improvement are lighting, thermal design and HVAC systems.
- As with industrial efficiency, an economic benefit of this SD-PAM lies in savings on fuel bills. From a social point of view, efficiency creates jobs. From an environmental perspective, local air pollution is reduced.
- One of the sustainable development benefits of commercial energy efficiency is reduced emissions of *local* air pollutants. This can be quantified from the energy modeling results, as shown for SO_2 emission reductions in Figure 7. Most of the reductions appear in the last decade of the study period, but note that the units are in Mt SO_2, that is, millions of tons of sulphur dioxide reduced.

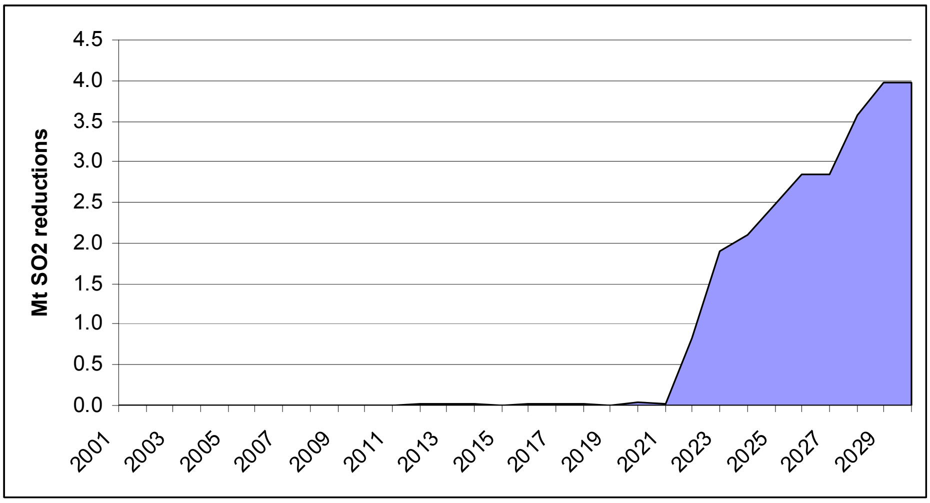


Figure 7: Reduced sulphur dioxide emissions due to commercial energy efficiency

- The case has GHG emission reductions of 112Mt CO_2-eq (relative to baseline) up to 2030.
- The mitigation costs for this scenario are negative and for each R1000 saved in the policy has associated savings of 2.1 t CO_2-eq.
- Commercial energy efficiency is another ‘Net negative cost option’.

2.2.5.3 *ResidentiaL energy efficiency*

- In this scenario, final energy demand is decreased by 10% in 2015 for residential energy and extended on to 2030.
- The social benefits of the measures taken would help to reduce energy poverty. Solar water heaters in many poor households would provide an energy service where previously there was none. And using energy more efficiently means that poor households can afford to use more – or spend the savings on other goods. In the former case, the ‘take-back’ effect deserves further study. The SD-PAM can also assist with improved indoor air quality, displacing the use of more polluting fuels which cause significant health problems.
- Energy modeling allows us to quantify at least some of the local sustainable development benefits. Figure 8 shows the emissions of total suspended particulates (TSPs) in the residential case. Compared to the base case, there are clear reductions of emissions overall. They are mostly early in the period, but at the end, they actually increase. This is primarily due to *increased* use of paraffin, which is a modeling effect seen in higher-income households. This needs further investigation. Earlier on, the reductions in local air pollutants outweigh this increase. Towards the end, however, the line crosses over because

emissions from biomass also increase. These results suggest that, overall, health benefits due to reduce particulate emissions are to be had – but that care needs to be taken to understand with which fuels such reductions can best be achieved.

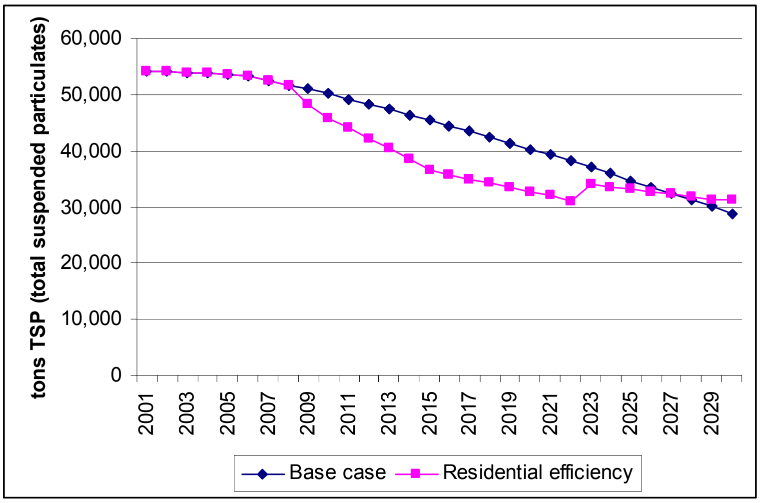
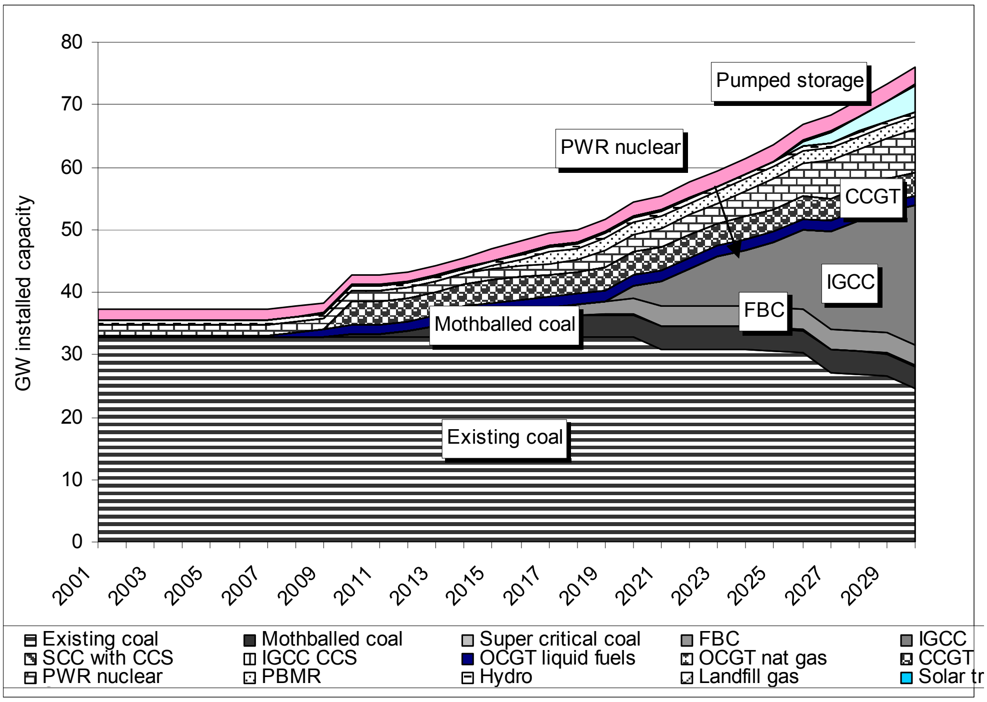


Figure 8: Emissions of particulate matter in base and residential efficiency cases

- The scenario shows GHG emission reductions of 136Mt CO_2-eq (relative to baseline) up to 2030.
- The mitigation costs for this scenario are negative and for each R1000 saved in the policy, there are associated GHG emissions mitigation of 2.247 t CO_2-eq.
- Most of the energy savings are from heating and water heating, with a smaller portion being from lighting. Residential energy efficiency is economical and delivers socio-economic benefits such as lower fuel bills and better heating.

2.2.5.4 Renewable energy

- Renewable energy supply is to supply 10,000GWh (36PJ) to South Africa's energy supply in 2013, and by 2030 will contribute 27% of the supply.
- Apart from reducing carbon emissions, this SD-PAM increases the use of domestic energy resources other than coal. By drawing on a resource that does not run out, the intervention contributes to energy security. The higher capital costs (at present unit costs) are off-set by lower fuel costs in the future.
- Emission reductions of 713Mt CO_2-eq (relative to baseline) up to 2030
- Mitigation costs, R71 / t CO_2-eq
- Of the renewable energy generation sources solar tower generation makes up approximately 2/3rds of the capacity, and solar trough generation the other one third. The contribution from wind power is minimal in the model.



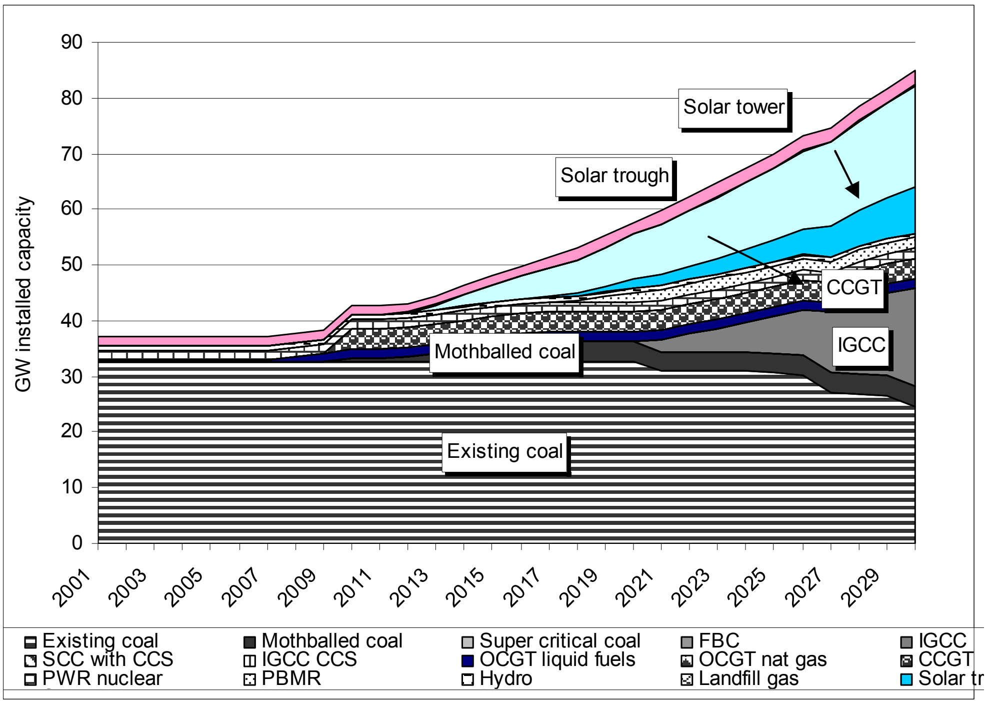


Figure 9: Electricity expansion with increased renewable energy compared to base case

2.2.5.5 Biofuels

- Under this scenario biofuels are blended together with petrol and diesel, such that by 2013 blend fractions are 8% ethanol with petrol and 2% biodiesel, and 20% ethanol, 5% biodiesel by 2030.
- Biofuels can contribute significantly to job creation, a major priority in South Africa. The implications for sustainable development overall require careful attention to issues of water scarcity, land availability, potential competition of energy and food crops, and potential impacts on biodiversity. This is not to suggest that biofuels are not SD-PAMs, but rather that very careful choice of crops, fuels and development paths is needed to ensure sustainability.

- Emission reductions 53.7Mt CO_2-eq (relative to baseline) up to 2030.
- Is also a net negative cost option, and for each R1000 spent, 0.96t CO_2-eq is saved.
- The promotion of biofuels as a mitigation option is not overwhelmingly positive.

2.2.5.6 Imported hydro

- The share of quantity of imported hydro power is increased significantly, with imports of 17TWh in 2015 increasing to 40TWh in 2020 and continuing to increase thereafter.
- Importing hydro-electricity does not promote development within South Africa, but could contribute massively to development in the broader Southern African region.
- Emission reductions 248Mt CO_2-eq (relative to baseline) up to 2030.
- This scenario has net negative costs and for each R1000 saved in the policy, GHG emissions savings amount to 275t CO_2-eq.
- Most of the increased imports are from Grand Inga in the DRC.

2.2.5.7 Imported gas and increased CCGT

- This policy promotes the use of imported natural gas as generation feedstock. New CCGT facilities are constructed in 2015, 2020 and 2025.
- Increased use of gas-fired electricity in South Africa would reduce local air pollutants as well as CO_2. Scaling up gas in the fuel mix would contribute to the energy policy goal of greater diversity of supply. Once gas is brought into the country, it also has potential to displace the direct use of coal in industry.
- Emission reductions 530CO_2-eq (relative to baseline) up to 2030.
- Mitigation costs, R338 / t CO_2-eq.
- The policy was modelled having gas replace coal as a mitigation option. Given the low cost of coal, the increased gas scenario is a costly mitigation option.

2.2.5.8 Improved light vehicle efficiency

- Standards and targets are set to improve the fuel efficiency of light vehicles by 1.2% per year, as opposed to a low improvement 0.4% increase in the base case.

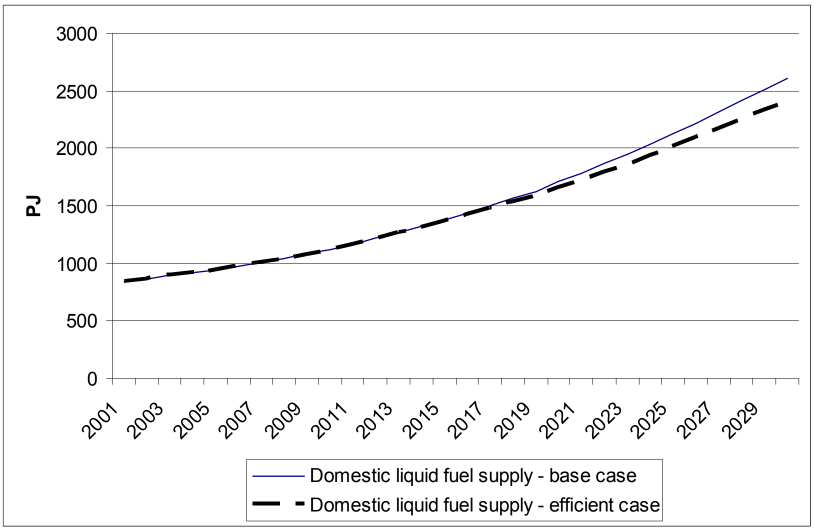


Figure 10: Domestic liquid fuel supply reduced with efficiency

- More efficient vehicles provide fuel cost savings for motorists. Since some 70% of our liquid fuel supply is derived from imported crude oil, using the resource more efficiently reduces dependence on oil imports, exposure to oil price volatility and potentially high future oil prices. Emissions of local pollutants would also be reduced.
- Emission reductions amount to 104Mt CO_2-eq (relative to baseline) up to 2030.
- The mitigation costs for this scenario are negative and for each R1000 saved in the policy has associated savings of 0.366 t CO_2-eq.
- The improvement in light vehicle efficiency has associated fuel and infrastructure savings.

