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**A comparative study of climate change mitigation
regime proposals, and the Triptych Approach, and a
South African energy model**

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Half-dissertation Presented for the degree of Master of Science in Engineering
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University of Cape Town
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Personal involvement on the workshops contributed significantly to this body of work. Involvement ranged from preparatory work to drafting the report for the workshops. The outcomes from the collaborative workshops, and parts of the workshop reports were used in this thesis. Some outcomes from the workshop are included in this thesis, and content from this thesis is included in the workshop report titled: *Quantifying SD-PAMs: National energy models and international allocation models for climate change mitigation – A South African Case study.*

Abstract

Global climate change is one of the most serious challenges facing the world with the cause being increased levels of greenhouse gas (GHG) emissions. The required solution is a decrease in global GHG emission levels. Under the UNFCCC a number of proposals exist for decreasing CO₂ levels. This thesis first makes use of the FAIR 2.2 policy support tool to determine South Africa's GHG reduction requirements under the South-North dialogue, Contraction and Convergence and Multi-stage proposals.

A Triptych 7.0 regime target was calculated for South Africa using both the FAIR 2.6 model and a MARKAL representation of South Africa, developed at the ERC. Despite the differences in growth projections of the two models, the Triptych 7.0 target for the two representations are similar: the MARKAL target level is 395MtCO₂e and the FAIR 2.6 target is 378MtCO₂e, a less than 5% difference.

Sustainable Development Policies and Measures (SD-PAMs) is a climate proposal focusing on development-based measures to reduce GHG emissions. Considering the necessity for development in South Africa, this approach benefits South Africa, while mitigating greenhouse gases. The reductions possible using this approach was compared to the Triptych target set for South Africa with promising results. It was determined that approximately 57% of the required GHG reduction target for 2030 could be met through implementing SD-PAMs which have overall net-negative costs to implement, and have numerous co-benefits.

Within this study comparisons were made between the representation of South Africa in an international and national model. Through this analysis there is a better understanding on how differences in the models may affect quantification of international climate change targets. Furthermore, the SD-PAMs approach is seen to be able to contribute substantially to GHG reduction targets. These positive outcomes can be used towards helping South Africa increase its contribution to address global climate change.

1 Introduction

1.1 Background to Problem

Climate change is a serious problem facing the world today due to ever-increasing amounts of carbon dioxide and other greenhouse gases being emitted into the atmosphere. Countries face the combined challenges of adapting to the approaching change and working towards mitigating the effect. Within the United Nations Framework Convention on Climate Change (UNFCCC), set up to address the problem, there are numerous proposals on how best to allocate GHG emission reduction burdens. Most of these are region or country-focused, requiring countries to lower emissions according to various criteria such as their emissions or GDP per capita, total emissions or historic emissions. At this stage it is still not finalised as to how countries will take on the momentous task of slowing down the change in the Earth's climate system.

An effective future climate regime requires that it be accepted and adopted by as many countries as possible, especially the large emitters. South Africa has a carbon-intensive economy as it derives much of its power from coal. As such, it is quite likely that South Africa will need to work towards reducing its overall carbon footprint at some stage in the future.

The first commitment period of the Kyoto Protocol, designed to lower global greenhouse gas emissions expires in 2012. In many of the proposals for future post-2012 climate regimes, developing countries such as South Africa are expected to play a more active role in mitigating climate change, as developing countries were not expected to accept GHG emission commitments under the Kyoto Protocol. The multitude of proposals for post-2012 use different methods to calculate countries' levels of responsibility. Therefore according to the methodology used, the target for South Africa is different. It is therefore relevant to investigate what the targets are for different regime proposals and to interpret the differences between them for South Africa. It is also necessary to compare the representation of South Africa under these global regime proposals with a national model. A target formulated using international collated data is likely to differ from one made using the national model. The degree to which this differs according to the data source used is investigated in this thesis.

There are currently proposals to address climate change in South Africa and other developing countries through sustainable development policies and measures (SD-PAMs). This approach will favour South Africa as it focuses on development, which is one of the country's prime objectives. This study investigates how effective this development-first approach may be in meeting the mitigation requirements of an effective global regime to counteract climate change.

1.2 Objective of Thesis

The objectives of this dissertation are:

- To investigate South Africa's commitment under a range of climate regime approach proposals especially the Triptych approach;
- To compare the representation of South Africa under an international climate allocation model to a national energy model of South Africa;

- To generate an emissions reduction target using the emissions projection from South Africa's national energy model;
- To compare the reductions required under an international climate regime to what would be possible from implementing a range of SD-PAMs.
- To make recommendations for further work that can be carried out under this topic of study.

1.3 Scope and Limitations

The scope of the dissertation is limited to comparisons between the FAIR 2.2, FAIR 2.6 and MARKAL modelling tools' representations of South Africa. The EVOC policy support tool developed by ECOFYS was also reviewed to be used for this project, but FAIR was selected for its user-interface and country-level representation of South Africa. The MARKAL model of South Africa was chosen as it has been used extensively in the analysis of SD-PAMs. Projections of future emissions and targets only extend up to 2030. The SD-PAMs assessed do not include nuclear power and carbon capture-and-storage technologies as their developmental co-benefits are considered to be limited. Non-energy emissions and land-use, land-use change and forestry (LULUCF) emissions are not included in the study.

1.4 Plan of Development

Chapter 2 is a literature review and presents the science behind climate change and the international negotiations that are taking place to address the problem. South Africa's situation with regards to the climate challenge is introduced using data from national inventories and the South African national energy model. The chapter explains a number of the proposals for a post-2012 international climate regime. FAIR 2.2 policy support tool is then used to demonstrate South Africa's requirements under a selection of regimes.

Chapter 3 shows the methodology used in this thesis and explains how the various sections interlink with one another in this thesis.

Chapter 4 introduces the Triptych approach from its origins and background, and some of the adjustments and expansion it has undertaken to-date. It details the operation of the most recent iteration, the Triptych 7.0 approach, and shows how targets under this updated method are calculated and the methods used.

Chapter 5 shows the results from applying the Triptych 7.0 approach to South Africa, using the FAIR 2.6 policy support tool.

Chapter 6 introduces the national energy model of South Africa developed under the MARKAL modelling tool. The chapter introduces the major drivers used in the MARKAL model and those used in the two main models.

Chapter 7 compares the baseline projections of the FAIR 2.6 and MARKAL versions of South Africa under all the sectors used in the Triptych approach. It then goes on to develop Triptych targets for the MARKAL model of South Africa, which is one of the key results of the project.

Chapter 8 presents SD-PAMs that can be used as part of South Africa's strategy for reaching climate change goals. A selection of SD-PAMs is shown, and their sustainable development benefits and climate change mitigation potential discussed.

Chapter 9 discusses the major outcome of this project which is a comparison of the potential of the SD-PAMs with the Triptych targets calculated for the MARKAL model in Chapter 7.

The final sections are on the major conclusions that can be reached from this project and the recommendations made for future actions related to the research.

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2 Literature Review

The literature review will begin by reviewing the science behind climate change. The political actions being undertaken to address climate change are then discussed followed by a review of the proposals that have been made that aim to mitigate the problem over the long term. The implications for South Africa with regards to global climate change mitigation efforts are then explored. This section includes details on the energy and GHG emissions profile of South Africa, following which the requirements for South Africa under a selection of climate regimes is described. This literature review also includes information on the MARKAL and FAIR tools which have been used to do the analysis for South Africa under various climate regime proposals.

2.1 The Science and Impacts of Climate Change

Global climate change is one of the most serious problems facing the World today. There is now "very high confidence" in scientific evidence that the climate is warming due to anthropogenic activity enhancing Earth's greenhouse effect (IPCC, 2007a).

The continued use of fossil fuels to meet our energy needs has seen annual anthropogenic GHG emissions increase by 70% from 1970 to 2004. Ice core samples indicate that the current concentration of GHGs far exceeds the natural range of atmospheric concentrations of these gases for the last 650,000 years (IPCC, 2007a).

Scientific observations of the climate system deliver strong evidence of change in the system, and include:

- eleven of the last 12 years being recorded as the hottest on record, and higher temperature increases per decade over the last 50 years;
- an increase in average temperature of the ocean;
- a 3.1mm per year average sea-level rise from 1993-2003;
- a decrease in mountain glaciers and snow cover;
- large decreases in arctic sea ice extent by (2.7% per decade average and 7.4% per decade summer cover);
- droughts have become more frequent and widespread since 1970;
- Increased tropical cyclone activity has been observed. (IPCC, 2007a)

It is expected that these trends will continue and intensify if global emission trends continue along the same trajectory (IPCC, 2007a). The warming effect of present GHG emissions will continue to accumulate for decades due to the inertia of the climate system.

The projected impacts of climate change are predicted to be far-reaching, and there is an increasing level of certainty for many of them. These impacts include:

- Increased fresh-water availability at high latitudes, and decreased availability at lower latitudes and water-stressed regions;
- extent of drought-affected areas to increase;
- decrease of water supplies stored in glaciers and snow cover;
- many ecosystem's resilience may be exceeded due to increased temperatures;

- an estimated 20-30% of plant and animal species assessed to date could face extinction if temperatures increase beyond 1.5-2.5°C
- increased occurrences of drought and floods will negatively increase crop production;
- More frequent and severe floods, due to increased sea-level, will affect and displace larger swathes of the population.
- Health effects will be severe, especially in regions with low adaptive capacity. These will include malnutrition, death from severe weather events, cardio-respiratory and diarrhoeal disease occurrences. (IPCC, 2007b).

Africa is one of the most vulnerable continents to the effects of climate change, due both to the limited adaptive capacity and numerous stresses. By 2020, between 75 and 250 million people in Africa will be exposed to increased water stress due to a changing climate if current projections are accurate (IPCC, 2007b).

The human effects of climate change will be intensified when combined with low-adaptive capacity and those most severely affected by climate change are from those regions least responsible for the change.

2.1.1 The IPCC

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to provide decision makers with independent scientific information on all aspects of climate change and its causes. Its role as a scientific body is not to carry out its own research, but rather assimilate and review material on the most recent view of the scientific community regarding climate change. Assessment Reports are the main outputs of the work of the IPCC and are prepared on a regular basis to update decision makers and experts on the latest climate information. The information presented in "IPCC First Assessment Report, 1990" played a crucial role in the creation of the UNFCCC. The "IPCC Second Assessment Report: Climate Change 1995" provided key inputs in the negotiation of the Kyoto Protocol. Subsequently, the IPCC Fourth Assessment Report informed the Bali Action Plan in 2007. Special Reports are also intermittently prepared to further inform aspects of the UNFCCC, Kyoto Protocol, and other multilateral environmental processes.

2.1.2 Greenhouse Gases

The greenhouse gases covered by the UNFCCC are shown in Table 1. Of these gases CO₂ is the most prevalent, and accounts for the highest volume of emissions, contributing 77% of the anthropogenic GHG emissions in 2004 (IPCC, 2007).

GHG	Symbol	GWP ¹	Sources of emissions
carbon dioxide	CO ₂	1:1	fossil fuels, land use change
Methane	CH ₄	1:21	agriculture, natural gas
nitrous oxide	N ₂ O	1:310	combustion
hydro fluorocarbons	HFCs	1:140 – 11700	production and refrigeration
per fluorocarbons	PFCs	1:6500 - 9200	aluminium production
Sulphur hexafluoride	SF ₆	1:23900	Electrical industry

Table 1 - Greenhouse gas information
Sources: Climate Change 2007 , IPCC

¹ Global Warming potential

Each gas varies in its radiative forcing properties over the lifetime of the gas, and are said to differ in their Global Warming Potential (GWP). Measures of the different gases are therefore expressed and compared according to their GWP relative to the GWP of CO₂ over a 100 year period, using the standard metric CO₂-equivalent (CO₂e) (IPCC, 2007). The conversion factors used to convert the gases to CO₂e are shown in **Table 1**.