2.2.5.9 Transport mode shift

- The purpose of this policy is for commuters to use public transport instead of personal vehicles. This would result in more passenger-kilometres being produced by the same amount of energy. This is modelled by increasing public transports share of passenger km's increases from 50% in 2001 by 0.5% per year to 65% in 2030.

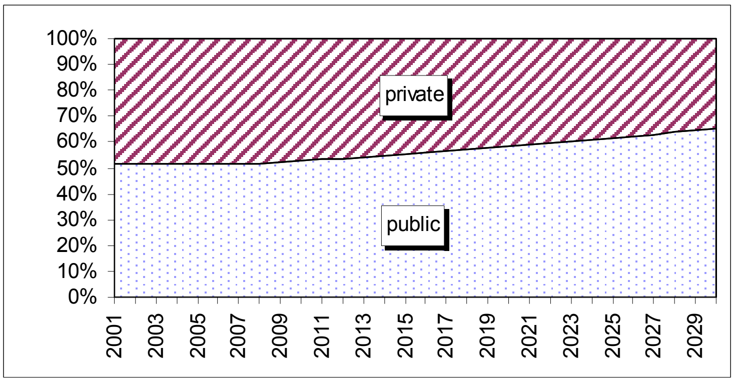
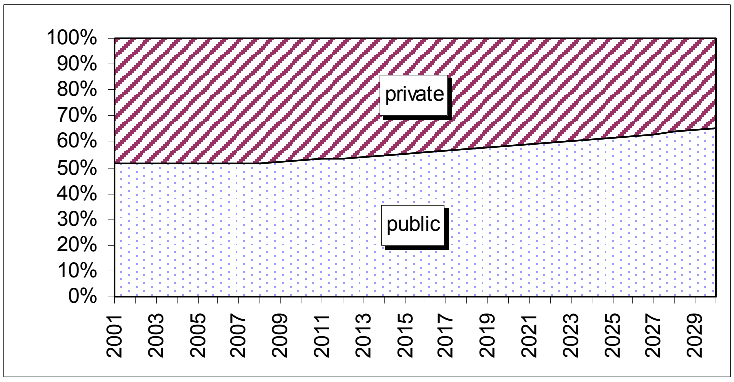


Figure 11: Shift from private to public passenger transport

A shift to public transport, as shown in



- Figure 11, would relieve congestion on roads, increasing mobility. It would also help to slow the growth in demand for diesel and petrol.

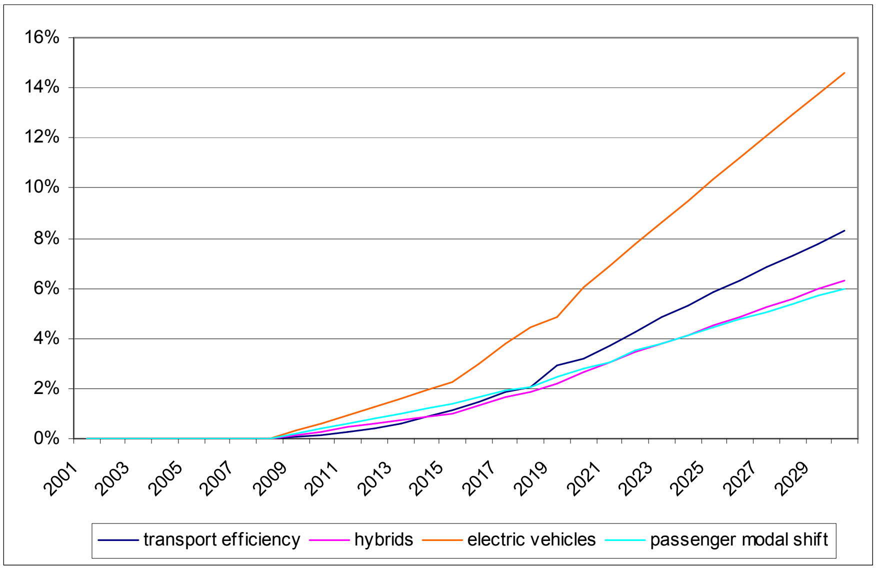


Figure 12: Energy savings in the transport cases

- Emission reductions 79CO_2-eq (relative to baseline) up to 2030.
- The mitigation costs for this scenario are negative and for each R1000 saved in the policy there are associated GHG emissions savings of 0.176 t CO_2-eq.
- Increasing the share of public transport for passenger kilometres results in significant savings in fuel and infrastructure.

2.2.5.10 Hybrid vehicles

- The share of hybrid vehicles is increased such that hybrids account for 7% of private passenger kilometres by 2015 and 40% of private passenger km's by 2030. The ratio of public to private kilometres remains 50% for the whole scenario.
- Environmentally, hybrid vehicles will reduce local air pollution per passenger-kilometer. They would contribute to the economy by lowering the need for fuel imports.
- Emission reductions of 82 Mt CO_2-eq relative to baseline up to 2030.
- Mitigation costs, R643 / t CO_2-eq .
- The efficiency of hybrid vehicles leads to substantial savings over the period, but at substantial costs. The significantly higher price for hybrid vehicles over normal passenger vehicles is the reason for the high mitigation costs.

2.2.5.11 Electric vehicles

- In this scenario, the share of private vehicle kilometres travelled using electric cars is increased to 37% by 2030. This scenario is run under the assumption that renewable energy will account for 27% by that time, ensuring that the electricity used is low emission.
- Electric vehicles offer a potential alternative to seeking cleaner liquid fuel *supply*. While the overall effects depend significantly on where the electricity comes from (greater improvements in a renewables-based grid), improvements are possible even in the existing coal-based grid (EPRI & NRDC 2007).
- Emission reductions 229Mt CO_2-eq (relative to baseline) up to 2030.
- This is also a net negative cost option, and for each R1000 spent, 0.544t CO_2-eq is saved.
- Considering that this case is run against a baseline grid (dominated by coal), most of the savings are from the better 'well-to-wheels' energy efficiency of electric vehicles. Larger

emissions cuts could be obtained through sourcing non fossil fuel electricity for electric vehicles, which would displace fossil fuel-based liquid fuels emissions, but not replace them with coal emissions.

2.2.5.12 Summary for all SD-PAMs

Table 4 summarises the sustainable development policies and measures analysed above. The total emission reductions over the period (2001 to 2030) and the mitigation costs (R / t CO_2-eq) can be compared.

Table 4: Summary of cases with total GHG mitigation 2001 - 2030 and associated costs for the scenarios

Case name	*Cumulative emission reductions, 2001-2030 (Mt CO_2-eq)*	*Rank (most reductions = 1)*	*Mitigation costs (R / tCO_2-eq)*	*Rank (lowest cost = 1)*
Industrial EE	1231	1	-95	7
Commercial energy efficiency	112	7	-480	5
Residential EE	136	6	-445	6
Renewable energy	714	2	71	9
Biofuels	54	11	-1 038	4
Imported hydro electricity	248	4	-3.6	8
Imported gas / increased CCGT	530	3	338	10
Improved light vehicle efficiency	104	8	-2 734	2
Transport mode shift	79	10	-5 671	1
Increased hybrid vehicles	83	9	644	11
Increased electric vehicles	229	5	-1 836	3

As the rankings make clear, the greatest emission reductions over the 30-year period are from industrial energy efficiency, followed by renewable energy for electricity generation and imported gas. The most cost-effective, according to this analysis, is transport modal shift – but it may be that infrastructure costs are not fully accounted for yet, an issue deserving further, dedicated study. What is notable and a robust result is that there are several efficiency measures which are negative cost measures, that is, while requiring an upfront investment, they save more money over time in fuel costs than that expenditure.

The reductions in Table 4 cannot simply be added up, due to energy system effects. Perhaps the clearest example is that energy efficiency would reduce demand, and thus supply-side mitigation options would reduce less than if modelled individually. These and other system interactions can best be modelled by combining cases.

The way in which sustainable development co-benefits can be quantified has been illustrated in several of the SD-PAMs reported above. Fuel savings are shown, for example reducing coal and electricity in industry due to efficiency. Transport cases show savings in liquid fuels, with shift from private to public modes. Reduced local air pollution is quantified in terms of NO_x, SO_2, particulates in industry, commercial and residential sectors. Greater energy security through diversity is illustrated in the renewable SD-PAM.

These co-benefits address all three dimensions of sustainable development – economic, social and environmental. A key consideration, that of job creation, requires further analysis. Macro-economic analysis, applied this to industrial energy efficiency as an SD-PAM, elsewhere (Winkler *et al.* 2007). Energy efficiency measures create some jobs directly in the programme, but more important are the indirect effects. The savings on energy efficiency are spent on more energy or other goods, and input-output tables are one way of considering the economy-wide effects. For net job creation, the jobs not created in avoided power stations were also taken into account. Net jobs are calculated through the economy, and this can be introduced within Markal by adding the job gains and losses through the 'operation life' and initial 'investment' in energy efficient technologies in question. The results from the previous analysis are shown in Figure 13.

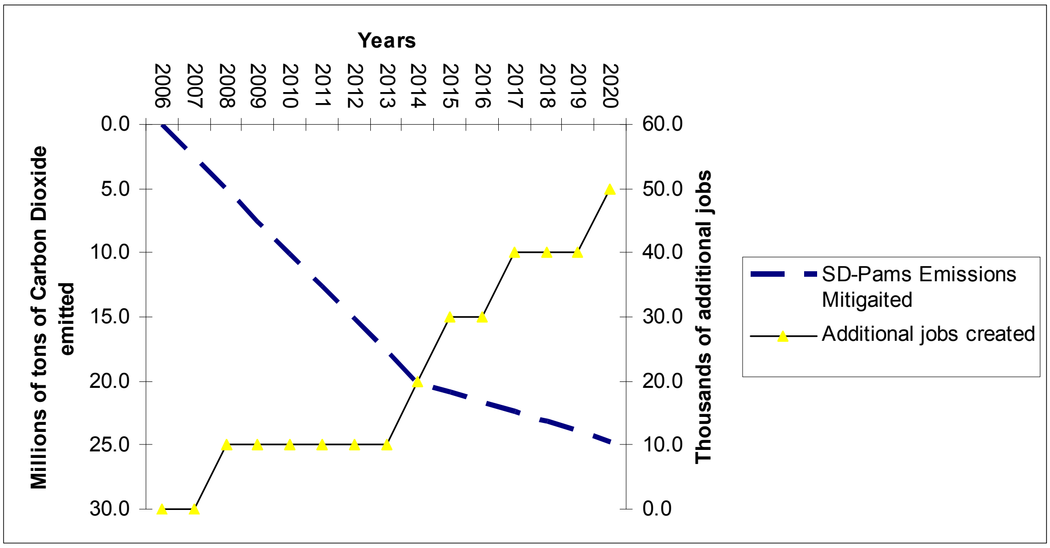


Figure 13: CO_2 savings by scenario and jobs created through SD-PAMs in industrial energy efficiency

Some limitations and caveats on the results should be noted. While no formal uncertainty analysis was conducted on the results in Table 4, the ERC researchers do have different levels of confidence in particular results. In particular, the level of confidence for the transport cases is high for the emission reductions, but relatively low for the costs. While costs of transport infrastructure have been included at a first cut, the underlying data still needs further investigation; compounded by the inclusion of relatively unknown technologies such as hybrids and electric vehicles. For none of the modeling here is technology learning explicitly included, a factor that would have significant impact on new technologies, also renewable electricity. Otherwise, costs of electricity and energy efficiency cases are fairly well understood, giving greater confidence.

2.2.5.13 Combining and running the SD-PAMs cases

The cases were combined sequentially in the least cost optimisation model. The emission reductions for individual SD-PAMs in Table 4 cannot simply be added up. For example, if both an energy efficiency and a renewable energy SD-PAM were combined, the renewables would show smaller reductions – since less electricity needs to be delivered due to efficiency. Table 5 addresses this problem by running one SD-PAM, then adding another, so that systems effects are properly taken into account and double-counting is avoided. Adding each SD-PAM one by one means that the sum of emission reductions in the right-hand column of Table 5 is a cumulative total.

There was however the need to run the transport cases as a combined case, as they use activity ratios in their calculations. If not combined, activity ratios in one run will over-write those in the previous run. The combined scenario included: transport mode shift, increased electric vehicles and increased hybrid vehicles.

The first combined run yielded the following mitigation reduction for each successive case:

Table 5: First combined run of SD-PAMs, transport combined

Case Name	*Mitigation costs (R/tCO_2-eq)*	*Emission reductions, 2001-2030 (Mt CO_2-eq)*	*Cumulative emissions reductions (Mt CO_2-eq)*
Combined transport case	-1555	319	319
Improved light vehicle efficiency	-2148	70	390
Biofuels	1192	35	425
Commercial energy efficiency	-527	111	536
Residential EE	-425	139	675
Industrial EE	-94	1204	1879
Renewable energy	87	611	2489
Imported hydro electricity	22	232	2721
Imported gas / increased CCGT	873	142	2863

From this combined run, it was noted that the combined transport case had a higher cost than the improved light vehicle efficiency case. In the combined run, system effects mean change to the costs. However comparisons can be drawn with the least-cost modelling of the individual cases. The mitigation costs for the first five cases are comparable. The renewables case is significantly cheaper to run in the combined case (based on lower demand). Imported hydro and gas become more expensive in the combined case.

The combined case was re-run a second time, changing the sequence in which the policies are implemented. The improved light vehicle efficiency and biofuels cases are run before implementing the combined-transport case, as running them after the combined case causes results not consistent with running the individual SD-PAM scenarios.

Table 6: Second combined run of SD-PAMs, revised sequence

Case Name	*Mitigation costs (R/tCO_2-eq)*	*Emission reductions, 2001-2030 (Mt CO_2-eq)*	*Cumulative reductions*
Improved light vehicle efficiency	-2734	104	104
Biofuels	-940	50	154
Combined transport case	-1012	271	425
Commercial energy efficiency	-527	111	536
Residential EE	-425	139	675
Industrial EE	-94	1204	1879
Renewable energy	14	240	2119
Imported hydro electricity	91	602	2721
Imported gas / increased CCGT	873	142	2863

Also it was noted that if the Biofuels case was run after implementing the combined transport case, it became a net positive cost option. This is due to the changes in fuel-use that the combined transport case imposes. The mitigation costs are not identical to the mitigation costs when scenarios are run individually (in Table 4). In particular, biofuels have now changed to a positive cost in the first combined run (Table 5), which suggests that the sequence has an effect. The revised order (and the results in Table 6) are considered more reliable than in the previous sequence, since the biofuels is again a negative cost option.

In these results the mitigation costs per case are different to the previous combined run of the model and the emissions reductions per case introduced change, however, the cumulative reductions if all the cases implemented remains the same, at 2863Mt CO_2-eq.

2.3 Results for South Africa from international models

Collaborative analysis of national policies in international context

2.3.1 Results from group work using FAIR in first workshop [2]

In the first workshop, the ERC team provided information on analysis of South African SD-PAMs, as well as the drivers underlying the national energy modeling. Netherlands Environmental Assessment Agency provided an introduction to the FAIR 2.1 model. These were discussed in four days of intensive collaborative work.

On 11 and 12 September 2007 in the first workshop, a group exercise was done to look at the implications that different climate regime proposals would have for South Africa. Using the FAIR software (in particular the country-version of the FAIR 2.1 model, described in detail in den Elzen *et al. (2007a)*, participants were able to see what the mitigation effort required would be for some different emission reduction regime proposals. The proposals were: South-North Dialogue, Multi-stage, Contraction and convergence and Triptych approach.

In running the scenarios, participants were asked to explore what assumptions, for the cases, would need to be made in order to stabilize global emissions at 450 and 550 part per million CO_2-eq levels by 2050. Participants were also asked to compare South Africa's future commitments to a selection of other countries:

- China
- The US
- UK
- Germany
- China
- India
- Brazil
- Argentina
- Nigeria

This is a report on the results from the running of the scenarios.

2.3.1.1 South-North Dialogue Proposal

Under this proposal, countries are divided into 6 categories and have emission reductions based on that category. There is a strong emphasis on three basic criteria for setting emission reductions; these are: the responsibility of the country to the global climate change problem; the capability the country has to reduce their emissions; and the potential of the country to reduce emissions.

The categories are:

- Annex II countries
- Annex I, but not Annex II countries
- Newly industrialized countries (NICs)
- Rapidly industrializing developing countries (RIDCs)
- Other developing countries (ODCs) and
- Least developed countries (LDCs)
-

For the first two categories, Annex II countries and Annex I, but not Annex II countries, the countries in these categories are the same as the Kyoto Protocol countries. For the other four categories, countries are sorted according to a weighted index. A country's index is based on the following: energy GHG emissions produced per unit GDP, all GHG emissions produced per capita, cumulative energy CO_2 emissions per capita from 1990 onwards, and GDP in purchasing power parity (PPP) per capita (den Elzen *et al.* 2007b).

[2] This section of the report was compiled by Jonathan Manley.

For non-Annex I countries, the countries with the lowest indices are categorized as LDCs and those with the highest as NICs. The category above LDCs are ODCs and above that are RIDCs.

For the case study of South Africa under the South-North Dialogue proposal, the following reductions were required for the 550ppm CO_2-eq case.

- Annex II countries: 15% below 1990 emission levels
- Annex I but not Annex II: 20% below 1990 emission levels
- NICs: 30% below baseline emissions
- RIDCs: 10% below baseline emissions
- ODCs and LDCs: no commitment.

By 2020 the following reductions were required (per decade) to stabilize CO_2-eq emissions at 550ppm.

- Annex II countries: 30%
- Annex I but not Annex II: 25%
- NICs: 27%
- RIDCs: 25%
- ODCs and LDCs: no commitment.

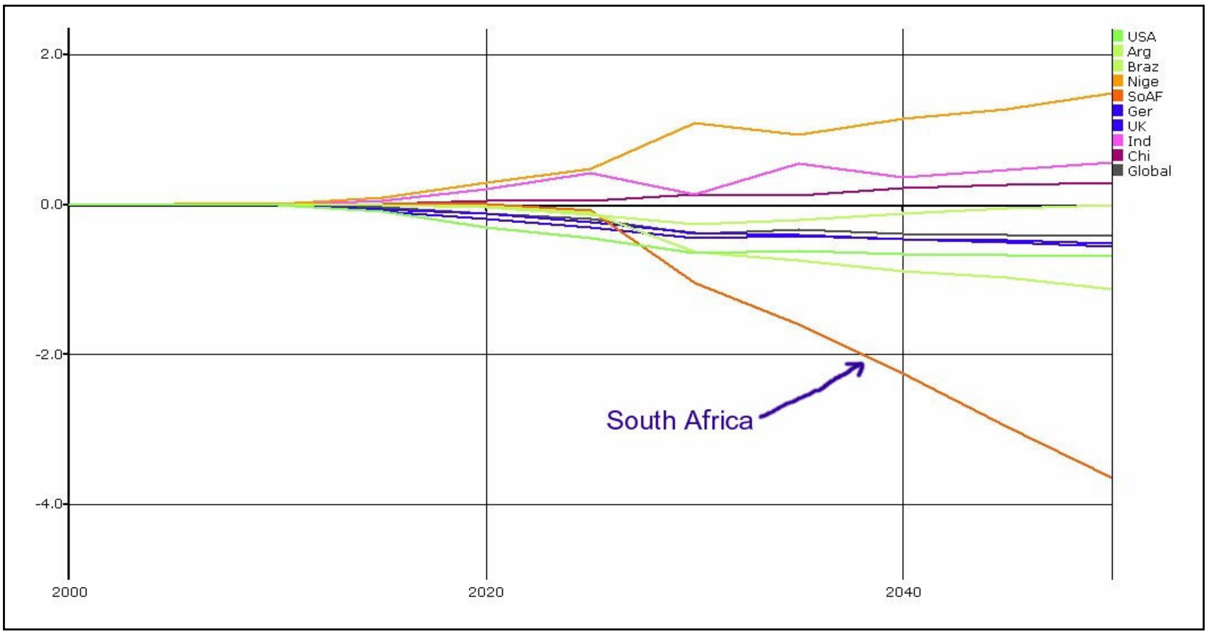


Figure 14: Costs as a percentage of GDP for the 550ppm case

In 2020, South Africa will be categorized as a RIDC, but from 2030 onwards will be categorized as a NIC. South Africa has a similar shaped emission reduction profile as Brazil and Argentina, but it was found that the abatement costs for South Africa is much higher than the other country cases, and amounted to almost 4% of GDP by 2050.

To stabilize the emissions at a 450ppm CO_2-eq level by 2050, the following reductions were required in 2020:

- Annex II countries: 30% below 1990 emission levels
- Annex I but not Annex II: 25% below 1990 emission levels
- NICs: 30% below baseline
- RIDCs: 15% below baseline
- ODCs and LDCs: no commitment.

And the following commitments per decade thereafter:

- Annex II countries: 37%
- Annex I but not Annex II: 35%

- NICs: 25%
- RIDCs: 45%
- ODCs and LDCs: no commitment.

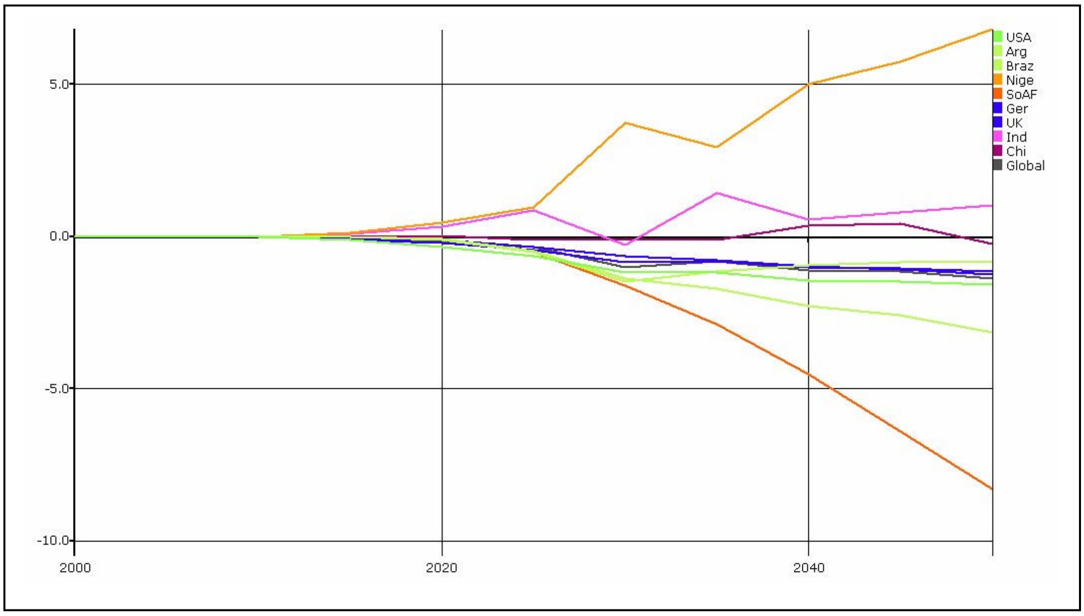


Figure 15: Costs as a percentage of GDP for the 450ppm CO_2 –eq case

To stabilize emissions at 450ppm CO_2-eq, a much larger reduction in emissions is required. The emission reduction curve for South Africa resembled that of Brazil and Argentina, and it was once again categorized as a NIC very soon after 2020. In this scenario, the high mitigation reductions required for South Africa requires almost 10% of GDP (PPP) to meet the targets.

From these two cases it was seen that South Africa would fall into the category of a developing country that is further along the development path, and would therefore have emission reduction targets. The emission reduction targets are based on 1990 levels and not baseline levels, therefore the absolute reductions required are high as the baseline development model shows a big increase in emission levels. Using baseline development levels South Africa could have targets that were not as high and did not cost as high a portion of GDP.

2.3.1.2 Contraction and convergence

Under this proposal countries are assigned targets to reduce emissions based on their population size. Under such a proposal the global target would be calculated, as the amount of emissions permitted that would enable CO_2-eq concentrations in the atmosphere to stabilize (450ppm or 550ppm). This global allowance budget would then be divided amongst countries according to the populations of the countries.

For the scenario where CO_2 concentrations are stabilised at 450ppm CO_2-eq, South Africa must decrease its emissions by approximately 40% of its baseline levels by 2020. By 2050, South Africa will need to reduce emissions by 90% compared to baseline levels. In this proposal mitigation costs are 10% of GDP by 2050.

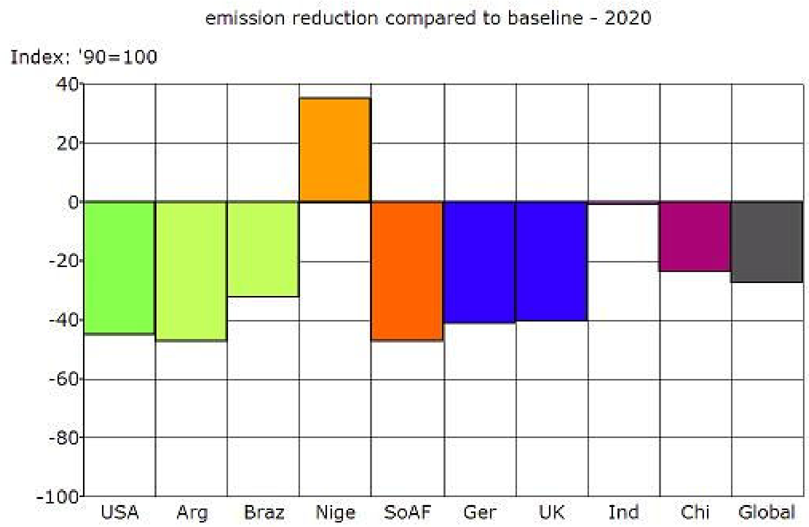


Figure 16: Emission reductions in 2020, compared to baseline emissions

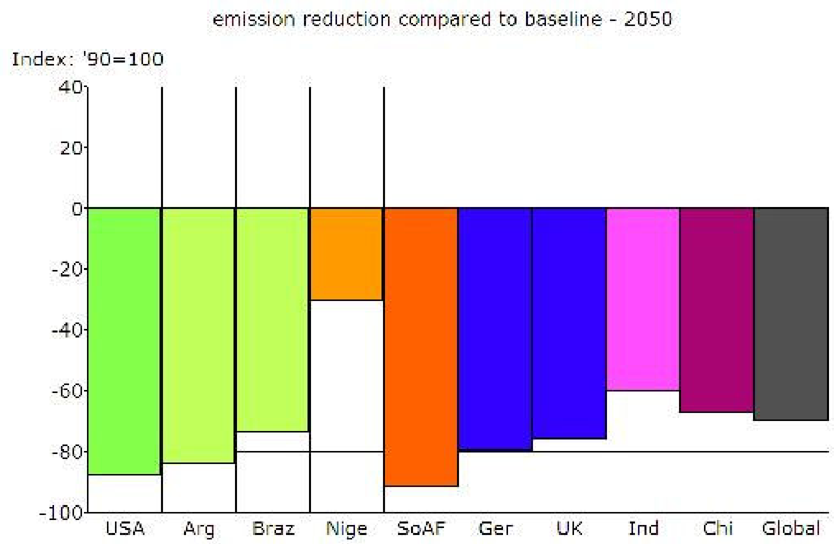


Figure 17: Emission reductions in 2050, compared to baseline emissions

2.3.1.3 Multi-stage approach

The Multi-stage approach is, a staged approach, where countries' emission reduction commitments are based on their stage of development. The Multi-stage approach is based on a country's capability to mitigate and looks at the level of GDP per capita of the country. There are four stages through which a developing country can progress, each requiring a different level of emissions reduction:

- Stage 1: GDP per capita is lower than 40% of Annex I income in 1990 (PPP basis). No emission reduction commitments.
- Stage 2: graduate into stage 2 when GDP per capita is 40% of Annex I income in 1990. GHG intensity targets are made for countries belonging to this stage.
- Stage 3: graduate when GDP per capita is 75%, and CO_2 per capita is Annex I average. GHG emission stabilization targets set.
- Stage 4: All Annex I countries are in this stage. Total cumulative emissions reduction is required for this stage.