2.1.3 IPCC SRES Scenarios

The IPCC Special Report on Emission Scenarios (SRES) (IPCC 2000) reports on a set of emission scenarios that were developed by the IPCC to represent potential GHG emissions pathways. These emission scenarios were formulated as an update and improvement on the 1992 IPCC emission scenarios.

At the initial stages of the process, the 1992 IPCC scenarios and over 400 other emissions scenarios were reviewed and added to a database of scenarios. This exercise established the range of possibilities for future emission pathways. It was decided that this number be reduced down to 40 scenarios and grouped in to 4 "scenario families". These scenario families, called A1, A2, B1 and B2 were developed, each based on a different storyline for the future. These storylines, which describe four possible futures where development has taken different paths at differing speeds, can be seen in Appendix A. None of the scenarios contain assumptions that explicit GHG mitigation action is taken. Within the A1 scenario family the emissions scenarios were further grouped into technology specific "scenario groups": A1B, A1FI and A1T, resulting in six scenario groups. The SRES scenario groups and families presented by IPCC were therefore:

- A1B
- A1T
- A1FI
- A2
- B1
- B2

Six modelling teams were given the task of generating the families of scenarios according to the storylines. The scenarios from the six modelling teams constituted a variety of approaches and included a mix of top-down and bottom-up approaches. The result of this approach was a range of model projections for each family, based on the same storyline assumptions, but differing in implementation of said storyline. For each storyline there is one "marker scenario" selected to best represent that storyline.

Of the six scenario groups and families, the IPCC recommends that they be used together as a package and not individually, as none of them should be selected as the most-likely or the best scenario grouping at this point in time.

The range of projected global CO₂ emissions, in GtC, for the six scenario families and groups are shown in Figure 1. The breadth of the range for possible futures modelled can clearly be seen, ranging from low emissions options B1 and A1T to high emissions futures in A1FI and A2. CO₂ is the dominant GHG and the data for other GHGs have much higher levels of uncertainty due to the complexity of the drivers of the non-CO₂ GHGs. Due to this high level of uncertainty, the total GHG

emissions are not presented as a summation using GWPs (IPCC, 2000). The trends followed by non-CO₂ GHGs from the SRES scenarios are similar to the CO₂ emissions.

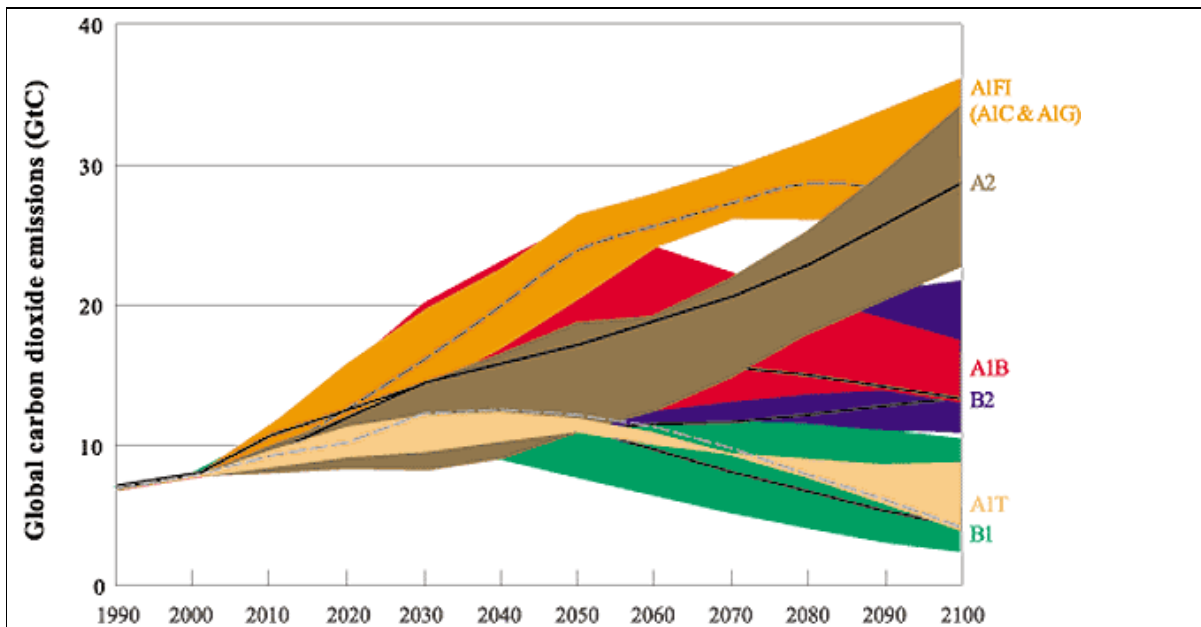


Figure 1 - Global CO₂ emissions (GtC/yr, standardized) from all sources for the four scenario families from 1990 to 2100.

Scenarios are also presented for the three constituent groups of the A1 family (fossil-intensive A1FI group, resulting by merging A1C and A1G as in the SPM, the high non-fossil fuel A1T, and the balanced A1B) and for the other three families (A2, B1, and B2), forming six scenario groups altogether. Each coloured emission band shows the range of the scenarios within one group that share common global input assumptions for population and GDP. The scenarios remaining outside the six groups adopted alternative interpretations of the four scenario storylines.

Source: IPCC Special Report on Emission Scenarios, 2000

2.1.4 IPCC Stabilisation Scenarios

The contribution of Working Group III (WGIII) to the IPCC Fourth Assessment Report, titled "Mitigation of Climate Change" presents possible measures to mitigate climate change, the timeframe for these actions, and the associated costs and policies necessary to do this in a sustainable manner. The updated knowledge from this and the other working groups emphasize that urgent action is required to mitigate the effects of climate change.

The stabilisation scenarios presented in the WGIII report project different average temperature increases associated with different atmospheric CO₂ and GHG concentration stabilisation levels. These updated emissions scenarios are classified into six groups, according to the resulting CO₂ levels. These six categories along with stabilisation levels and associated best estimate temperature increases are shown in Table 2. The level of temperature change is therefore associated to a specific concentration of GHGs, and not to a specific family of emissions scenarios as in the SRES scenarios.

The stabilisation levels are expressed both in CO₂-only concentrations and total GHG concentrations (expressed in ppm CO₂e). Category I contains scenarios with the most ambitious stabilisation levels (445-490ppm CO₂e) and Category VI contains those scenarios with the highest GHG stabilisation levels (855 – 1130ppm CO₂e). At each incremental stabilisation level, there is an associated projected increase in mean temperature. This ranges from a 2.0 – 2.4°C increase for Category I stabilisation levels to a 4.9 – 6.1°C increase for Category VI stabilisation levels. A total of 177 scenarios are categorised into these six groups, with Category IV containing the most scenarios assessed (118). The level of effort is expressed in the level of reductions required compared to emissions in 2000. For a 445-490 ppm CO₂e stabilisation, a reduction in 2050 of 50% to 85% below 2000 emission levels is required.

Category	CO ₂ Concentration (ppm)	CO ₂ e concentration (ppm)	Global mean temperature increase above pre-industrial at equilibrium using best estimate climate sensitivity (°C)	Peaking year for CO ₂ emissions	Change in global CO ₂ emissions in 2050 (% of 2000 emissions)
I	350 – 400	445 – 490	2.0 – 2.4	2000 - 2015	-85 to -50
II	400 - 440	490 - 535	2.4 – 2.8	2000 – 2020	-60 to -30
III	440 – 485	535 – 590	2.8 – 3.2	2010 – 2030	-30 to +5
IV	485 – 570	590 – 710	3.2 – 4.0	2020 – 2060	+10 to +60
V	570 – 660	710 – 855	4.0 – 4.9	2050 – 2080	+25 to +85
VI	660 - 790	855 - 1130	4.9 – 6.1	2080 - 2090	+90 to +140

Table 2 - Classification of stabilisation scenarios according to different stabilisation targets and alternative stabilisation metrics
Source: Climate Change 2007, IPCC

Figure 2 gives a graphical representation of Table 2. The centre line running through the wedge expresses the range of 'best estimate' of 3°C climate sensitivity. The upper line expresses the upper bound of for temperature increase for a 4.5°C climate sensitivity case. The lower line shows the lower bound for a 2°C climate sensitivity case. The shaded bands show the range for Categories I to VI of the aforementioned stabilisation levels (IPCC, 2007c).

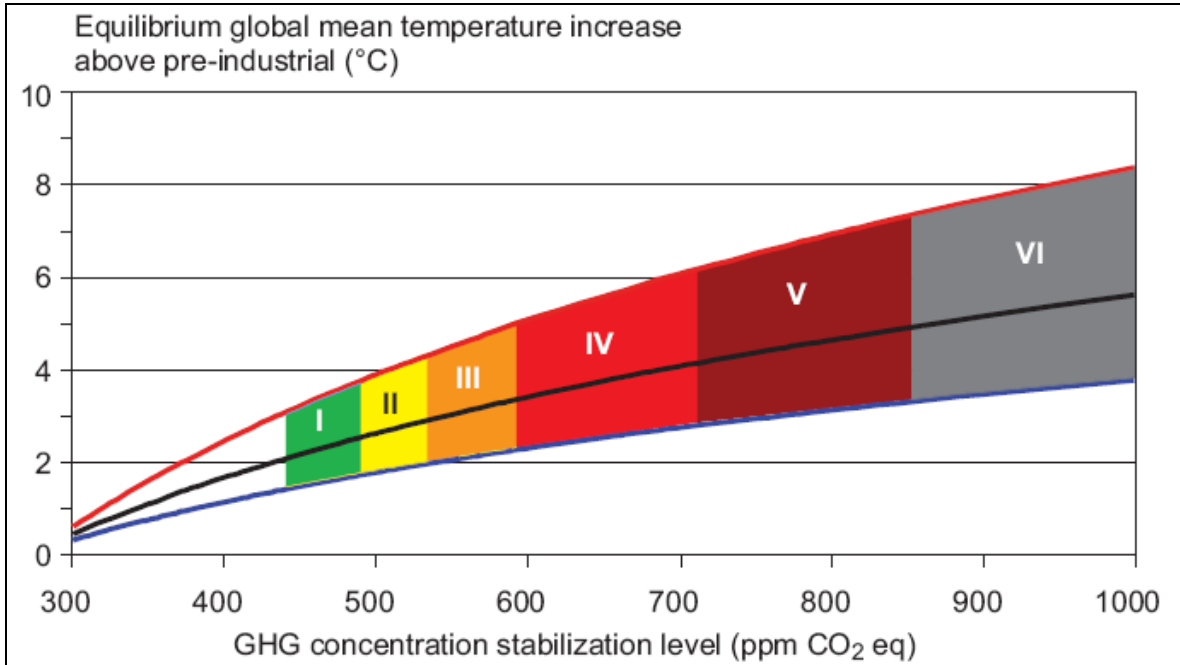


Figure 2 - Stabilisation categories and their relationship to equilibrium global temperature change above pre-industrial temperatures
 Source: Climate Change 2007, IPCC

The estimated global macroeconomic mitigation costs for stabilisation levels between 710ppm and 445ppm CO₂e range from a 1% gain to a 5.5% decrease in GDP. This will vary considerably between countries (IPCC, 2007c). In determining an ambitious, yet achievable, stabilisation the mitigation costs will play an important influencing role both globally and on a country to country level, especially if development goals are affected. Contrary to this though, are the consequences of inaction and the high associated adaptation costs. The stabilisation scenarios are thus essential to the climate change debate, both in terms of informing decision makers and applying the necessary pressure to the negotiations. Supporting the case for earlier action, The Stern Review states that “the benefits of strong, early action considerably outweigh the costs.” The Stern Review estimates the annual costs for stabilising GHG concentrations at a 500 - 550ppm CO₂e stabilisation level to be in the region of 1% of GDP per year in 2050 (Stern, 2006).

2.2 International Climate Change Negotiations

2.2.1 The UNFCCC

The United Nations Framework Convention on Climate Change (UNFCCC) is a global treaty that was established to address the threat of climate change. It was adopted and opened for signatures in 1992, and entered into force on 21 March 1994. The Convention has been ratified by 192 countries.

The goal of the UNFCCC according to Article 2 of the Convention:

"The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner." (UNFCCC, 1992)

Parties to the Convention meet annually at the Conference of the Parties (COP) where progress on the implementation of the Convention is reviewed, rules to the Convention are refined and new commitments may be negotiated. Although the UNFCCC sets the foundation from which work could originate, it is dynamic in that it can, through amendments or protocols, be weakened or strengthened to accommodate actions supporting the latest scientific information. The Parties to the Convention are divided into two groups: Annex I and non-Annex I countries, with an additional grouping, Annex II, which is a subset of Annex I countries. Annex I countries are mainly industrialised countries with the capacity to take on GHG emission reduction targets, whereas non-Annex I countries, at the time of the grouping were developing countries or those with economies in transition. Annex I countries, were to reduce their GHG emissions to 1990 levels by the year 2000. Annex II countries which excluded the economies in transition (EIT) were to fund mitigation and adaptation efforts in developing countries. Non-Annex I countries are mainly developing countries some of which are particularly prone to the effects of climate change and may be recipient candidates for Annex II assistance.

Parties to the Convention are required to fulfil a number of commitments that include: preparing programmes to reduce GHG emissions; compiling and submitting reports on national GHG inventories; and promoting climate research and education on climate change.

2.2.2 The Kyoto Protocol

The Kyoto Protocol is an international agreement, adopted in Kyoto, Japan in 1997, that was established to build upon the objectives of the UNFCCC. This was in response to increased public pressure and increasing scientific evidence that more action was needed to address climate change.

The major progression in the establishment of the Protocol is the legally binding quantified emission reduction targets set for the Annex I countries (UNFCCC 2007). The emissions targets are the result of intensive negotiations where countries took on more stringent targets than those specified under the Convention, with an average target of 5.2% below 1990 emission levels, excluding LULUCF emissions (UNFCCC 2007). These emissions targets, as specified in Annex B of the Protocol, are to be met in the first commitment period from 2008-2012. Emissions trading, the Clean Development Mechanism (CDM) and Joint Implementation were all developed to assist Annex I countries achieve their emission reduction targets by

allowing them to purchase credits through quantified emission reductions achieved in other countries. The Protocol entered into force in February 2005.

2.2.3 Post-2012 Climate Regimes

The Kyoto Protocol's first commitment period extends from 2008 – 2012. Negotiations are still to determine the structure of post-2012 climate regime. At COP-13 in Bali, Indonesia, December 2007 the post-2012 discussion received strong boosts from the Bali Action Plan decision (Decision 1/ CP.13). This decision specifies actions to be taken to carry out the Bali Roadmap, a two year negotiating process that includes the following elements:

a) A shared vision for long-term cooperative action, including a long-term global goal for emission reductions, to achieve the ultimate objective of the Convention, in accordance with the provisions and principles of the Convention, in particular the principle of common but differentiated responsibilities and respective capabilities, and taking into account social and economic conditions and other relevant factors;

The shared vision will be realised using the following building blocks:

*b) Enhanced national/international action on mitigation of climate change;
With mitigation commitments being adopted by developed countries, and developing countries taking on actions to mitigate climate change.*

c) Enhanced action on adaptation,

d) Enhanced action on technology development and transfer to support action on mitigation and adaptation,

*e) Enhanced action on the provision of financial resources and investment to support action on mitigation and adaptation and technology cooperation.
(UNFCCC, Decision 1/ CP.13)*

The decision established the Ad-Hoc Working Group on Long-term Cooperative Action (AWGLCA) as a subsidiary body under the UNFCCC to undertake the task of developing the plans laid out in the decision. The AWGLCA and the Ad-Hoc Working Group on Further Commitments of Annex I countries under the Kyoto Protocol (AWG), met from 31 March to 4 April 2008. At this meeting, the AWGLCA developed their work programme for 2008, an important outcome of their first session. Discussions in this the Fifth session of the AWG included focused discussion on the role of sectoral targets in meeting quantified emission reduction targets under Kyoto (Carter 2008).

As it stands the next commitment period will be primarily informed by the work of the AWGLCA and the AWG. The work of the AWG is based on the structure of the Kyoto protocol. A natural progression may be for them to define emission reduction targets based on Annex B of the Protocol, and to add targets for developing countries.

The mandate given to the AWGLCA is to define the commitments for developed and developing countries. Whereas the work of the AWG is strongly defined by the

country groupings of the Kyoto protocol and working on Annex I commitments, the AWGLCA will work towards informing the Convention on an equitable, acceptable solution limiting emissions in response to the findings of IPCC AR4. Numerous proposals exist in allocating responsibility with differing philosophies on “fairness” and “responsibility”.

Although it is unlikely that any single proposal will be chosen to allocate responsibility on a global level, outputs from these global allocation models are likely to help inform negotiations. The different approaches seek to distribute the required emissions according to different notions of fairness and responsibility. The following section lists and summarises some of the proposals.

2.3 South Africa and Climate Change

2.3.1 South Africa under the UNFCCC and Kyoto Protocol

South Africa became a Party to the UNFCCC in June 1993. It ratified the Convention in August 1997, and entry into force followed in November 1997. South Africa ratified the Kyoto Protocol in July 2002. Under the UNFCCC, South Africa as a developing country is recognized as a non-Annex I country. As such it does not have any binding emissions reductions targets under the Kyoto Protocol for the first commitment period (2008-2012).

South Africa has been active in UNFCCC and Kyoto process negotiations and plays a leading role in representing developing countries at negotiations. A case of this would be a number of “stinging” interventions made to get the U.S. to withdraw its objection to an Indian proposal on technology transfers for mitigation efforts at COP-13 talks (Carter 2008). As negotiations take place on the post-2012 climate regime South Africa could play an important role in negotiations for determining the actions required by developing countries.

2.3.2 The Initial National Communication

Under the UNFCCC, South Africa is required to submit intermittent national communications to the COP in compliance with Article 12. South Africa completed its Initial National Communication in 2000 and submitted it at COP-9 in Milan, Italy in 2003.

The Initial National Communication report includes: GHG inventories for the years 1990 and 1994, information on SA’s vulnerability to climate change and its adaptive capacity, climate change research and education being undertaken, and related national policies and mitigation options (RSA 2004). Work commenced on the second national communication in 2007.

According to the Initial Communication, emissions from energy-use account for the highest share of SA’s GHG emissions (Figure 3), with emissions from agriculture, industrial processes and waste accounting for the remainder. International bunker fuel emissions are not included as part the inventory, and the study does not take into account CO₂ sinks from forestry activities.

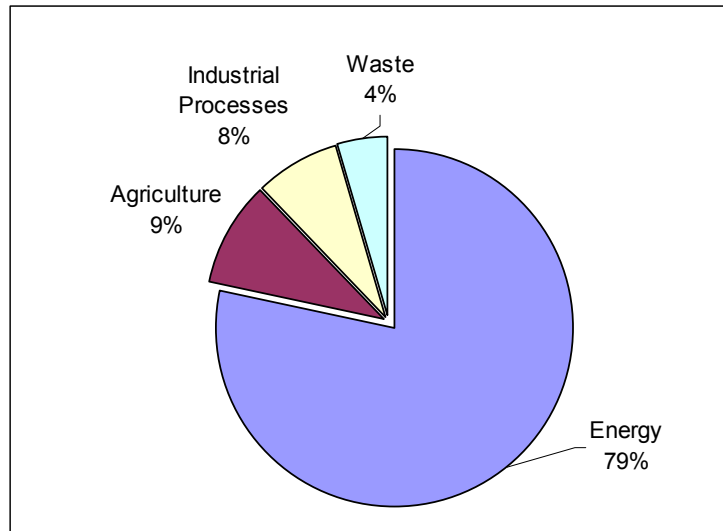


Figure 3 – Total GHG emissions by source for South Africa, 1994
Source: Initial National Communication, RSA 2001

Overall, GHG emissions from energy-use increased from a share of 74% to 79%, from 1990 to 1994. Within the energy sector, the growth in energy used in industry, transport and agriculture accounted for the increase. These changes can be seen in Table 3, which includes the contribution from N₂O and CH₄ emissions.

	CO₂-e emissions 1990 (MtCO₂)	CO₂-e emissions 1994 (MtCO₂)
Total	347.3	379.8
Energy	260.9	297.6
Energy Industries	160.0	168.6
Industry	47.4	53.6
Transport	31.5	43.5
Commercial	5.1	0.85
Residential	6.9	7.4
Agricultural/Forestry/Fishing	3.2	16.8
Fugitive Emissions	6.8	6.9
Industrial Processes	30.8	30.4
Mineral Products	5.5	5.3
Chemical Industry	3.5	4.2
Metal Production	21.8	20.8
Agriculture	40.5	35.5
Enteric Fermentation	19.2	17.7
Manure Management	2.2	1.7
Agricultural Soils	18.5	15.5
Savanna Burning	0.4	0.5
Agriculture Residue burning	0.1	0.1
Waste	15.2	16.4
Solid Waste on Land	14.1	15.2
Wastewater Handling	1.1	1.3

Table 3 – Breakdown of total GHG emissions for 1990 and 1994
Source: Initial National Communication, RSA 2001

Within energy use as a GHG source, energy industries are the single largest contributing sub-sector to CO₂ emissions. This is mainly due to South Africa's use of coal as the main feedstock for approximately 90% of electricity generation. Due to its price and availability, coal-fired electricity generation is South Africa's primary fuel for electricity generation. The large percentage change between 1990 and 1994 for the agricultural and commercial sub-sectors is attributed to using different consumption categories in the two years (RSA 2001).

2.3.3 GHG inventory information from CAIT

The World Resources Institute (WRI) Climate Analysis Indicators Tool (CAIT) is a database of climate indicators. This includes GHG emissions collected and available up to 2003. As the second National Communication on GHG emissions is still under progress, CAIT is a useful resource for collecting more recent GHG emission data. The data is collected from numerous external sources, whereas national communications are collected within the country.

The CAIT data shows that total CO₂ emissions increased steadily from 1990 to 2000. Table 4 shows South Africa's total CO₂ emissions for 1990, 1995 and 2005, including the contribution of all six UNFCCC GHGs. CO₂ emissions from the energy sector

accounts for about 70% of the total GHG emissions and CO₂ makes up the significant portion of total GHG emissions.

Description	1990	1995	2000	2008
Energy CO ₂ emissions (MtCO ₂)	254.6	276.8	298.8	334.2*
Total CO ₂ emissions (MtCO ₂)	295.0	337.4	349.6	486.0*
Total GHG emissions (MtCO ₂ -e)	356.3	399.1	417.6	470.7*

Table 4 – South Africa’s total Energy CO₂ emissions, total CO₂ emissions, total GHG emissions

*2008 values projected from CAIT data up to 2004.