Under this scenario given the above assumptions it was seen that South Africa would have to reduce emissions by 20% in 2020 and would have to reduce its baseline emissions by 60% by

2050. The abatements costs were seen to be low, however, with South Africa's abatement costs only being about 0.5% of GDP by 2050, which was one of the highest abatement costs. Running the scenario again using the default assumptions gives abatement costs of about 5% for the 450ppm scenario. The 0.5% cost to GDP does is not consistent with results from the other runs of the model as a reduction of 60% by 2050 would require levels of investment significantly higher that 0.5%.

2.3.1.4 Triptych approach

Under this approach, emission reduction targets for a country are calculated taking into account the differentials between a country's power, industrial and domestic sectors. The targets are set based on reductions possible for each sector, but compliance depends on attaining the overall target, not per sector targets. Under this scenario, the assumption was made that the energy efficiency index (EEI) of South Africa would need to converge towards a target of 1.2. The EEI starting point for the convergence is almost 3 which implies a very low level of efficiency. The low energy efficiency in South Africa makes this a challenging target to reach.

By 2020 South Africa must reduce its emissions by 15% compared to baseline levels, and by 2050 must reduce these by 65% compared to 1990 levels. Under this scenario, 10% of South Africa's GDP will be used towards meeting the emission reduction target.

Further work is to be done on this approach to determine what the sources of the data for the EEI are, and to calculate South Africa's EEI using national datasets.

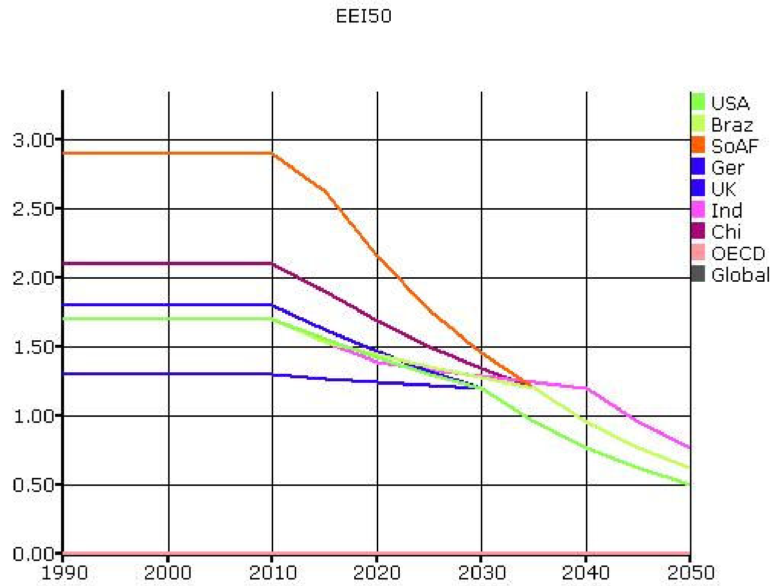


Figure 18: Energy efficiency index improvements required in Triptych approach

2.3.2 Results from group work using EVOC in second workshop [3]

2.3.2.1 Multistage

The case was run with the objective or reaching a 450ppm CO_2-eq stabilisation level target. This then required a global GHG emissions reduction of 20% below 1990 levels by 2020, and a 35% decrease below 1990 levels in 2050. A comparison was made between South Africa and a selection of other countries under this climate regime. These can be seen in Figure 19: .

[3] This section of the report was compiled by Jonathan Manley.

The commitment types for Stage 2 and Stage 3 countries were set relative to the BAU case. The resulting reductions required relative to 1990 levels can be seen in Figure 19.

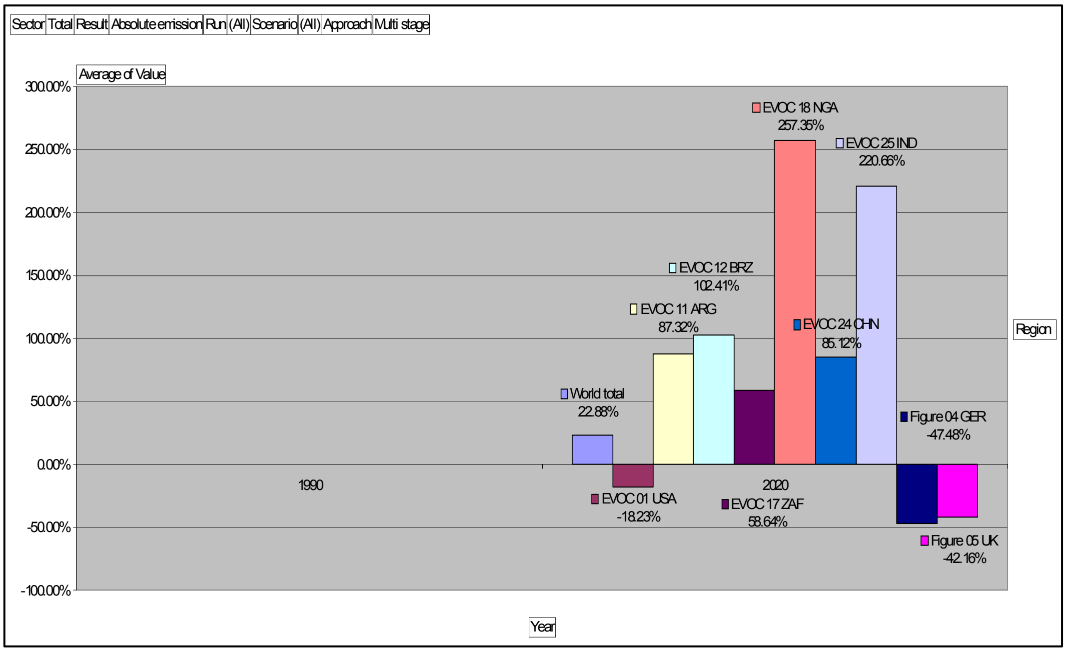


Figure 19: Comparison of commitments under the Multi-stage approach

Several iterations were performed for the Multi-stage approach where the global emissions targets were set according to the BAU and to IPCC SRES B1 and A1B scenarios. In addition, an investigation was conducted on changing the type of targets for countries in Stage 4 of the approach from national absolute reductions to per capita emissions reductions.

The B1 and A1B scenarios were selected, to allow Stage 1 countries to follow these softer development scenarios. Concerning achieving the 20% target in emissions reductions, the development path assumed is very influential. In a future with a cleaner development path, mandated climate targets would be lower relative to that particular baseline. It was noted that some developing countries do not reach the Stage 4 graduation criteria by 2020, and would not have any reduction commitments during this time.

In order to ensure that the global climate change mitigation target is reached, graduation thresholds may be adjusted downward to include a higher number of developing countries, or increase the year-on-year reduction commitment. The question of responsibility and capability would then be significant.

To reach the 2050 targets, a very ambitious level of 8.5% per year for country-level reductions is needed to reach the goal. If the reductions are based on per capita emissions, high reductions would be required across the board.

2.3.2.2 South-North

For this regime, to stabilise at 450ppm, the same targets were used as in the S-N dialogue paper (den Elzen, Höhne, Winkler, 2007). In this EVOC implementation of the proposal, the overall world totals increase using the same emission reduction commitment figures from the S-N paper. In FAIR 2.1, these targets resulted in a reduction in overall GHG emissions. This could be explained due to the different downscaling methodologies used. EVOC as downscaling applied the growth rates of the IMAGE IPCC SRES implementation of the 17 IMAGE regions at the level of countries, whereas FAIR uses a recently developed new downscaling method of van Vuuren *et al*. (2007).

For country baselines of population, GDP and emissions, both FAIR 2.1 and EVOC use downscaled averages of the SRES scenarios. Figure 20 shows global emissions resulting from the approach taken in the South-North dialogue, as implemented through EVOC.

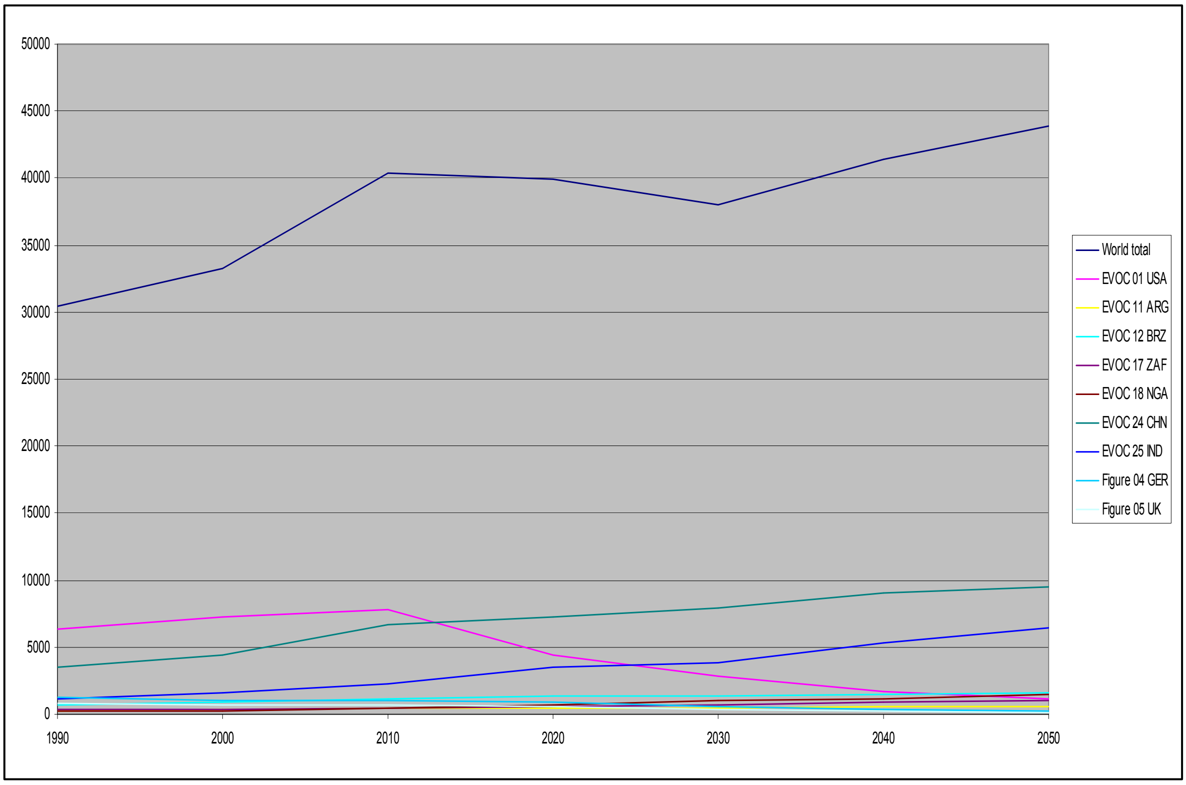


Figure 20: Global emissions using the EVOC South-North Approach implementation

The updated South-North approach in FAIR 2.1 includes some implementation modifications not included in this version of EVOC, such as the RIDCs being selected from those countries with medium index values and a higher annual growth in 1991–2000 than 2% (see den Elzen, (2007b)). This set of results was interesting in that the EVOC and FAIR 2.1 implementations of the proposal would lead to different targets for individual countries. This illustrates the sensitivities the models have in their configurations of underlying drivers and assumptions. The downscaling methodology was identified as one of these key differences.

2.3.2.3 Triptych

Results from the EVOC implementation of South Africa were compared to results from FAIR 2.1. The resulting emission reduction sectoral targets were comparable to one another, but not identical. One of the main differences emphasized was the role of the 'structural change index' parameter as included in EVOC. Results for sectoral targets under the Triptych approach, using the EVOC tool, are shown in

Figure 21.