Source: CAIT online resource, WRI 2007

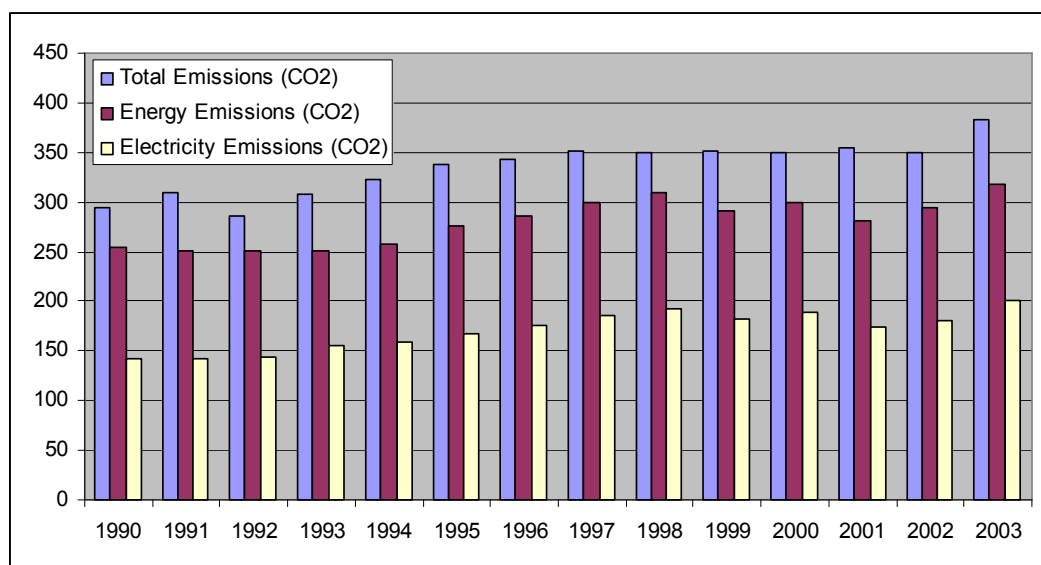


Figure 4 – CO₂ emissions from electricity generation, the energy sector and total CO₂ emissions

Source: CAIT online resource, WRI 2007

2.3.4 Energy and Emissions

Electricity generation in South Africa is the main source of emissions due to coal-fired generation being used to generate most of the countries power. It will require considerable effort to move away from this trend, especially considering that plans to increase the amount of coal-fired generation are being implemented. The transport sectors use of energy in the form of liquid fuels also continues to grow, increasing emissions proportionately.

In the past few years, there has been a large increase in the share of electricity and a decrease in the share of renewable energy (mainly biomass) from 1994 to 2005. This is due both to economic growth and the extensive electrification roll-out that has occurred since the early 1990’s. Rural electrification along with strong economic growth have contributed to the electricity shortage facing South Africa, as insufficient new generating capacity was dimensioned to cope with the growth in demand. As such, growth in energy emissions may slow over the period 2008-2010 as ESKOM’s generating capacity is increased to catch-up with demand.

In 2005 coal accounted for 67.4% of SA's total energy supply as seen in Figure 5 (DME, 2007). Some of this was used for end-use purposes, while large amounts were utilised for electricity generation and conversion to liquid fuel. A low level of nuclear and gas-based power complement the coal-based electricity generation. Crude oil is largely used to supply the transport sector, and renewables consists mainly of biomass. Of the primary energy sources shown in Figure 5, most of the coal originates from South Africa, with most of the gas and crude oil being imported. Coal is also converted into liquid fuels by SASOL. Although about 8% of primary energy is in renewables, this does not represent electricity generation, but rather heating applications.

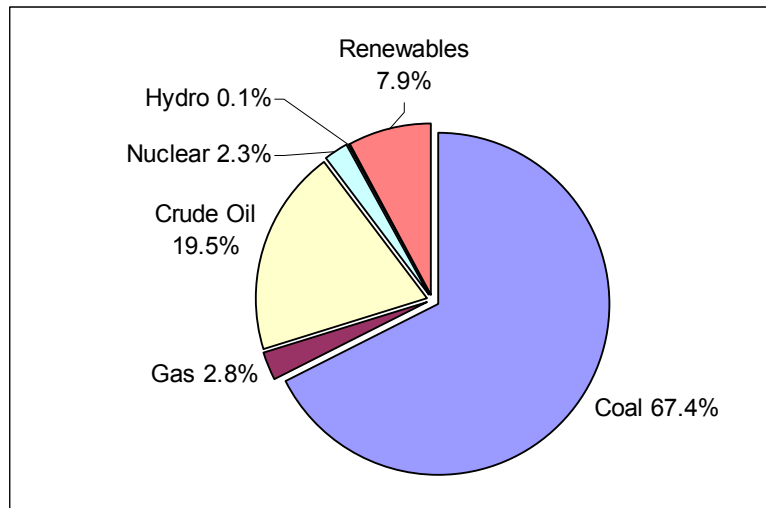


Figure 5 – Primary energy supply for 2005
Source: Collated data from DME online resource, 2008

2.4 Decision Making Tools

2.4.1 The FAIR Policy Support Tool

FAIR (Framework to Assess International Regimes for the differentiation of commitments) is a "policy-decision-support" tool, developed at RIVM (National Institute of Public Health and Environment, the Netherlands), used to assist decision makers assess a number of future climate regime proposals, including: Contraction and Convergence, Multi-stage, South-North Dialogue and an updated Triptych 7.0 approach. The FAIR tool enables users to explore the economic and environmental implications of these future climate regimes for different regions and countries (den Elzen and Lucas 2003). The outputs of such assessments may strongly inform country positions and decisions at climate change negotiations.

The model consists of three main components:

- a climate model – used to derive the climatic effects of emissions,
- an emissions-allocation model – divides emission reduction burdens according to one of several emission allocation proposals, and
- a mitigation costs and mitigation-trading model – calculates the associated mitigation costs also accounting for emissions trading.

Historical emissions, baseline scenarios, climate models, emissions profiles and marginal abatement costs (MAC) all serve as input data to the model. Originally developed as a regional model, with 17 world regions, the FAIR 2.6 version of the model is now disaggregated down to the level of 224 countries. Continuous development is carried out to keep the model consistent with updated scientific knowledge.

To date, assessments of climate regimes using the FAIR tool have been presented at a number of the Conference of the Parties to the UNFCCC (COPs), and under the Task Group on the Kyoto Protocol. It can be expected that outputs from such decision making support tools will serve to inform negotiations under the Bali Action Plan.

2.4.2 Mitigation Cost Projections under FAIR

Under the FAIR tool, cost estimates are made to calculate the costs for reducing emissions under the different climate regime proposals. This goes towards expressing the level of effort needed to achieve climate reduction targets. Mitigation costs vary across different world regions, and countries that are heavy polluters should be able to mitigate GHG emissions at lower costs. Equalising the mitigation costs by introducing global emissions trading schemes sets absolute global cost levels. Using these global marginal abatement cost estimates, the cost to a country to reduce its emissions by a certain level can be calculated. Marginal Abatement Cost calculations are then done for each country and varying levels of emissions taxes are simulated to calculate the abatement costs in that country.

There are certain limitations to using these cost estimates as they don't take consequential factors such as "leakage" into account, where emission reductions in one location lead to increased emissions in other areas. Other factors not accounted for using these cost estimates are changes to infrastructure that will take place, effects of time and the effects of mitigation efforts taking place in other countries (den Elzen, M. and Lucas, P. 2003).

2.4.3 Emissions and Population

One of the metrics used to compare countries emissions is GHG emissions per capita. Emissions per capita levels give a relative indication of how accountable a country is to adding to climate change. Although there are other factors to take into account such as the nature of the countries economy and level of equality in their society, the per capita emissions gives a quick comparative metric. The climate regime approaches may make use of annual per capita emission rates or historical per capita emission rates.

According to some proposals, including Contraction and Convergence, the climate goal should be achieved through allocating the emissions reductions burdens according to per capita targets. Countries would aim to reduce their per capita emissions towards a future emissions per capita target. This would entitle countries with larger population sizes more emission allowance, and less allowance for those with smaller populations.

Future per capita emission projections are functions of projected population size and economic growth. South Africa has a relatively high per capita emissions level. This

is due to the reliance on coal, and due to the highly energy-intensive industrial sector.

According to the FAIR 2.2 figures for South Africa, the per capita emissions in 2005 were 9.9tCO₂e per capita, and for the BAU case will increase by 54% to 15.3tCO₂e per capita in 2030.

2.4.4 Emissions and GDP Growth

GDP per capita and GHG emissions per unit GDP are other metrics used to assess a country's level of emissions and ability to afford emissions targets. The GHG per GDP metric reveals the energy intensity of an economy, with high levels suggesting that an economy is founded on high emissions technologies and processes.

According to FAIR 2.2, the emissions level was 308gCO₂e per \$ GDP_{PPP} in 2005. This will decrease marginally to 305gCO₂e per \$ GDP_{PPP} in 2030.

2.5 International Greenhouse Gases Emission Allocation proposals

Noting that strong emissions reductions are required to curtail climate change it is necessary for all countries to take some level of action. Due to their historical and current emissions and their present capacity to carry out mitigation measures, developed countries are in most cases taking the lead in reducing their emissions pathways. The high level of growth in emissions from major developing countries is making it increasingly necessary for developing countries to accept emissions limiting commitments in the short-term.

The perceived high costs make mitigation seem like an unwanted burden, so the Bali Action Plan calls for formulation of

"A shared vision for long-term cooperative action, including a long-term global goal for emission reductions, to achieve the ultimate objective of the Convention, in accordance with the provisions and principles of the Convention, in particular the principle of common but differentiated responsibilities and respective capabilities, and taking into account social and economic conditions and other relevant factors" (Decision 1/CP.13 UNFCCC, 2007)

There are a large number of published proposals for approaches some of which may strongly influence the next post-Kyoto regime if the principles on which they are based are acceptable to a majority of the Parties. Bearing in mind the need for significant emissions reduction commitments, approaches for consideration under the UNFCCC, as collated in Bodansky 2004- A survey of Approaches, include:

- **Ability to Pay** is based on the Kyoto architecture with emissions targets determined by a country's GDP per capita level;
- The **Brazilian Proposal** allocates emission reduction burdens according to countries' historical emissions and the associated temperature increase caused;
- **Contraction and Convergence** sets regional per capita emissions levels according to a global emissions stabilisation target;
- **Further Differentiation** approach sets strong absolute targets for developed countries and indexed targets according to the wealth of developing countries;

- **Global Framework: Kyoto, Decarbonisation and Adaptation** is a staged approach where developing countries progress from decarbonisation to carbon stabilisation and to reduction targets;
- The **Triptych Approach** bases emission reductions on sectoral emissions intensity targets, with later versions including stages for developing countries participation;
- **Graduation and Deepening** has developing countries taking on emission reductions based on a per capita income, per capita emissions index;
- **Intensity Targets** is an approach that targets specific sectors that are major emitters, and sets GHG emission targets for the sectors based on best practices;
- **Multi-Sector Convergence** bases emissions reductions on convergence towards equal per-capita emissions in seven sectors;
- the **Multistage** approach is a staged approach that allow developing countries "time to develop"; developing countries are categorized according to their GDP per capita and burdens are allocating according to the category of the country;
- the **South-North Dialogue** is also a staged approach, with categorisation criteria based on a combination of historical responsibility, capability and capacity for mitigation;
- the **Sustainable Development Policies and Measures (SD-PAMs)** approach allows developing countries to implement development oriented emission reduction measures as an initial step towards reducing emissions.

The above approaches recognize a difference between developing and developed countries, while working towards reducing global emissions to reach a stabilisation level. The Contraction and Convergence approach may be perceived to be too demanding on developed countries while being too light on larger developing countries, whereas the Triptych approach in its original form placed very demanding targets on developing countries with low sectoral efficiencies. From the review of approaches, it seems that a staged structure that allows for developing countries to delay their emission reduction burden to a later stage seems more likely to be acceptable to developing countries.

The Entry into Force of the UNFCCC in 1994 was a major accomplishment in international cooperation to address climate change. The convention encourages parties to reduce their emissions, but does not set targets or bind countries to do so. The Kyoto Protocol was accepted in 1997 and entered into force in 2005. The Protocol commits industrialised countries to reduce their emissions in accordance with negotiated targets. In the first commitment period from 2008 to 2012, Annex I parties were to reduce their emissions to, on average, 5% below their 1990 emission levels.

Following the first commitment period, the post-2012 regime will have to be both agreeable to parties to get them to join, but also be stringent enough to ensure significant reductions in GHG emissions can be made. Negotiations will determine what form of agreement will follow the first commitment period's absolute emission reduction commitments. Many of the proposals take a long-term view of what is ultimately required to curtail climate change over a long time-frame. This section

considers several of the regime proposals and describes what the implications to South Africa's future GHG emission levels may be.

For this section, the emission reductions for the different scenarios are calculated for GHG stabilisation levels of 450ppm CO₂e and, where possible, 550ppm CO₂e. As this study will be for projections up until 2030, where necessary, the FAIR model is run to stabilise at 2050 and then the results truncated to 2030.

2.5.1 The Contraction and Convergence Approach

This proposal is based on the premise that every person should only be allowed to generate the same level of GHG emissions and that per capita emissions should be equal. Regional emission entitlements are therefore dependent on the population of a region.

This proposal aims to stabilize global GHG concentrations at a level of 450ppm CO₂e or less over a long-term period. Under this approach countries are grouped into regions and an emission allowance, in accordance with a 450ppm CO₂e stabilisation goal, are allocated amongst the regions. The allowed regional emissions are then divided amongst countries within those regions. The emissions for regions are required to converge to the same per capita emission levels (Bodansky, 2004). This convergence is calculated linearly by FAIR 2.2 from the starting year. The entitlements are based on a figure for the starting year's population, ie: 2001, and there will be a limit for increases in a countries' population reportable. Emission entitlements will be tradable, and trade would be encouraged between entitlement holders. The approach is equitable, wherein every single person has the right to emit the same amount of GHGs.

South Africa under the Contraction and Convergence approach

Figure 6 shows that a selection of countries' per capita CO₂ equivalent emissions converges to the same level by 2050. After this, the per capita emissions continue to decrease until 2100 to reach the 450ppm CO₂e stabilization target.

The implementation of Contraction and Convergence in the FAIR 2.2 model has total global emissions increasing from 30GtCO₂e per year in 1990, to 42GtCO₂e per year in 2010, and then decrease steadily to 27GtCO₂e year in 2030. Figure 6 shows a number the emissions per capita profiles for a selection of countries, to illustrate the contraction and convergence of emissions under the approach. South Africa follows the trend of other fairly developed countries, in that its per capita emissions will begin reducing emissions after 2010, which can be seen in **Figure 7**.

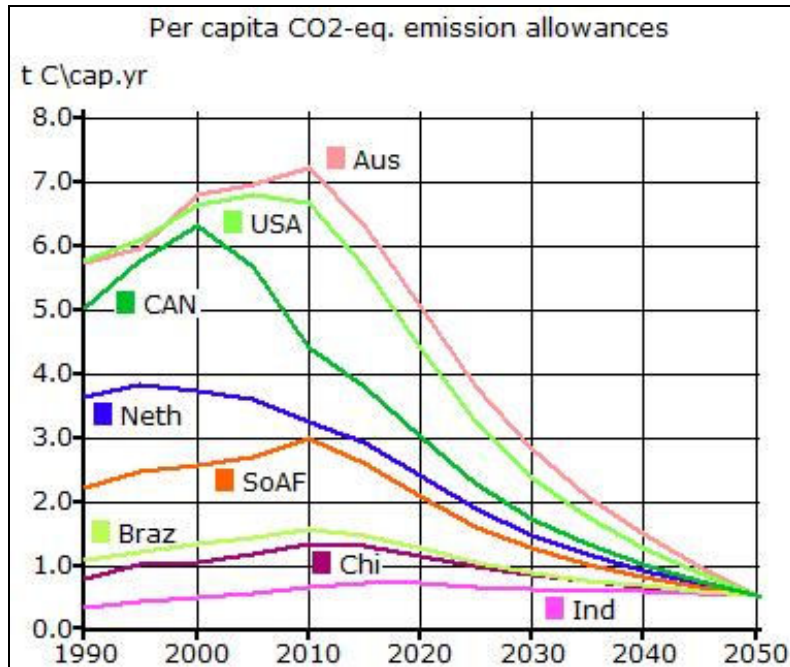


Figure 6 - Global Contraction and Convergence
Source: Own analysis using FAIR 2.2, 2007

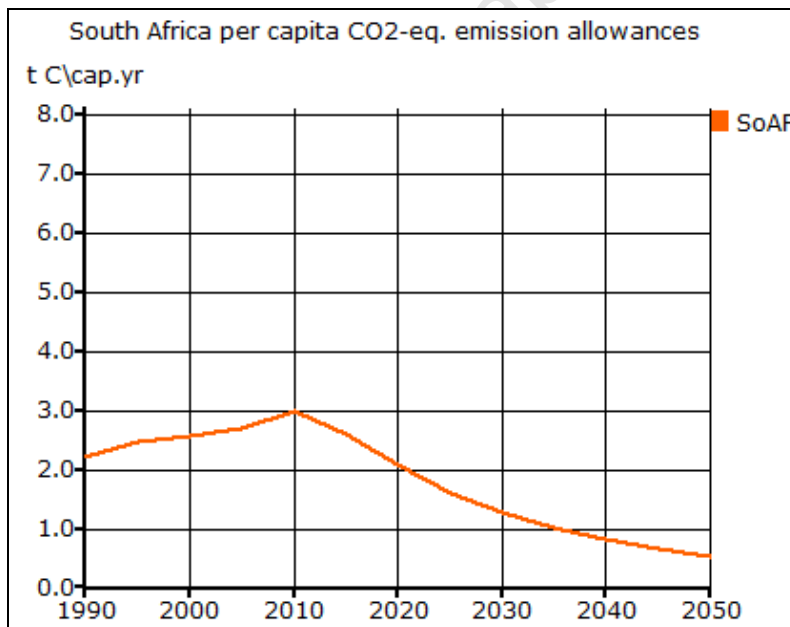


Figure 7 - per capita emission levels for South Africa
Source: Own analysis using FAIR 2.2, 2007

In the FAIR 2.2 model, South Africa's emissions will increase from 480MtCO₂e per year in 2005 to 568MtCO₂e in 2010. Business as usual (BAU) emissions in 2020 is 743MtCO₂e and need to be reduced by 40% to 443MtCO₂e to meet the target. In 2030 the BAU emissions are projected to be 954MtCO₂e, and the target for 2030 is 288MtCO₂e per year. The target level of emissions is 70% below the BAU emissions level.

Taking the possibility of emissions trading into account, SA's national actions should reduce emissions to 424MtCO₂e per year by 2030. With trading enabled, it would need to buy 136MtCO₂e worth of emissions reductions in 2030, to meet the total target of 288MtCO₂e. This would be in addition to South Africa implementing large scale emission reduction policy.

Figure 8 shows South Africa's baseline emissions (BL), emissions allowance (EA) and emissions allowance with trading (EAT). South Africa's costs to mitigate will increase from 1.4% of GDP_{PPP} in 2020 to 6.1% of GDP in 2030. Under Vessia 2006 projections, the GDP in 2030 is R4177 billion and the mitigation costs under Contraction and Convergence would therefore be in the order of R255 billion₂₀₀₀ in 2030. Global costs under this approach increase from 0.5% GDP_{PPP} in 2020 to 3% GDP_{PPP} by 2030.

According to the Stern Review on the Economics of Climate Change (2006), global costs to stabilise emissions at 550ppm CO₂e would be approximately 1% of global GDP. A level of spending that is significant, but manageable.

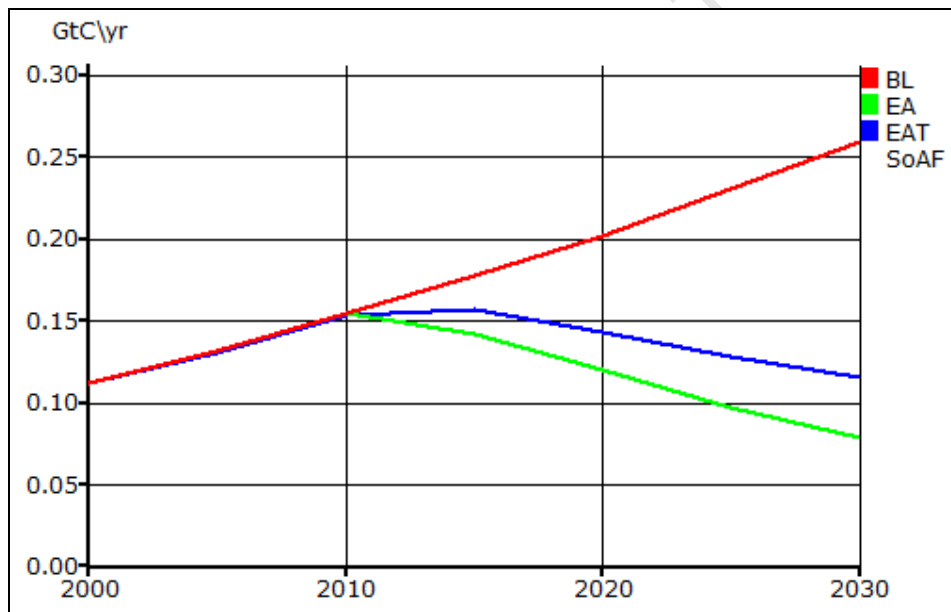


Figure 8 - Emission reduction compared to baseline emissions for South Africa
 BL: Baseline; EA: Emission allowance; EAT: Emissions allowance with emissions trading.
 Source: Own analysis using FAIR 2.2, 2007

The required reductions under the Contraction and Convergence approach are ambitious for South Africa. The large associated costs in 2030 to mitigate GHG emissions would be too high for South Africa (6.1% of GDP), as a developing country, to buy-in to this approach.

2.5.2 The Multi-stage Approach

The Multi-stage approach uses countries level of development and their ability to act as criteria for allocating GHG emission reduction targets. It is a long-term approach in which countries have emission reduction targets according to indexed levels of

development. This works on the premise that countries that are not as developed should be allowed more freedom to develop their economies further, and not have stringent GHG mitigation commitments imposed on them. At later stages when they have transitioned to more developed economies, their GHG mitigation commitments are increased to the higher levels of commitments.

The approach aims to get developing countries to accept commitments, by assigning manageable targets to not impede development in those countries. The approach has variations in the criteria for categorizing countries and in the size of reductions for each category. This section describes the Original and New Multi-stage approaches and the implications for South Africa GHG emissions.

Original Multistage Approach

This was proposed by RIVM (Berk and den Elzen 2001) and outlined four stages through which developing countries would pass. Countries are categorized according to GDP per capita, GHG emissions per capita or a combination of these.

The stages used in this proposal are as follows:

- Stage 1: Business as usual, with no commitments. The least developed countries would be in this stage.
- Stage 2: De-carbonisation and GHG intensity targets where the rate of reduction would be specified according to CO₂ output per unit GDP produced.
- Stage 3: Stabilisation of absolute emissions or of per capita emissions.
- Stage 4: Reduction of absolute emissions, (Bodansky, 2004) where international emissions trading would be advocated.