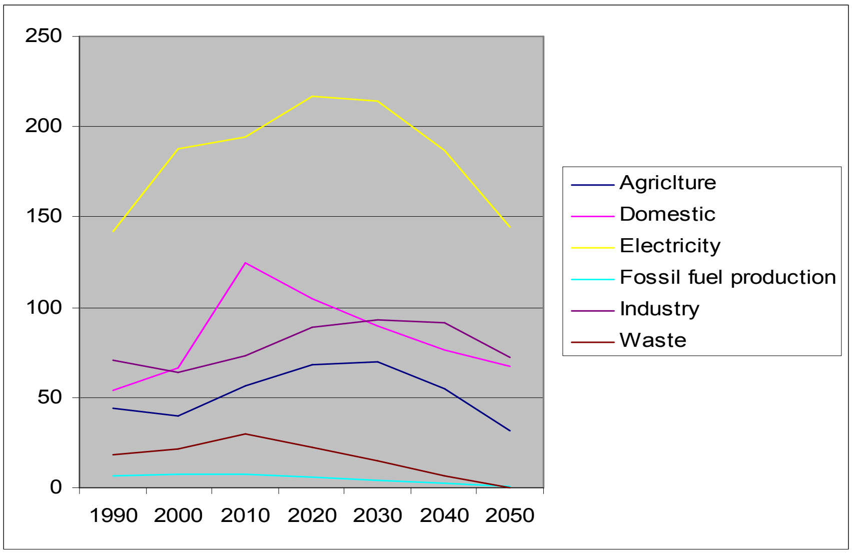


Figure 21: Sectoral targets for South Africa under the EVOC Triptych approach

In FAIR 2.1 the physical growth in industry's energy demands (and hence GHG emissions) are based on total final energy consumption in industry taken from the recently updated IMAGE implementation of all six IPCC SRES scenarios. As such, it also better accounts for structural changes in the industrial sector as well as autonomous baseline energy-efficiency improvements. EVOC uses a uniform 'structural change factor', which converts the total 'industrial value added' (the economic indicator used for the industrial production) into physical production growth of heavy industry. The index is set at 0.35, based on an assumption of growth for global industry, and very much influences the results as the industrial emissions for all countries are reduced with 65%. Further work could include determining the value of the index using historical values.

2.3.2.4 Comparison across EVOC results

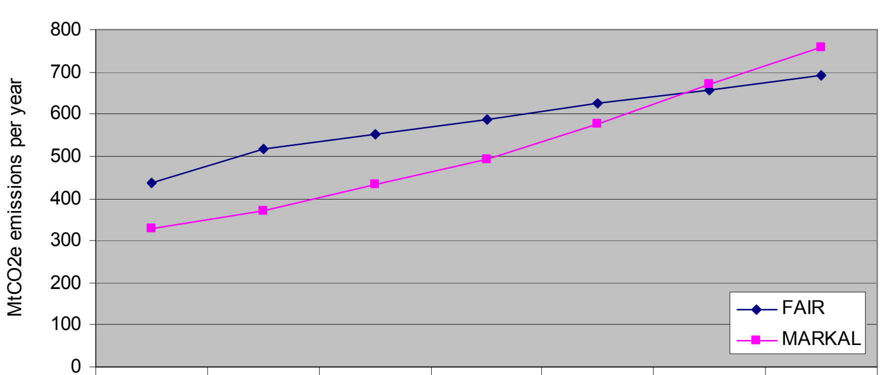
South Africa has particular national circumstances that influence the results: South Africa ranks above the average of developing countries with respect to its state of development. Its emissions and GDP per capita are well above world average. Its emissions per capita are close to Annex I average. South Africa is strongly dependant on coal, which makes up three quarters of its energy use. South Africa's emissions per kWh electricity are among the highest in the world.

Under all future scenarios South Africa would need to slow the growth of emissions already by 2020 and reduce emissions thereafter. In a multistage approach, South Africa would move very quickly into higher stages due to the relative high emissions per capita and would have to slow emission growth significantly. The South North Dialogue proposal allows for more room for South Africa in the beginning, but soon requires substantial reductions. The Triptych approach is less stringent for South Africa as it considers the particular national circumstances most, especially the relatively high emissions in the electricity sector.

3. Comparison of results

3.1 Comparison on baseline emissions

This section compares the baseline for the Triptych Approach modelled in FAIR 2.2 (den Elzen *et al.* 2008) to that of the Markal model for GHG emissions for the period 2000 – 2030. It will briefly explain the source of the data and some of the assumptions that have been made forming them. Figure 22 shows the baseline projection for the FAIR and Markal baselines.



	2000	2005	2010	2015	2020	2025	2030
FAIR	438	516	553	587	626	658	690
MARKAL	329	369	434	494	575	671	760

Figure 22 - FAIR 2.2 Triptych baseline and Markal CO_2-eq emissions baselines

3.1.1 Baseline projection of emissions from international model (FAIR Triptych)

The baseline shown below is taken from the FAIR 2.2 model. It shows the emission projections for the different sectors for the period 2000 to 2030.

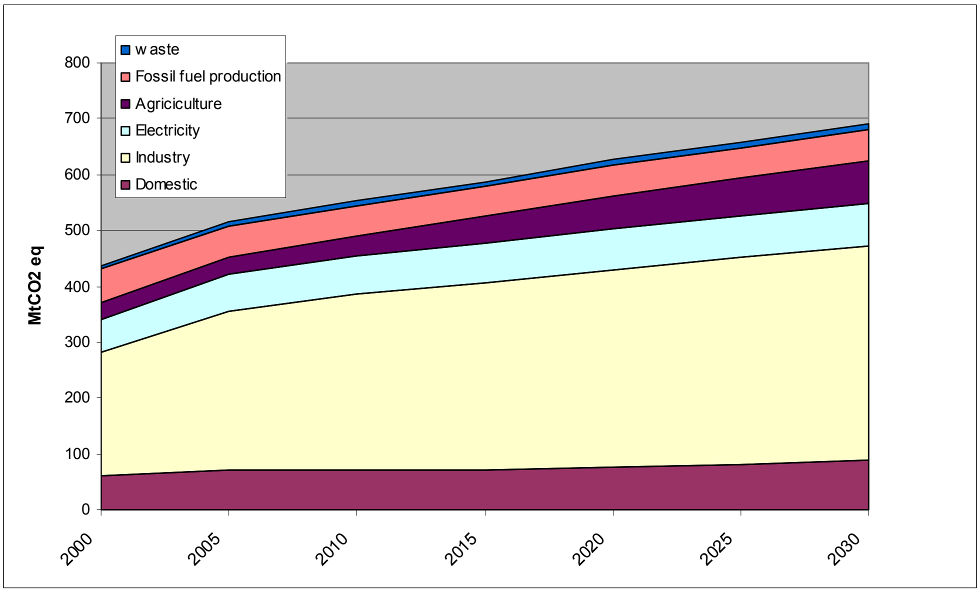


Figure 23: Baseline emissions projections using FAIR 2.2 Triptych approach

The biggest contribution to GHGs is from the electricity sector. Emissions from the domestic and industrial sectors are relatively steady with a gradual decline in industrial emissions over time. Emissions from fossil fuel production increases steadily. Emissions from agriculture are seen to decrease significantly from 2000 onwards. This is most likely due to an improbably high figure having been used around the year 2000. The IMAGE 2.3 reference scenario developed for the ADAM project (MNP 2007) (also called ADAM scenario) is used here, which is an elaboration of the World Energy Technology Outlook (WETO) reference scenario (DG-Research 2007). The GDP and population figures used for the projection are shown in the table below:

Table 7: Comparison of population and GDP projections underlying Markal and FAIR modeling

	2000	*2005*	*2010*	*2015*	*2020*	*2025*	*2030*
FAIR 2.2							
GDP ($US bill/ year)	181	206	212	219	231	245	263
Population (millions)	46	47	48	48	48	48	48
Markal							
GDP (R bill/ year)	949	1 147	1 429	1 844	2 444	3 238	4 179
Population (millions)	45	48	49	50	51	52	52

The GDP projection from Markal shows a significantly higher growth rate than the FAIR projection for GDP. The FAIR 2.2 GDP is in $US and Markal is expressed in Rands, therefore a conversion should be done to make them directly comparable.

3.1.2 Baseline projection of emissions from national energy model (Markal)

From the initial look at the Markal baseline, the projections are distinctly different. Markal projects the emissions profile of South Africa to be higher than the FAIR 2.2 projections. The growth in industrial and domestic emissions appears to be higher in this Markal projection, and lower than FAIR 2.2 for the electricity sector.

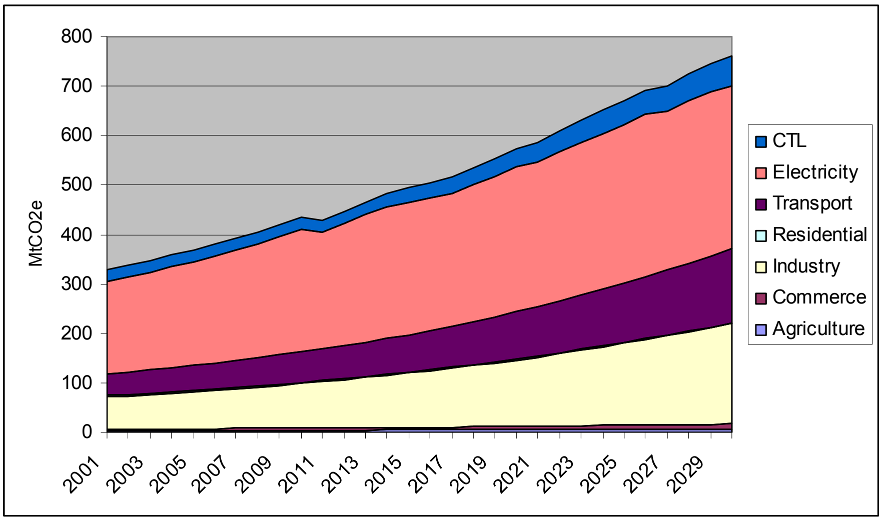
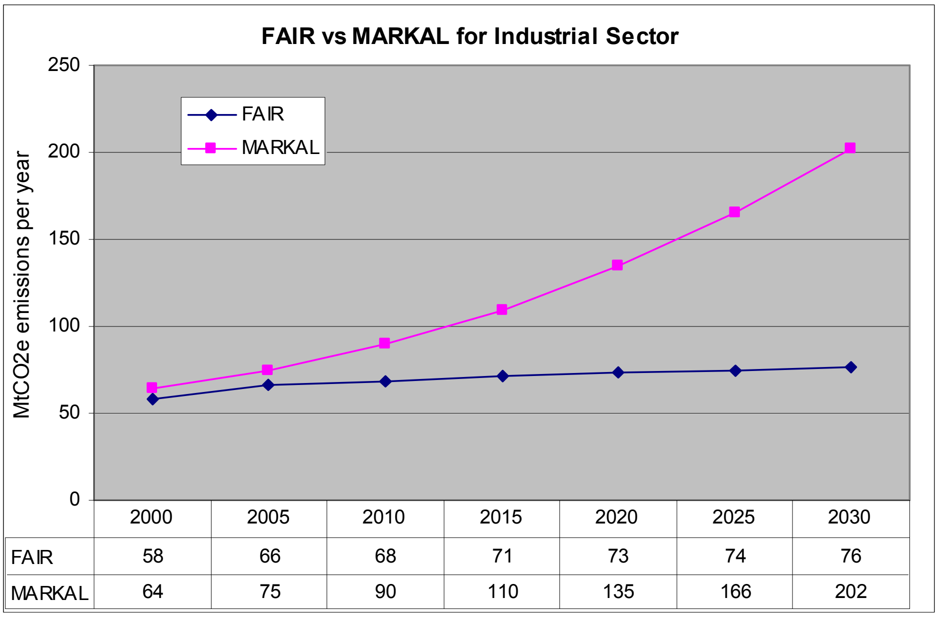


Figure 24: Baseline emissions emission projections in FAIR and Markal model baselines

Note that emissions considered 'domestic' in FAIR is equivalent to in the national Markal model to domestic and transport sector emissions. In the national context, domestic refers to primarily to households, while in the international approach, domestic also includes transport.

3.1.3 Industrial sector



	2000	2005	2010	2015	2020	2025	2030
FAIR	58	66	68	71	73	74	76
MARKAL	64	75	90	110	135	166	202

Figure 25: Industrial sector emission projections in FAIR and Markal model baselines

The projected growth in emissions for the industrial sector is significantly higher in the Markal projection for the period 2000 to 2030. The FAIR 2.2 industrial emission profile for South Africa is based on the IMAGE 2.3 ADAM scenario (MNP 2007). Changes in population, per capita GDP and emission intensity have been used to project industry sector emissions.

Another of the baseline drivers is the energy intensity per $US GDP. In the FAIR 2.2 Triptych baselines, this increases marginally from about 1.6tCO_2-eq per USD GDP in 2000 to 1.75tCO_2-eq per $US GDP. The key difference in the industrial sector emissions is due to the different underlying assumptions about GDP.

3.1.4 Domestic sector

The growth in the domestic sectors emissions is also relatively low in the FAIR 2.2 Triptych 7.0 version of the baseline. This would once again be for the same reason as the above, where the population growth, GDP and intensity have been used to project future emissions. Bearing in mind that domestic emissions in the Triptych approach are a combination of transport and residential, the Markal and FAIR 2.2 baseline projections are compared below.

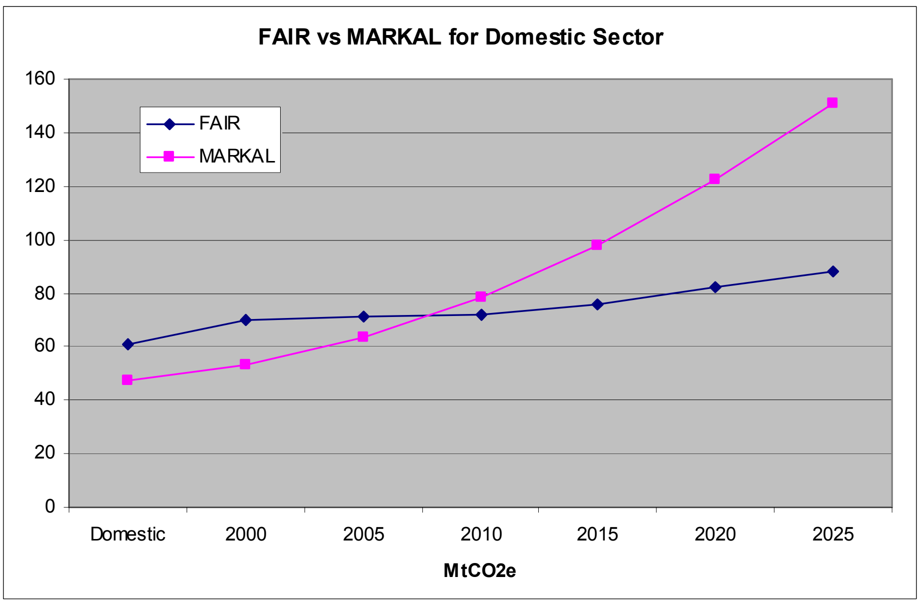


Figure 26: Domestic sector emission projections in FAIR and Markal model baselines

As in the industry sector, growth in the Markal baseline is higher.