In this proposal country groupings are re-assessed every five years. In this assessment a GHG emissions ceiling is calculated, considering the long-term stabilisation objectives. The business as usual emissions for the countries in Stage 1 would be subtracted from the GHG ceiling. The emissions for countries in Stage 2 and Stage 3 would be calculated considering their targets and reductions, and subtracted from the remainder of the ceiling. The remainder of the ceiling is then divided amongst Stage 4 countries, either according to historical responsibility for accumulated GHG gases (Brazilian proposal) or their share of overall emissions (Bodansky, 2004).

The amount by which Stage 4 parties have to reduce emissions in this scenario depends on the calculated global emissions ceiling for the five year term, and the amount by which stage 2 and 3 parties have to reduce emissions. It is also dependent on the number of countries in each of the different stages.

Original Multi-stage in FAIR 2.2 (Simple Multi-stage)

Within FAIR the Simple Multi-stage approach makes use of CR (Capacity-Responsibility) indices, whereas the complex Multi-stage allows users to set specific thresholds, such as GDP and emissions per capita, for countries to graduate into higher stages. The CR index is a combined index of the countries GDP per capita (capacity) and the GHG emissions per capita (responsibility).

Within the FAIR 2.2 Simple Multi-stage model, the thresholds are set as follows:

- Stage 1: CR < 5;
- Stage 2: 5 < CR < 12; and
- Stage 3: 12 < CR
- Stage 4: Following 5 years in Stage 3.

Then result for South Africa is as follows:

- 2010; South Africa- Stage 1: no commitments;
- 2015; South Africa- Stage 3: burden sharing for emissions allowances based on per capita emissions;
- 2020; South Africa- Stage 4: has fixed emission reductions.

For the 450ppm CO₂e stabilisation target, **Table 5** shows the required reductions for South Africa from FAIR 2.2.

	Stage	BAU MtCO ₂ e	Target MtCO ₂ e	reduction	cost (GDP(PPP)) %
2010	1	568.3	568.3	0.0%	0.0%
2015	3	649.0	579.3	10.7%	0.0%
2020	4	740.7	487.7	34.2%	-0.5%
2025	4	843.3	374.0	55.7%	-3.2%
2030	4	953.3	282.3	70.4%	-5.4%

Table 5 - GHG emission reduction target for Multi-stage approach in 2030

Source: Own analysis using FAIR 2.2, 2007

Using the GDP projections of Vessia, 2006, the 5.4% cost to GDP in 2030 would be equivalent to R225 billion₂₀₀₀. These commitments are similar to the Contraction and Convergence approach, and are stringent for a developing country.

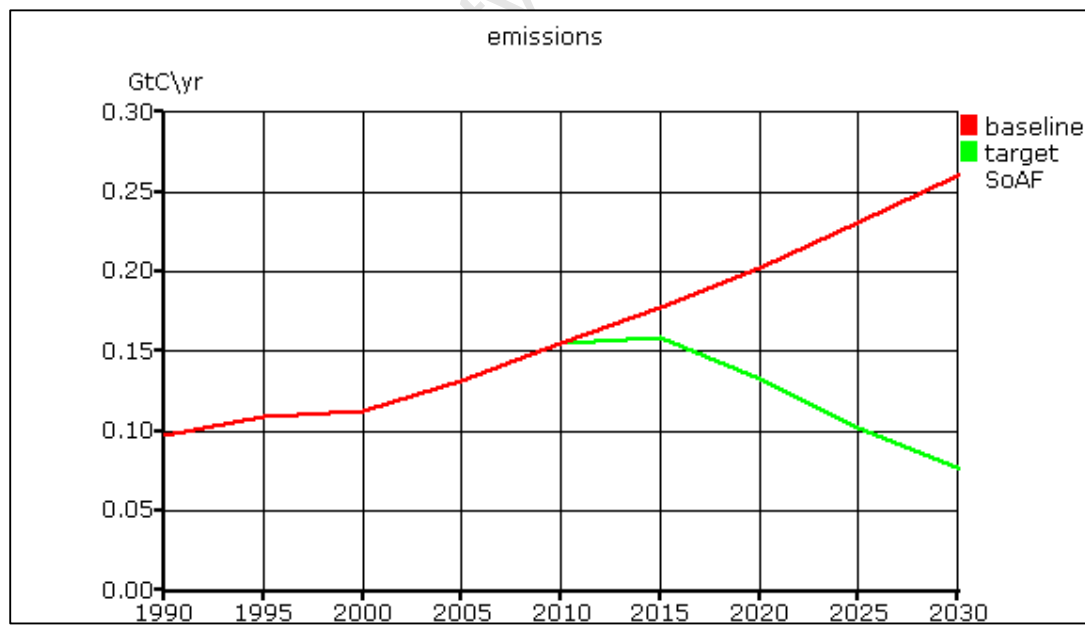


Figure 9 - Baseline vs target emissions for the multi-stage approach using Capacity-Responsibility indices

Source: Own analysis using FAIR 2.2, 2007

New Multi-stage Approach

This staged approach, developed by Ecofys (Höhne, Harnisch et al. 2003), is not very different from the Original Multi-stage, but in FAIR 2.2 it categorizes countries by indicators instead of indices.

Operation

There are four stages through which a developing country will progress. These are:

- Stage 1: No commitments or reductions;
- Stage 2: Pledge for sustainable development, for example phasing out inefficient equipment, with international monitoring and review;
- Stage 3: Moderate absolute targets, such as a growth target or inclusion of a safety valve. The targets would possibly be voluntary and would allow emissions to increase but at a level lower than the BAU case; and
- Stage 4: absolute reduction targets until a sustainable per capita level is reached. Stage 4 commitments may be for 10 year periods and require fairly significant reductions. Countries in Stage 4 could contribute towards SD measures in Stage 2 countries or towards mitigation costs in Stage 3 countries as emission reduction measures (Bodansky, 2004).

Graduation criteria in the New Multi-stage are dependent on countries' GHG emissions per capita. Countries can only move to higher stages, and cannot regress to lower stages.

New Multi-stage in FAIR

The parameters for the New Multi-stage approach are can be adjusted in the FAIR 2.2 model. The conditions for countries to graduate from stages can be adjusted for varying emissions per capita or GDP per capita levels.

The following conditions were set to reach a 450ppm CO₂e stabilisation target:

- Stage 1: no commitments. A country will be in this stage if income per capita is less than 40% GDP_{PPP} of the Annex I average;
- Stage 2: Countries will graduate from Stage 1 to Stage 2 if the income per capita increases to exceed 40% GDP_{PPP} of the Annex I average GDP_{PPP} in 1990 and CO₂e emissions per capita are less than the world average. Stage 2 countries will accept intensity targets
- Stage 3: Countries with per capita income greater than 40% GDP_{PPP} of the Annex I average GDP_{PPP} in 1990, and emissions per capita greater than the world average move into this stage. This is a stabilisation stage, and countries will only be in this stage for 5 years. During this time they would work towards stabilizing emissions.
- Stage 4: After being in Stage 3, countries graduate to this stage. The remaining CO₂ emissions burden is spread out amongst Stage 4 countries which are assigned absolute emission reduction targets. These may be divided according to CO₂ equivalent emissions per capita or other criteria.

The results for South Africa under these parameter settings are shown in Table 6. As a developing country that has a developed industrial sector and has high emissions, it moves from Stage 1 directly to Stage 3, followed by entry into Stage 4. This is because South Africa's projected per capita GDP_{PPP} is \$12,200 which is over

40% of the 1990 Annex I average of \$20,700. Due to South Africa's relatively high per capita emissions, the target is very stringent, which is reflected in the large reduction from the BAU case. The large reduction from the BAU case can be seen clearly in Figure 10.

	Stage	BAU	Target	reduction	cost (GDP _{PPP})
		MtCO ₂ e	MtCO ₂ e	%	%
2010	1	568.3	568.3	0.0%	0.0%
2015	3	649.0	608.7	6.2%	0.0%
2020	4	740.7	564.7	23.8%	-0.4%
2025	4	843.3	366.7	56.5%	-3.2%
2030	4	953.3	271.3	71.5%	-5.5%

Table 6 - Results of New Multi-stage approach for South Africa
 Souce: Own analysis under FAIR 2.2, 2007

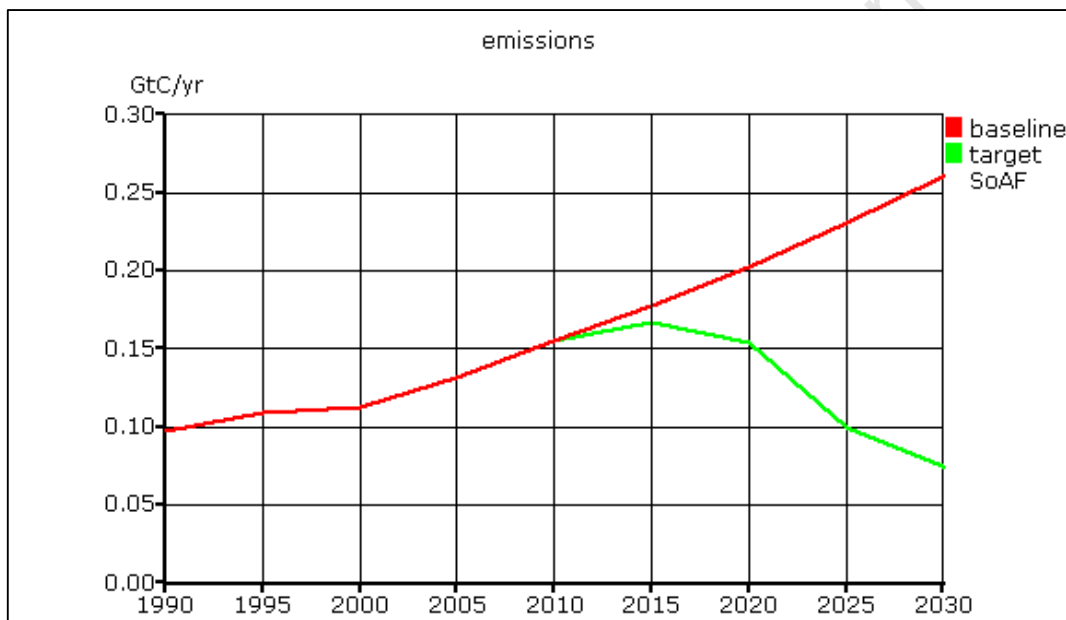


Figure 10 - Emissions reductions under the Multi-stage approach
 Source: Own analysis under FAIR 2.2, 2007

If, under this approach, the criterion to graduate from Stage 1 is increased from 40% GDP_{PPP} of the Annex I average to 50%, South Africa will remain in Stage 1 until 2030, and not have any emission reduction targets.

Adjusting Indices for Multi-stage Stage categorization

The Original Multi-stage can be seen to allocate heavy burdens on South Africa. A study was done to evaluate and adjust the calculation of indices and setting of thresholds to make the proposal more acceptable to developing countries (Torvanger, 2005).

In Torvanger, Bang, Kolshus and Vevatne, 2005, eight case studies were done to explore how combining the CR index with other indices could create an approach that would be more politically acceptable in its fairness with regards to developing countries. The criteria used in the eight case studies can be seen in Table 7.

Case	Characteristics
Case 1	Original CR index with original thresholds
Case 2	Original CR index with adjusted thresholds
Case 3	Original CR index + 10 HDI and adjusted thresholds
Case 4	Original CR index with HDI values and adjusted thresholds
Case 5	Normalized CR index and adjusted thresholds
Case 6	Normalized CR index with HDI and adjusted thresholds
Case 7	Normalized CR index with governance and adjusted thresholds
Case 8	Normalized CR index with governance + institutional affiliation and adjusted thresholds

Table 7 -Source: Torvanger, Bang, Kolshus and Vevatne, 2005

The case studies were done for the initial grouping phase of the multi-stage approach. The study showed how inclusion of additional indices can be used to better reflect national circumstances when grouping countries. The additional indices provide additional measures of the capacity of countries to adopt climate change burdens. South Africa has relatively high scores when considering GDP and GHG emissions, but its world-ranking is lower when HDI, governance indices and institutional affiliations are taken into account.

Of the eight cases described in the study in Table 7, SA was categorized as a Stage 3 country in Cases 1 and 2, but in Cases 3 to 8 was categorized as a Stage 2 country. It is therefore apparent, that inclusion of other developmental indices into calculations gives South Africa a relatively lower score hence grouping it with countries with lower emission reduction burdens.

Comparison of Original and New Multi-Stage Approaches

Under these two approaches the reduction required from South Africa is quite similar in 2030. Both approaches require reductions of approximately 70% from the BAU case in 2030 and GDP spending of over 5% to reach the mitigation targets. The graduation criteria for both Multi-stage approaches categorize South Africa as one of the more affluent developing countries with the capacity to adopt emission reduction burdens. The biggest difference for South Africa would be if the extended CR indices were implemented to include other development related metrics as presented in Torvanger et al. 2005. Using additional indices, South Africa has a lower world ranking on some of the scales and would therefore be categorized lower, leading to lower emission reduction burdens.

Setting the target stabilisation at 550ppm CO₂e would also lead to smaller GHG reduction commitments for South Africa and other countries.

2.5.3 The South-North Dialogue Approach

The South-North dialogue proposal is a staged approach that includes in its design allowances to encourage developing countries to take on commitments. Under other scenarios, demands can be high for developing countries which would discourage any form of commitment, as national growth and development are seen to be of higher priority than climate change. This proposal therefore takes into account the

level of development in more detail than other staged approaches, to make developing country targets more politically appropriate.

Under this approach countries are divided into six categories that have varying levels of emission reductions based on that category. The basis of this proposal is 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:

1. Annex II countries
2. Annex I, but not Annex II countries
3. Newly Industrialized countries
4. Rapidly Industrializing Developing countries
5. Other Developing countries and
6. Least Developed countries

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 CO₂ emissions per capita from 1990 - 2000, and GDP_{PPP} per capita. (Ott et. al 2004). For non-Annex I countries, the countries with the lowest indices are categorized as LDCs and those with the highest as NICs. Assessments were done for South Africa for the 450ppm and 550ppm CO₂ equivalent cases.

FAIR South-North Proposal 450ppm CO₂e stabilization level case

To stabilize the emissions at a 450ppm CO₂e level by 2050, the following reductions were required in 2020:

450ppm CO ₂ e goal	2020	after 2020
Annex II countries	24% below 1990	38% / decade
EU-25 Annex II countries	35% below 1990	38% / decade
Annex I, but not Annex II countries	24% below 1990	34% / decade
Newly Industrialized countries	30% below BAU	15% / decade
Rapidly Industrializing Developing countries	13% below BAU	20% /decade
Other Developing countries	BAU	BAU
Least Developed countries	BAU	BAU

Table 8 - Parameters assumed for South-North proposal for 450ppm stabilization level
Source: den Elzen et. al, 2007

To stabilize emissions at 450ppm CO₂e, a large reduction in emissions is required from most groups, except ODCs and LDCs who have no emission reduction commitments.

In the period leading up to 2020, South Africa is categorized as a RIDC and thus would have to reduce its emissions to a level 13% less than the BAU case as shown in Table 8. In 2025, South Africa progresses to NIC status and would therefore need to reduce emissions by 15% per decade. The GHG mitigation targets achieved for

South Africa under the proposed reduction levels for a 450ppm CO₂e stabilisation scenario are shown in Table 9.

	Category	BAU	Target	reduction	cost (GDP(PPP))
		MtCO ₂ e	MtCO ₂ e		
2010	RIDC	568.3	568.3	0.0%	0.00%
2015	RIDC	649.0	608.7	6.2%	-0.01%
2020	RIDC	740.7	649.0	12.4%	-0.04%
2025	NIC	843.3	601.3	28.7%	-0.48%
2030	NIC	953.3	484.0	49.2%	-1.53%

Table 9 - Results of South-North proposal for South Africa, 450ppm CO₂e stabilisation case

The targeted reduction level in 2030 is 49% lower than the BAU case, and would cost, according to the Vessia, 2006 GDP projections, R63.9 billion₂₀₀₀.

FAIR South-North Proposal 550ppm CO₂e stabilization level case

To stabilise global emissions at a level of 550ppm CO₂e, the parameters were set as detailed in Table 10.

550ppm CO ₂ e goal	2020	after 2020
Annex II countries	10% below 1990	30% / decade
EU-25 Annex II countries	25% below 1990	30% / decade
Annex I, but not Annex II countries	20% below 1990	25% / decade
Newly Industrialized countries	20% below BAU	17% / decade
Rapidly Industrializing Developing countries	10% below BAU	25% / decade
Other Developing countries	BAU	BAU
Least Developed countries	BAU	BAU

Table 10 - Parameters for South-North proposal for 550ppm stabilization level
Source: den Elzen et. al 2007

Leading up to 2020, South Africa will be categorized as a RIDC, but by 2030 onwards will be categorized as a NIC. The abatement costs for South Africa are lower than the 450ppm CO₂e case due to the lower emission reductions required. Details and results for South Africa's CO₂ equivalent reductions and associated costs for the 550ppm CO₂ equivalent case are in Table 11.

	Category	BAU	Target	reduction	cost (GDP(PPP))
		MtCO ₂ e	MtCO ₂ e	%	%
2010	RIDC	568.3	568.3	0.0%	0.00%
2015	RIDC	649.0	619.7	4.5%	-0.01%
2020	RIDC	740.7	667.3	9.9%	-0.01%
2025	NIC	843.3	693.0	17.8%	-0.12%
2030	NIC	953.3	546.3	42.7%	-1.06%

Table 11 - Results of South-North proposal for South Africa, 550ppm CO₂e stabilisation case
Source: Own analysis under FAIR 2.2, 2007

From these two cases it is apparent that South Africa would be categorised as a developing country that is further along the development path, and would therefore have emission reduction targets. The reductions however can be seen to be significantly lower than for the Contraction and Convergence and Multi-stage proposals.

2.5.4 Comparison of Climate Regime Approach results

The outcomes for South Africa from the different regimes are summarised in Table 12. Commitments and targets are higher for the Contraction and Convergence (C&C) and Multi-stage approaches, and lower for the South-North proposal. The percentage reduction relative to the baseline for 2030 is also shown in Table 12. This is also reflected in Table 13 that shows higher mitigation costs for the Contraction and Convergence and Multi-stage approaches.

	BAU	C&C		Multistage		South-North	
		450	550	New 450	Orig. 450	450	550
TARGET	MtCO ₂ e	MtCO ₂ e	MtCO ₂ e	MtCO ₂ e	MtCO ₂ e	MtCO ₂ e	MtCO ₂ e
1990	355.7	355.7	355.7	355.7	355.7	355.7	355.7
1995	399.7	399.7	399.7	399.7	399.7	399.7	399.7
2000	414.3	414.3	414.3	414.3	414.3	414.3	414.3
2005	484.0	484.0	484.0	484.0	484.0	484.0	484.0
2010	568.3	568.3	568.3	568.3	568.3	568.3	568.3
2015	649.0	524.3	550.0	608.7	579.3	608.7	619.7
2020	740.7	443.7	520.7	564.7	487.7	649.0	667.3
2025	843.3	355.7	480.3	366.7	374.0	601.3	693.0
2030	953.3	289.7	432.7	271.3	282.3	484.0	546.3
% reduction 2030		69.6%	54.6%	71.5%	70.4%	49.2%	42.7%

Table 12 - CO₂e emission targets for South Africa under different climate regimes
Source: Own analysis under FAIR 2.2, 2007

	C&C	Multi-stage	South-North	
Target	450	450	450	550
2005	0.00%	0.00%	0.00%	0.00%
2010	0.01%	0.00%	0.00%	0.00%
2015	-0.20%	-0.01%	-0.01%	0.00%
2020	-1.40%	-0.36%	-0.04%	0.00%
2025	-4.00%	-3.25%	-0.48%	-0.12%
2030	-6.10%	-5.52%	-1.53%	-1.06%

Table 13 – Mitigation costs (% of GDP_{PPP}) in South Africa for different climate regimes
Source: Own analysis under FAIR 2.2, 2007

The costs reflect the favourability of the South-North dialogue proposal to South Africa and other developing countries. The highest cost under the Contraction and Convergence approach demonstrates the effects of methodology used, which assigns commitments on emissions per capita alone, not taking into account the developmental conditions of the country. The Multi-Stage approach takes the first step in assigning emissions based on capacity to undertake emission reduction burdens, but may not scrutinize the level of development of countries in enough

detail. It was shown that introducing additional development metrics would lower the ranking of South Africa in relation to other developing countries. The South-North dialogue approach allows South Africa more time before accepting heavier emission reduction burdens, which are reflected in the significantly lower cost estimates for the reductions in 2030. Under the 550ppm CO₂e case

2.5.5 Outcomes of regime comparison

Following the introduction to climate change and the presentation of South Africa's emissions, the regime comparison introduced a number of proposals for post-2012 climate regimes. The analyses of the three regimes show how the application of different methodologies would lead to different emissions reduction targets for South Africa. The decision on a post-2012 regime will come from negotiations under the UNFCCC and could follow one of the approaches presented in the previous section. The previous discussion of the Multi-stage, Contraction and Convergence and South-North dialogue proposals will lead into the later analysis of the Triptych approach. The analysis in the Triptych approach later shows how a sectoral approach differs in its calculation of country targets, and how the targets may differ.

3 Methodology

3.1 Overview

The methodology of this study is as follows (as in Figure 11):

The literature review sets the scene for the study and explains the science and impacts of climate change. An overview on the political negotiations to solve the climate change problem is then given. Following this there is a review of the major proposals for approaches that may follow the first commitment period of the Kyoto-Protocol.

The FAIR policy support tool is used as the international climate modelling tool for this study. The tool allows users to navigate through a number of different climate regime proposals and determine the effects of altering the targeted stabilisation levels, or see how changing parameters affects global stabilisation targets. It also contains a cost model that projects the costs for implementation of climate regimes. More recent versions of the modelling tool have also included South Africa at a country-level making it ideal for this study. Previous models had South Africa included as part of a Southern African region.

South Africa's commitments under a variety of post-Kyoto climate regimes are quantified using the FAIR policy-support tool. Quantification is done for the Multi-stage, Contraction and Convergence and South-North Dialogue approaches for climate stabilisation targets of 450ppm and 550ppm CO₂e. These approaches contain a variety of methodologies for allocating emissions, and results yield different mitigation targets under the different approaches. The FAIR tool is used to approximate both the GHG targets, and associated costs for the different scenarios. A comparison is done on the results of the GHG reduction targets from the three approaches.

Following the initial analysis of these three regime proposals, an in-depth description is given for the methodology used in the Triptych Approach. Of the approaches covered, Triptych is the most data-intensive in its derivation of targets, and uses a bottom-up rather than a top-down methodology. It is also the approach that is most compatible in structure to the South African National energy model, as it is based on sectoral outputs.