3.1.5 Electricity sector

The growth rate in electricity sector baseline projections although comparable, differ in absolute terms by an average of more than 15%. The FAIR 2.2 Triptych baseline's electricity sector includes the transformation and refinery sectors.

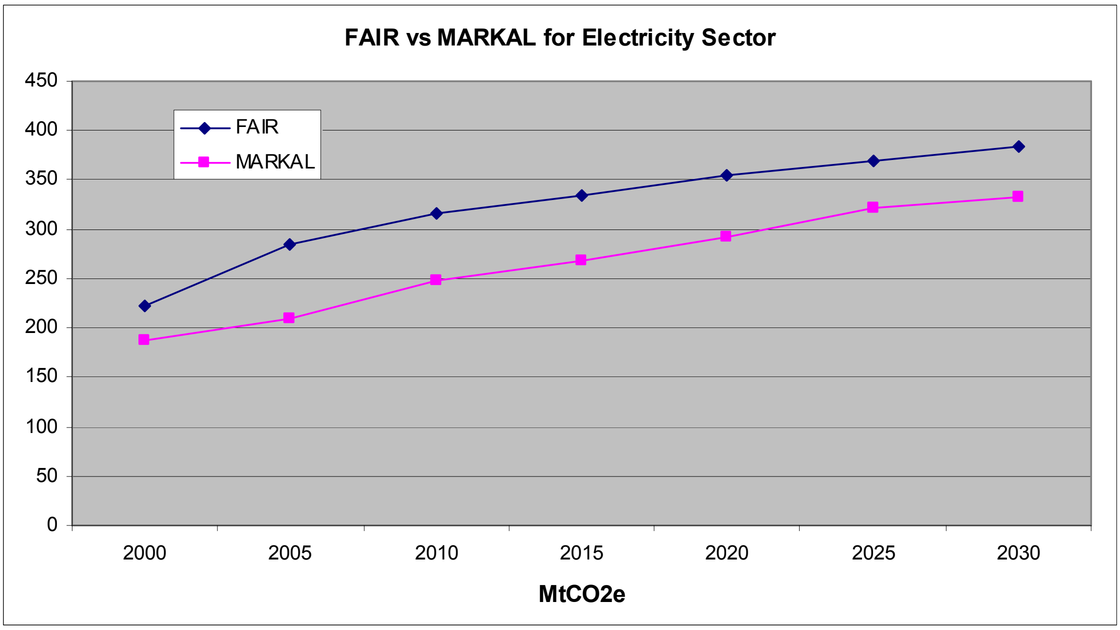


Figure 27: Electricity sector emission projections in FAIR and Markal model baselines

3.1.6 Agriculture and waste

The FAIR 2.2 version of the agricultural sector includes non-energy emissions from agriculture. There is no 'waste' sector in the Markal emissions projections

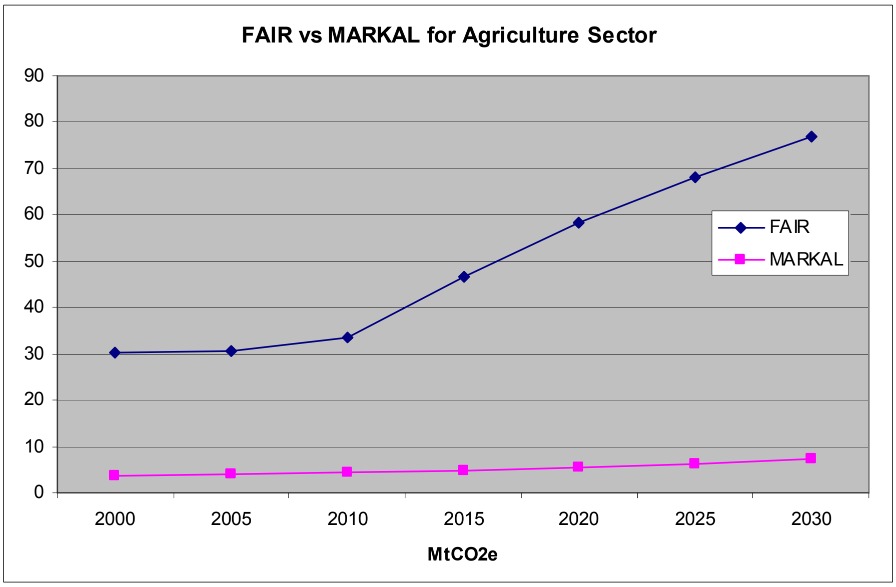
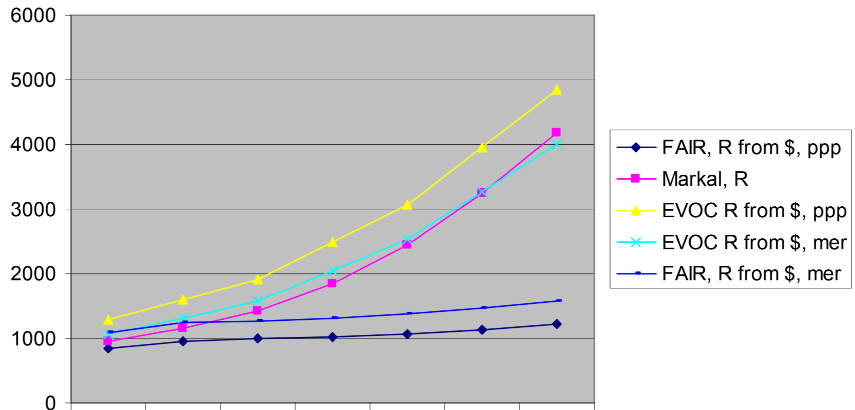


Figure 28: Agriculture sector emission projections in FAIR and Markal model baselines

3.1.7 Conclusions on comparison of baseline emission projections

The differences in the total baselines can be attributed to variances in the modelling of the sectors. The South African baseline emissions under the Markal model showed higher emissions and growth in emissions in the industrial and domestic sectors. This is related to the higher rate of economic growth that is projected under the national model. The FAIR 2.2 baseline model shows higher emissions in the agriculture and electricity sectors. This can be attributed to the FAIR 2.2 including non-energy emissions for agriculture, where the Markal model only includes energy.

These differences were examined in some detail in a collaborative workshop involving researchers from ERC, Netherlands Environmental Assessment Agency and Ecofys. An exercise in comparing the baselines from Markal, FAIR 2.2 and EVOC followed the discussion and the GDP and population projections for South Africa were extracted and plotted alongside one another (see Figure 29). Different assumptions about GDP as a key driver were found to account for most, but not all, of the differences in baseline emissions.



	2000	2005	2010	2015	2020	2025	2030
FAIR, R from $, ppp	846	960	991	1025	1077	1143	1226
Markal, R	949	1147	1429	1844	2444	3238	4179
EVOC R from $, ppp	1289	1600	1911	2487	3063	3958	4853
EVOC R from $, mer	1064	1321	1578	2053	2529	3268	4007
FAIR, R from $, mer	1088	1234	1274	1317	1384	1468	1575

Figure 29: Comparison of GDP drivers for different modelling approaches

The GDP projections in Figure 29 draw on different sources and have different growth rates. EVOC has a higher GDP growth than FAIR 2.2, as EVOC uses the GDP growth of the region South-Africa for the country South-Africa, and EVOC uses the average of the 6 IPCC SRES scenarios, which is mainly based (3 out of 6 scenarios are A1b) on the high A1b scenario. The graphs can be seen in Figure 29.

FAIR 2.2 and EVOC draw GDP data from international sources (IEA, UN), while the Markal model draws on data from the South African Reserve Bank. Part of the difference is explained by difference between GDP at market exchange rates and power purchasing parity, but not all the difference. While none of the research teams would necessarily want to change this key driver (at least not with further investigation), it was agreed that when comparing results, it would be helpful to do runs in one or the other model with the same GDP time-series.

3.2 Results of emission reductions and implied costs from national and international models

During the second workshop, an exercise was conducted to examine one of the larger SD-PAMs, i.e. the renewables in the power sector, to compare its effects to the base-case, and see how far we can go in terms of analysing that in FAIR 2.2 and EVOC.

As reported in section 2.2.5.4, national energy modeling assumed that South Africa's renewable energy target for 2013 was met, and by 2030, 27% of electricity generation was from renewable energy sources, with local benefits of diversification, energy security, lower fuel costs and reduced local air pollution. From a climate point of view, the renewable SD-PAM reduced emissions by 713 Mt CO_2-eq relative to baseline, at a cost of R 71 / t CO_2-eq. The electricity expansion plan in Figure 9 above illustrates that most of the renewables were solar, with little wind.

Implementing a renewable SD-PAM was simulated in FAIR 2.2 using the Triptych approach. The share of renewable energy in total electricity generation was increased to about 30% in 2030. The parameter to control the decrease in the use of coal was changed from 60% (reduction compared to 2000 levels) to -50%, to allow the share of coal in electricity to only decrease to 70% of baseline (BAU) in 2030 instead of 40% of BAU. As the efficiency of generation improves as does the share of oil, increasing the coal parameter, helps to get the overall power emissions to decrease to 30% compared to the BAU emissions as seen in Figure 30. Also increasing the parameter for emissions per kWh, would affect results. Emission reductions are seen to begin after 2015, increasing to 30%

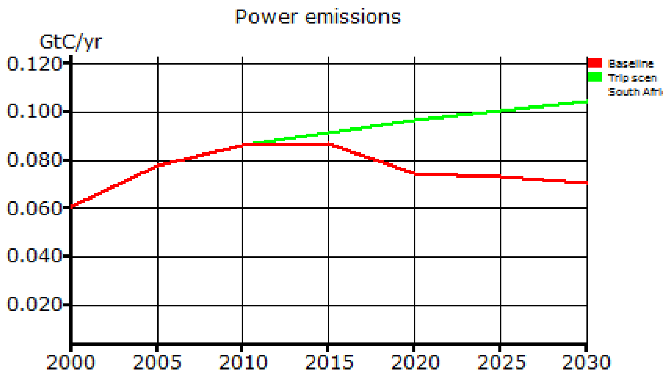


Figure 30: Emissions in the power sector from renewable energy policy for the baseline (BAU) and Triptych scenario

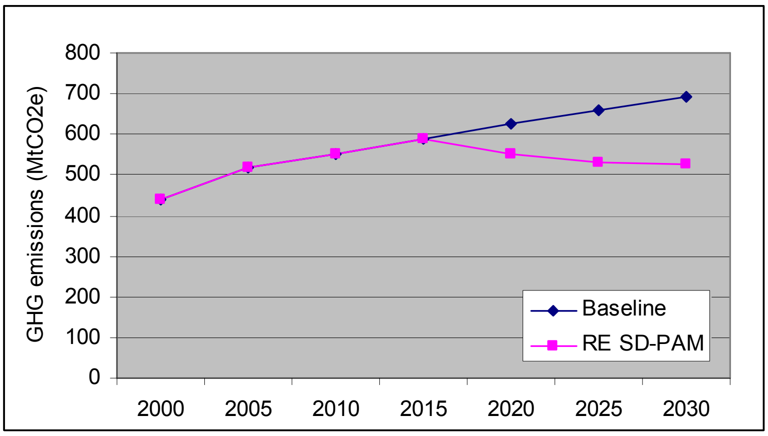


Figure 31: Total emissions for South Africa showing reductions from the renewable energy SD-PAM

By using the Triptych approach and tuning particular parameters, other SD-PAMs such as Industrial Energy Efficiency could also be simulated in FAIR 2.2.

The Triptych module of EVOC was also used to simulate a renewable energy SD-PAM. In this EVOC example, 27% of the electricity output was required to come from renewables by the year 2030, the following results on emissions were obtained.

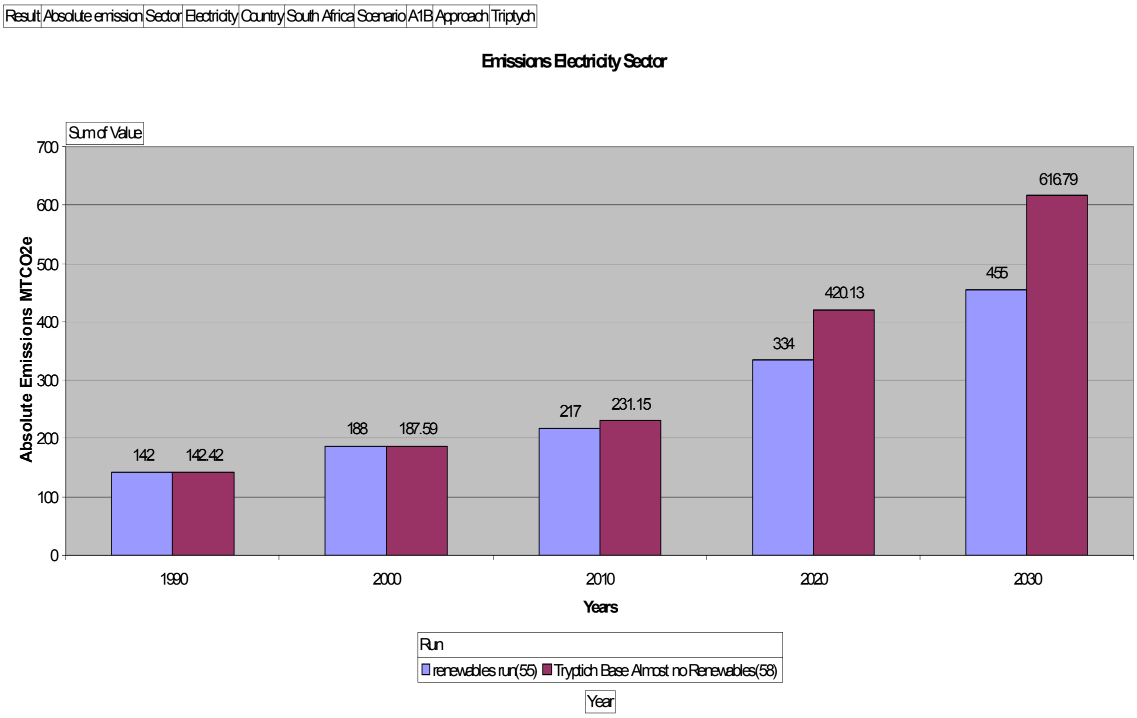


Figure 32: Emission reductions from renewable energy SD-PAM in the electricity sector using EVOC

In terms of emissions reductions over the Triptych base case with almost no renewables, the following resulting reductions were observed shown in Figure 32. These emission reductions are relative to baseline.

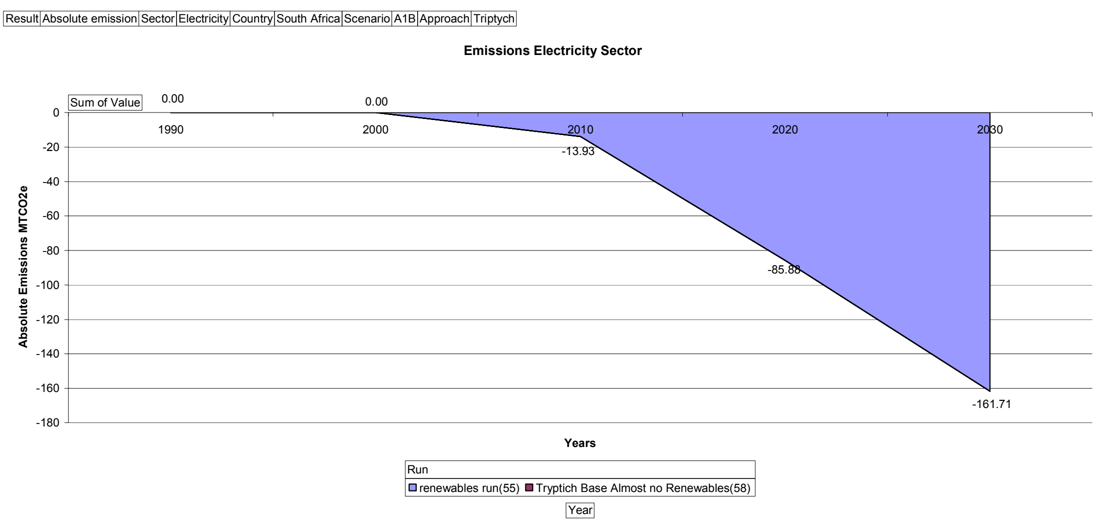


Figure 33: Emission reductions for renewable SD-PAMs using EVOC

The EVOC results reported here are only every ten years – linearly interpolating the emission reductions between the result values gives cumulative emission reductions for 2001-2030 would be 1 824 Mt CO_2-eq, i.e. significantly higher than in the national model. This compared to the Markal result of 713Mt CO_2-eq (relative to the Markal base case) over the same period.

The differences appear to result mainly from the generation mix used in EVOC that is largely fossil fuel based. This was confirmed through inspection of the configuration settings for EVOC, which assumed large investments (more than double) in coal power stations by 2030 followed by a decline up to 70% of total coal powered electricity output by 2100. Renewables are set to take up this capacity of generation required of up to 50% and 70% of total electricity output in 2050 and 2100 respectively. The resulting mix of generation technology categories is shown in the graph below for the year 2000 and 2030.

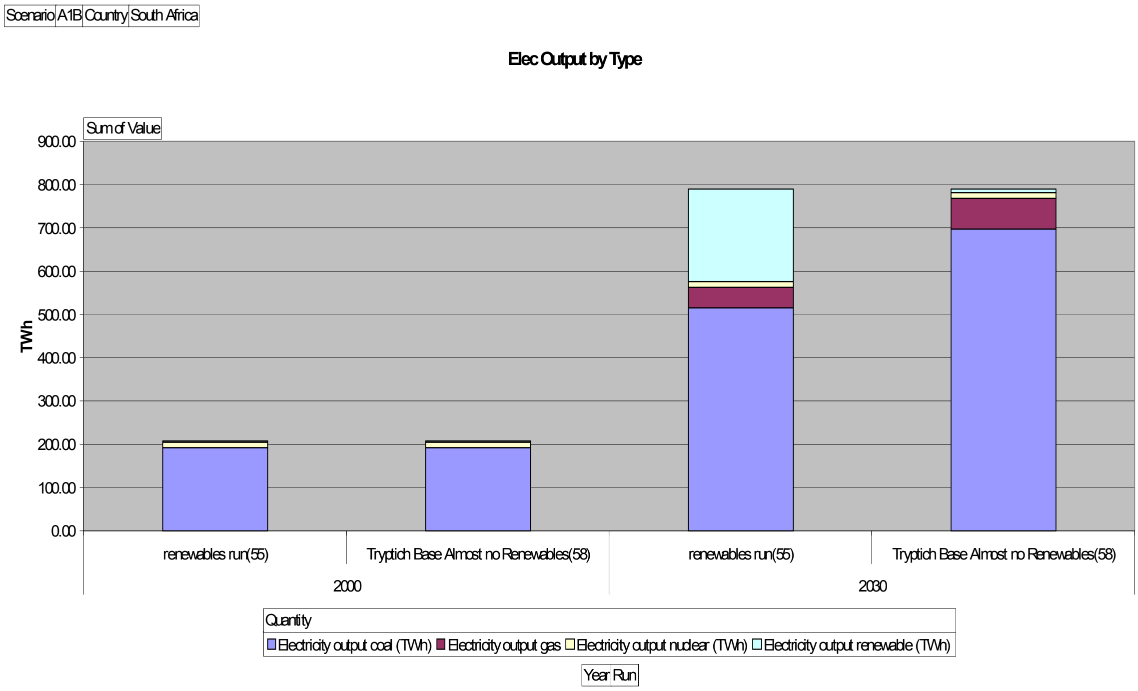


Figure 34: Generation mix by type of power plant in various cases

Most settings were left unchanged except for the electricity fuel mix to increase the share of renewable energy and the coal efficiency was also decreased with some natural gas included. The results showed the required increase share of renewables and a decrease in coal powered electricity generation.

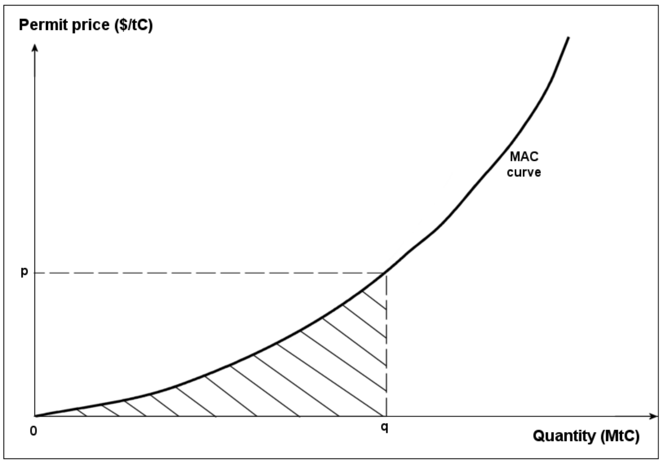
3.3 Cost curves

3.3.1 Marginal abatement costs curves[4]

A marginal abatement costs (MAC) curve reflects the additional costs of reducing the last unit of carbon and is upward-sloping: i.e. marginal costs rise with the increase of the abatement effort. Figure 3.1 shows a stylised MACt curve. The point (*q,p*) on the curve represents the marginal cost, *p,* of abating an additional unit of carbon emissions at quantity *q*. The surface under the curve (hatched area) represents the total abatement costs of carbon emission reduction *q*. In this way the MAC curves, representing the costs and potential of emission reductions for

4 This section draws on the FAIR documentation: Netherlands Environmental Assessment Agency report FAIR 2003, see www.mnp.nl\en.

the different regions, gases and sources, are used by the emission trading and abatement costs models and (see Chapter 6).[5]



The hatched area indicates the total cost of abatement under emission reduction objective q.

Figure 35: Marginal abatement cost curve

3.3.2 How are MAC curves constructed?

Macro-economic and energy system models are used as examples for constructing MAC curves for CO_2 energy-related emissions, for which a carbon tax on fossil fuels is imposed to induce emission abatements. Such a tax is differentiated according to the CO_2 emissions (the carbon content) from the fuels. In response, emissions will decrease as a result of such measures as fuel switching (e.g. from coal to gas), decreases in energy consumption and the introduction of zero-carbon energy options (renewables and nuclear). The carbon tax can be seen as an indicator of the marginal abatement costs. MAC curves can be created by plotting different tax levels against the corresponding emission reductions i.e.:

1. Working with a reference projection (baseline) in which the carbon tax is zero.
2. Calculating by successive simulations, the emission reduction levels (q) associated with the carbon tax (p) through successive simulations that change from level to level.
3. Developing the MAC curve as illustrated in Figure 35 on the basis of the points (q,p).

Opposite to the above described top-down method, MAC curves can also be constructed through a bottom-up approach. In a bottom-up approach, the MAC curves are constructed according to detailed abatement options per gas and source. The different options are sorted according to their relative costs and plotted against their reduction potential. The fitted line then forms the MAC curve. To use the MAC curves for the different baseline scenarios of the various models, we have to express the MACs as percentile reductions with respect to the baseline emissions. Absolute MAC curves can be created by projecting the relative MAC curves on to the baseline emissions used in the FAIR 2.2 model.

3.3.3 MAC curves for South Africa derived from national and international models

In order to compare the mitigation costs used in the FAIR model with those projected by the South African Markal model, a scenario was constructed in the South African Markal model

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5 One great advantage of using MAC curves is that they clearly show the effects of permit trading. However, there are also some limitations: carbon leakage cannot be taken into account, and while total abatement costs are reflected by MACs, welfare losses are not (see section 6.2).

with a varying carbon tax level,[6] which was assumed to be a proxy for mitigation costs.[7] The model is fairly constrained, but is able to choose a range of power generation options from around 2010, improved energy efficiency technologies, and a range of lower-carbon transport options The FAIR curves are portrayed in Figure 36 and Figure 38, and the Markal curves in Figure 37 and Figure 39. Both sets of results are portrayed as fraction reductions in relation to an emissions baseline. The first two graphs portray a curve for each five-year interval, which relate percentage reduction to the tax level, whereas the second set are the inverse, i.e. these portray a curve for each tax level, and relate percentage reduction to the five-year intervals. PPP exchange rates were used in both cases, which are significantly different from nominal exchange rates (around R3 per PPP $ as opposed to around R8 per $ nominal). In an actual international carbon market, nominal rates would obviously apply. The implication of this is that the South African energy system would be responsive to a much lower international carbon price than modeled here.

The most notable feature of this comparison is the minimal responsiveness of the Markal model to tax levels above $200 per ton (PPP), and the non-resposnsiveness above $700/ton, by comparison with the FAIR curves, which are quite responsive throughout the range, with diminishing returns as the tax rises towards $1000. This is most obvious in Figure 39 where the response to taxes $700 or higher is insignificant. The reason for this difference can probably be partly attributed to constraints in the Markal model, coupled with the absence of higher-cost technology options, and partly to overoptimistic assumptions concerning technology switching in the FAIR curves.

3.3.4 Conclusions on MAC curves

Although more examination of key assumptions in the different models would be required for a more detailed comparison, there are some interesting similarities in the range of costs in the curves. One outstanding problem highlighted by this comparison is the difference between using nominal and PPP exchange rates, which is necessary for valid national-level comparisons, but misleading in drawing conclusions on the impact of a future international carbon price.

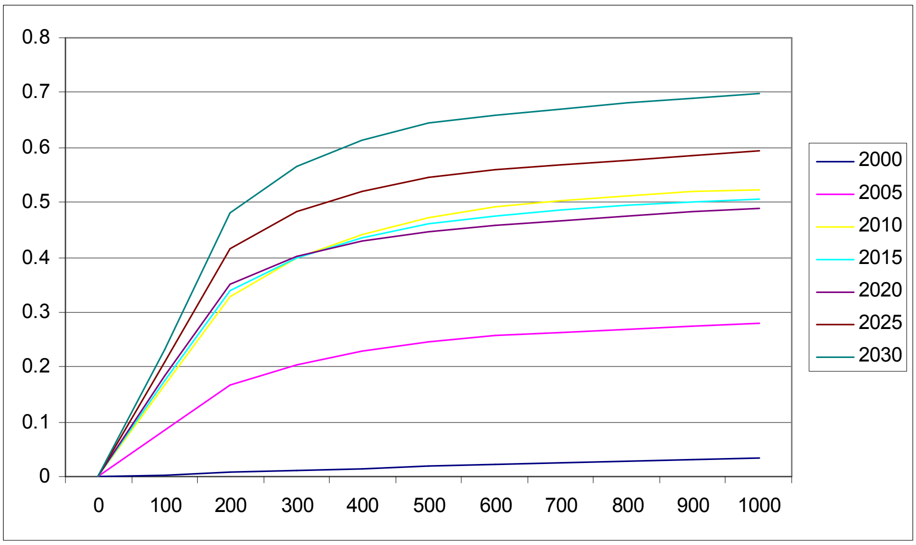

Figure 36: MAC curves used in FAIR for South Africa

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6 The tax levels were identical to the FAIR model assumptions, i.e. an escalating tax which increased linearly from zero until reaching the specified level in 2030.

7 In a top-down model this is probably a fairly good proxy for mitigation costs, since it is assumed that a certain carbon tax level will lead to mitigation up to the cost of the tax. However, this is based on the assumption that carbon taxes convey efficient price signals for investment in mitigation options. In a bottom-up model, however, constraints are often placed on the model (especially in the short term) to represent transaction costs and other factors which in reality prevent least-cost options being pursued. Thus, in the South African Markal model, energy efficiency measures have negative costs.

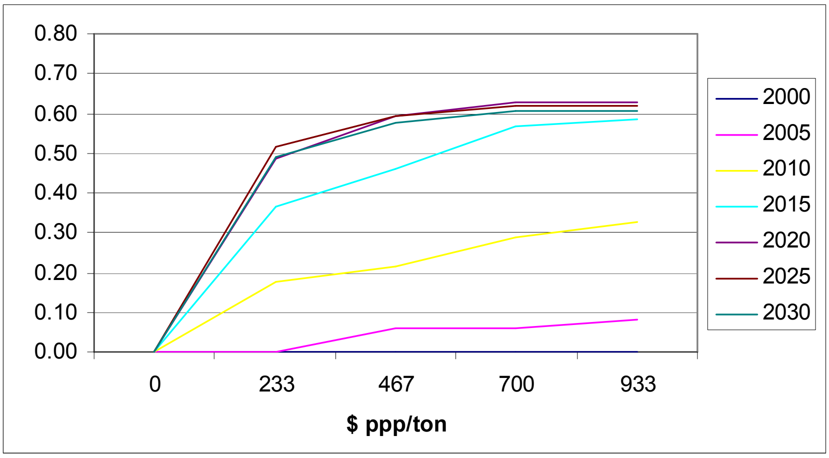

Figure 37: Markal-derived MAC curve for South Africa

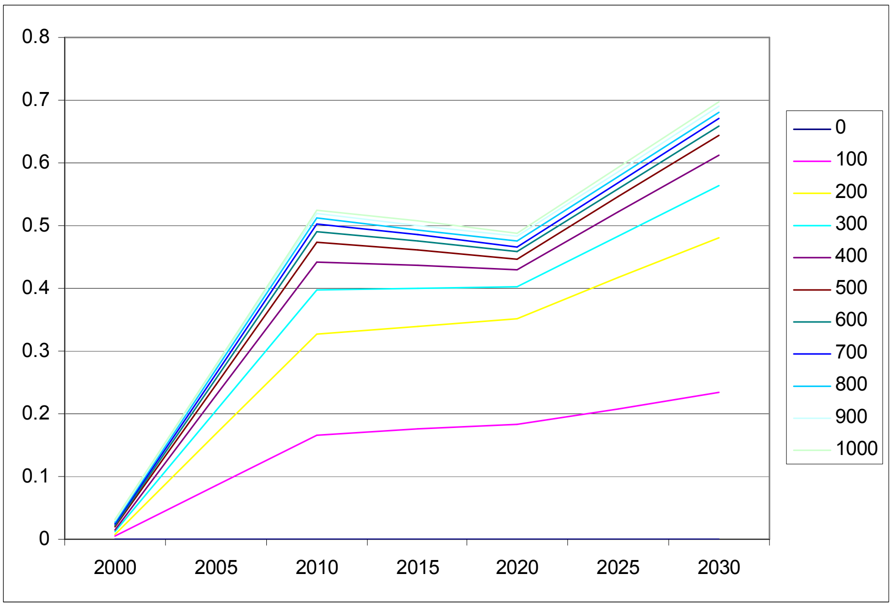

Figure 38: Inverted MAC curves from FAIR

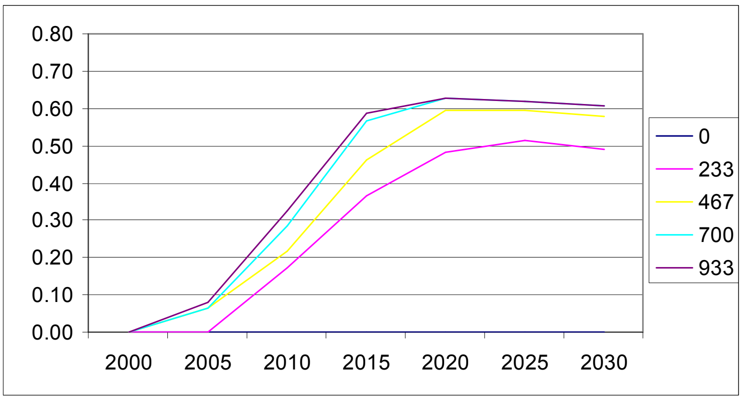

Figure 39: Inverted MAC curves from Markal

4. Lessons learned

The lessons learned from the collaborative work underpinning this report address two broad areas. Firstly, the research team considered what methodological lessons could be learned: What are the issues in linking national and international models for climate policy analysis? Secondly, the collaboration identified important issues and questions to investigate in further work. Building on the lessons learned in the collaborative work done between the Netherlands Environmental Assessment Agency, Ecofys and the Energy Research Centre (UCT), the researchers identified areas for possible future work. What would be needed to do better analysis? Both sets of questions are addressed in this conclusion.

The objective of the research at the outset was to examine potential linkages between national and international models, to contribute to the the discussion around future mitigation commitments under the UNFCCC. The first major lesson was that it is possible to bring together researchers using international ('top-down') and national ('bottom up') models and to generate comparable results.

The collaboration stopped well short of suggesting hard-wired linkages between the different approaches. However, the global and national perspectives were enriched – providing a reality check for global scenarios, and a broader perspective for nationally-focused analysis. For the purpose of developing future IPCC scenarios, in particular, it would be of significant benefit to examine national models in more detail as a 'reality check' for global scenarios.

There are limitations to the comparability, as highlighted throughout the report, but nonetheless it was possible to generate graphs from FAIR, EVOC and Markal that allowed some initial comparison. Some specific lessons drawn from these comparisons were drawn on the basis of the collaborative workshops.

Disaggregation in the international models is key to comparing results from international and national models. Within the policy-support tools, the Triptych approach has been identified as most suitable for SD-PAMs. The sectoral work being done on the TIMER model could possibly make the connection stronger, since as an energy model it relates more obviously and directly to Markal or other national energy modeling framework. Researchers found that these models talk the same language, or at least have more in common.

Modelling SD-PAMs in EVOC and FAIR could be used to complement the national work on SD-PAMs. FAIR and EVOC would enable users to calculate emissions targets under global regimes, then refer to the national model to work out development pathways to achieve these. Given the particular models including costs (FAIR and Markal), the researchers thought that reference to the energy model from the IMAGE family, TIMER, would provide further insight. Future work might be conducted using the TIMER model in more detail, given the common focus on the energy sector. Such a collaboration would include an introduction to the modelling technique and investigating interconnections, to support analysis of possible emission reduction target to a degree by stipulating roughly which sector emission reductions take place in. This would provide a closer analogue to the 'wedges' generated by national analysis.

Conversely, the research teams considered possible methods for representing the regimes in the national modelling. For example, constraints introduced for CO_2 emissions derived from various international approaches could be introduced in the national energy model. This might be a fruitful area for future work. Using LEAP, it would be possible to represent the targets for different climate regimes. Markal, using a least cost-optimisation methodology is less conducive to solving the emissions based targets, and would likely result in a higher cost energy system. If one wanted to lower emissions *per se*, further work would be needed to achieve the desired outcome. For example, one might need to derive the Multi-stage approach's emission baseline and then introduce this as a constraint in Markal.

There are limitations to this approach of representing emission allocation regimes in the national model. The technology-rich Markal model will only solve for up to certain levels of user-defined constraints, after which it will report that least-cost optimisation is 'infeasible'. In other words, with the specified technologies and currently known costs, the constraint cannot be met In part, this is an important result, illustrating the challenges for reducing emissions – as long as the analysis is based on known technologies and costs. This is a distinct advantage over international models when they simply use (regional) marginal abatement costs curves, without specifying which technologies would deliver the required emission reductions. In effect, an international model like FAIR assumes that given a high enough cost, societies and economies will adjust. National modeling through Markal will throw up limitations.

The area of costing and MAC curves in particular will be of great interest in the negotiations on the future of the climate regime (the 'post-2012' negotiations). Countries will be sensitive about the assumptions of mitigation costs assumed for their efforts, since this might affect the level of effort required. On the one hand, using regional MACs will not be accurate when applied to countries which are different to their region (as is the case in South Africa). On the other hand, the responsiveness of technology-rich models to cost changes may give too conservative a view of responses in the real economy. Future work might examine greater responsiveness in national modeling, entailing significant new analysis.

Further work is needed to refine uncertainty analysis. Some initial statements on the level of confidence in the results were made in sections 2.2.4 and 2.2.5. These are based on expert judgement of the researchers. A more systematic approach might draw on the method used in IPCC reports for statements relating to degree of confidence and amount of evidence to support a statement. More formally, sensitivity analysis could be conducted on the results to test their robustness to variations in important parameter values. Depending on model running time, repeated experimentation could be carried out on the various models to obtain distributions of results rather than point estimates. Further work could be done that utilises experimental design techniques to test the impact of varying individual parameters and whether simultaneously tweaking two or more parameter values produces any interesting interactive effects.

Given limited resources (notably human capacity and time), an important question is how much benefit would be gained from expanding global models to be more disaggregated, and also increasing the national model's flexibility. Further, there is the question of whether different modelling approaches should be reserved for the specific intention for which they are constructed. To what extent should the top-down and bottom-up approaches reach the same answers if the purpose for each of them is distinct? One could argue that comparability of outcomes is less important than the process of applied thinking to the specific model. IN addition to such applied thinking, a model funnelling approach could be developed to identify key connections between global and national models. Ultimately it is important that the proponents of the different modelling approaches engage with each other and share insights and critically evaluate their own and the others' approaches.

Particularly over longer time-horizons, however, the constraint of known technologies and costs might be relaxed. We expect that new technologies will emerge by 2025 – but a technology-rich model like Markal cannot represent these. It is possible to include changes in costs (technology learning), but not to include technologies (or behaviours, or resources) we do not yet know. Into the long-term future, the international models arguably provide a context against which the national analysis should be checked.

Appendices

A: Methodology for mitigation costing

The methodology for calculating mitigation costs is based on the approach developed for the SA Country Study (Clark & Spalding-Fecher 1999). The approach drew on international best practice, notably a report written by the United Nations Environment Programme's Collaborating Centre on Energy and the Environment entitled Economics of Greenhouse Gas Limitation: Technical Guidelines (Halsnaes *et al.* 1998). Other climate-change related sources include the guidelines developed by the Intergovernmental Panel on Climate Change (IPCC 1996) and costs reported in its assessment reports on mitigation (IPCC 2001a, 2007). Further references to the literature on mitigation costs methodology include OECD (2000), Sims (2003) and earlier works listed in Clark & Spalding-Fecher (1999).

The approach can be summarised as follows:[8]

- The life cycle costs of the mitigation options and baseline should be calculated by discounting all of the costs of these options to a present value.
- These life cycle costs should then be levelised, so they are expressed in Rands per year.
- The cost effectiveness analysis should be based on the difference in the levelised life cycle costs of the mitigation option and the baseline option (levelised annual cost), divided by the average annual reduction in emissions.
- The cost-effectiveness analysis should exclude taxes and subsidies, external costs, depreciation and interest payments but include private costs or costs which can easily be quantified. Implementation costs should be included.

For energy modeling, the approach used for LTMS is to replicate this approach, using Markal result parameters. Thus, unlike in the approach above, costs and emissions reductions do not relate to a specific project, but *to the modelled system as a whole*. Thus, a) the cost parameter used from Markal is the total system cost, not the cost of a specific part of the energy system, and b) emissions are similarly emissions for the whole system. The life cycle costs are thus replaced by the total system costs.

Thus, the cost effectiveness of a particular mitigation action, or the Mitigation Cost (MC), is the annual Levelised Incremental Cost (LIC) divided by the annual average Emissions Savings (ES), or

$$MC = LIC / ES,$$

where ES is calculated by adding the annual emissions for each case over the period (2003 to 2050) to get the Cumulative Emissions (CE) for the period, then subtracting the cumulative emissions for the mitigation action from those of the baseline. This difference is then divided by the number of years in the period (in this case 48) to get the annual average emissions savings. Thus,

$$ES = (CE_{\text{baseline}} - CE_{\text{mitigation action}})/(\text{end year} - \text{base year}+1).$$

Emissions saved in the mitigation case are thus reported as a positive number. However, costs saved in the mitigation case are reported as a negative number (and thus extra cost incurred in the mitigation case are reported as a positive number).

The Markal parameter which is used to derive the discounted system costs is U.ANNADJTOTCOS, an annual real undiscounted cost of the total energy system in the model for a particular year, excluding taxes and subsidies. Thus, to calculate the total discounted

[8] Readers seeking more detailed are referred to the full report (Clark & Spalding-Fecher 1999), particularly the Executive Summary and the illustrative example in section 6.2.

system cost, the values for U.ANNADJTOTCOS for the years 2003 to 2050 is discounted using an appropriate discount rate (in this case, for four discount rates: 0%, 3%, 10% and 15%) for the baseline, and for the mitigation action. U.ANNADJTOTCOS does not include taxes and subsidies. Thus, to calculate the LIC, the discounted cost of the baseline and the mitigation action is calculated from U.ANNADJTOTCOS for each case, and then levelised for the total period. LIC is the difference between the levelised costs (LC) of the baseline and the mitigation action, thus,

$$LIC = LC_{\text{mitigation action}} - LC_{\text{baseline}}$$

Non-energy modeling uses the same fundamental methodology, although a significant difference is that each sectoral model compares emissions and costs only within that sub-sector, e.g. emissions in agriculture with and without low tillage. Using Excel, costs are derived by discounting future payments to net present value; these are then levelised (PMT function) to derive annual costs. These are divided by the average annually emissions difference between the baseline and mitigation cases.

B: Collaborative workshops

Two workshops were organised by ERC in South Africa, in which Netherlands Environmental Assessment Agency and EcoFys participated. The workshops provided hands on experience of FAIR 2.2 and EVOC for South African experts.

Officials from the Department of Environmental Affairs & Tourism, the focal point for climate change in South Africa, were invited to the workshop and accepted, but unfortuantley were unable to attend in practice. Workshop reports are available separately.

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