The level of compatibility and comparability between the Triptych approach and the national energy model, which is modelled in MARKAL, are examined. The population and GDP drivers for South Africa used in the FAIR tool are compared with the drivers used in the national model. The baseline emissions projections of the sectors are then examined and the FAIR and MARKAL growth projections within the sectors compared with one another. It is then possible to apply the Triptych approach to the modelling data from the MARKAL model. The results from this yield a South African Triptych target for 2030.

The SD-PAMs approach is presented as possibly the most favourable pathway towards meeting GHG mitigation targets in South Africa. The SD-PAMs approach is important for South Africa as it is a development focused approach to work towards

reaching climate change goals. Developing countries main focus is on growth, development, and poverty alleviation and the UNFCCC recommends achieving climate goals in a sustainable way.

A number of SD-PAMs are presented and their GHG mitigation potentials are computed within the MARKAL national model. The SD-PAMs are relevant to specific sectors and can therefore be compared with the sectors defined in the Triptych approach. The total mitigation potential for all the SD-PAMs presented is then modelled using MARKAL and this result is compared with the mitigation target under the Triptych approach.

Following this, comparisons can be made between Triptych, the national model, SD-PAMs approaches, and the top-down and bottom-up approaches. These comparisons are discussed in terms of how far the SD-PAMs can go towards reaching the Triptych targets, and also for which sectors the SD-PAMs are comparable to the Triptych targets.

Conclusions will then be drawn from these results as well as recommendations on their applicability. Recommendations will also be made for additional research work that could contribute in this area.

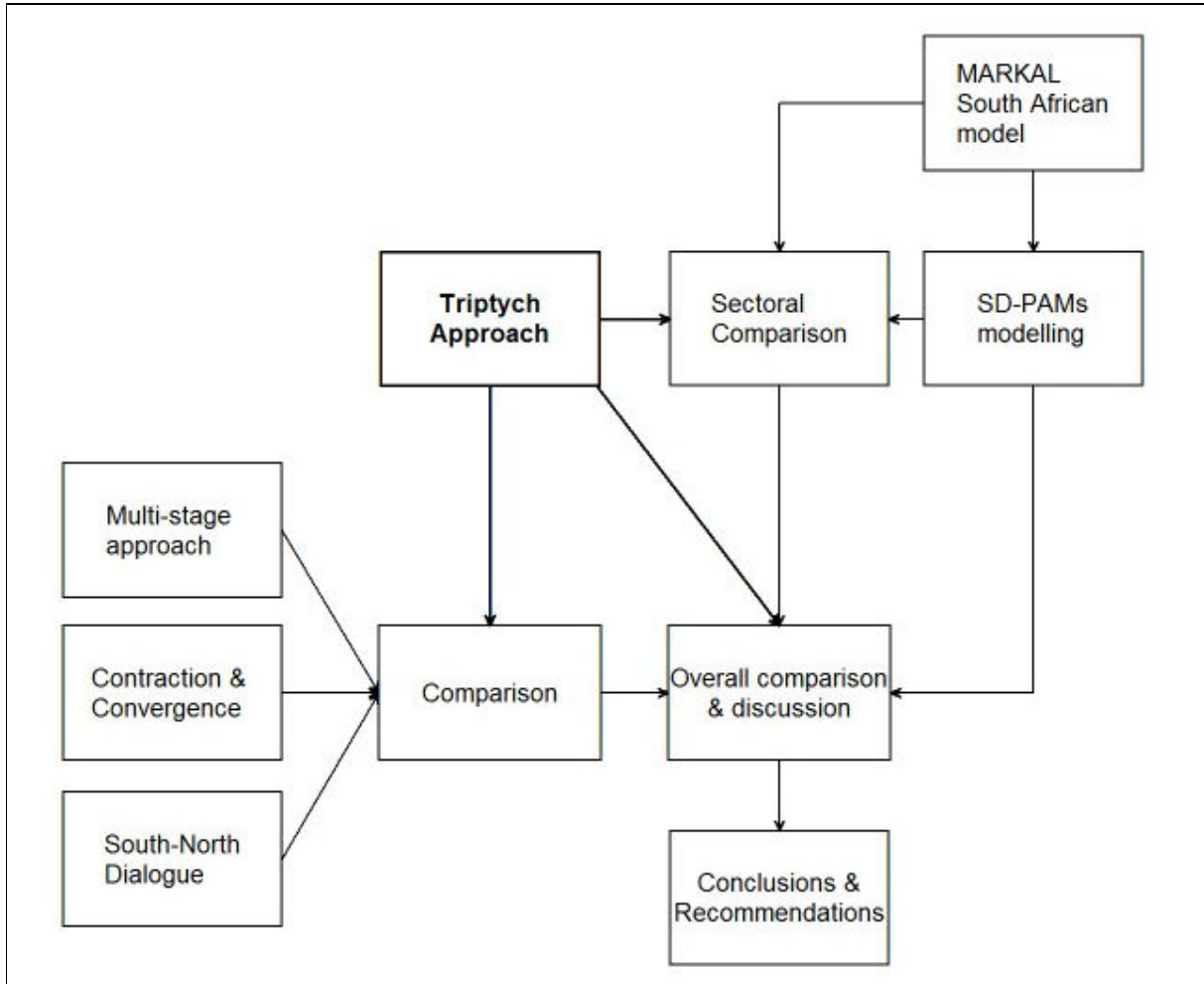


Figure 11 - Schematic for structure of work

4 The Triptych Approach

The original Triptych or “Triptique” proposal was developed by researchers from the University of Utrecht as a sectoral approach with a scientific basis, to allocate burden sharing commitments between the EU Member States in 1997 (Blok et al. 1997). The original proposal called for total emission reductions of 15% from 1990 levels of CO₂, CH₄ and N₂O by 2010. The approach gained approval for its scientific approach, where countries were able to identify the differences in emissions sources and pragmatically allocate burden sharing (Faure 2003).

The EU-15’s ambitious target was lowered after the Kyoto Protocol negotiations, where they were assigned a lower than anticipated emissions reduction target of 8% from 2008-2012. Under provision of Article 4 in the Protocol, that allows for “joint fulfilment” of the burden, Members of this so-called “bubble” were able to draw on the work done using Triptych to share out this Kyoto target. Emission reductions shares were therefore based on the original targets, but re-adjusted for the 8% total emissions reductions target.

The approach was named Triptych as it used indicators from three sectors to allocate emission reductions: electricity generation, heavy industry and the domestic sector (which included residential and transport). These sectors have the main proportion of GHG emissions sources. By measuring the relative efficiencies of these sectors, countries’ inefficient sectors can be identified. Poor sectoral efficiency is penalised under this approach, and it encourages the adoption of better technology and practices.

There have been several subsequent versions of Triptych, expanding the approach to include more world regions, additional sectors, and developing countries.

The Original Triptych by Blok et al. 1997, had 2010 as the target year, only took account of energy-related CO₂, and was for the EU member states. The target was a reduction in CO₂ emissions relative to the base-year 1990.

The Global Convergence Triptych by Groenenberg, 2002, included CH₄, N₂O and PFCs. As its name suggests, it was applied at a global level, to 13 world regions, and 48 countries. The Global Convergence Triptych approach added the Fossil-fuel production, agriculture, and deforestation sectors. The target year for this approach is 2020, and instead of a percentage reduction target, stabilisation targets of 450ppm and 550ppm CO₂e are used.

Extended Global Triptych (Höhne et al. 2003) also contained 48 countries, and included emission reductions for the waste sector.

Triptych 6.0 by Höhne et al. 2005 expanded the country-level data to include up to 192 countries. The proposal includes SF₆ and HFCs. Furthermore, the target year is extended to 2050. Growth trends in the sectors were approximated through downscaling regional growth trends from IMAGE 2.2 scenarios.

Triptych 7.0, by den Elzen et al., 2007, further extends the number of countries to 224 according to data availability. The approach uses an improved down-scaling methodology, a staged-approach for developing countries, and makes use of country-specific growth projections for population.

The work in this chapter refers to Triptych 7.0 implementation in the FAIR 2.6 policy tool, which includes South Africa as a country in the model. This chapter explains

how the Triptych 7.0 approach is used to calculate country-level emission reduction targets.

4.1 Target allocation under Triptych 7.0

The Triptych approach uses a bottom-up approach by setting targets according to the GHG emissions from sectoral activities. Although it is necessary to decrease emissions below specific levels to mitigate climate change, the reductions required relative to BAU scenarios will depend on the BAU scenario chosen. As such, the emission reductions required in a high GHG growth scenario would be greater than reductions required for a low GHG growth scenario to reach the same GHG stabilisation level. The FAIR model uses the IPCC SRES B2 family as its central median baseline (den Elzen et al., 2007), but also makes use of the other six IPCC SRES groupings as it is acknowledged that any of them may be likely to occur.

Using this bottom-up approach, national emissions reduction targets are calculated by adding all the sectoral GHG emission reduction targets. The target is a GHG emissions target based on the GHG reduction opportunities in the sectors, but not limited to being achieved in those sectors. So although sectoral analysis is the basis for setting the targets, the methods that countries use to achieve these targets are not prescriptive, and reductions can be achieved through other means, ie: emissions trading, forestry or bigger focus on a particular sector.

The overall global GHG concentration stabilisation level depends on the stringency of the sectoral targets. In den Elzen 2007, Strong, Medium and Slow sets of sectoral targets are presented. The stabilisation levels reached using these targets under the IPCC SRES B2 baseline are approximately the 450, 550 and 650ppm CO₂-e (den Elzen et al., 2007).

Strong Scenario

Initial targets are set for 2030, for Annex I countries to achieve sectoral targets of the best performing Annex I sectors in 2004. The subsequent target is for Annex I and newly industrialised countries (NICs) to achieve the lowest technical sectoral target by the year 2050. The advanced developed countries and least developed countries (LDCs) would have the same goals pushed back by five and ten years respectively.

Medium Scenario

The medium scenario assumes technology transfer will take longer than is possible in the Strong scenario. The goal is for Annex I and newly industrialised countries to converge towards 2004 Annex I best performing countries levels by 2050, with advanced developing countries (ADCs) and least developed countries having the same goals delayed by 10 years and 20 years respectively.

Slow Scenario

The slow scenario has as its convergence level goal, a level 10-15% higher than Annex I 2004 best performing levels. The convergence year for Annex I countries is 2050, with NIC's and ADC's having the same goal delayed by 10 years. Least developed countries have the same goal delayed by 20 years under this scenario (den Elzen et al., 2007).

Only targets for the Strong and Medium scenarios are discussed in the following section as these will show the largest changes from the baseline levels.

4.2 Sectoral Targets

The following sectors are used to calculate targets in the Triptych 7.0 approach:

1. Industrial
2. Domestic
3. Power and Electricity
4. Fossil fuel production
5. Agriculture
6. Waste

The industrial, domestic and power and electricity sectors were included in the Original Triptych (Blok et al. 1997). Fossil fuel production and agriculture were included in Global Convergence Triptych (Groenenberg, 2002), and the waste sector was introduced in Extended Global Triptych (Höhne et al. 2003). A sector for deforestation was also included in Global Convergence Triptych, but is not included in this study.

These sectors are the major contributors to GHG emissions in the world. These sectors are composed of a number of sub-sectors, such as the Domestic sector which includes transport, commercial and residential emissions. This section looks at the constitution of each of the above sectors and how the method used to calculate the each of their targets. Land-use change and forestry are not included in the Triptych 7.0 approach due to uncertainties related to emissions from this sector (den Elzen 2007).

4.2.1 Industrial

The industrial sector consists of the energy used within both heavy and light industry. Targets are based on the overall efficiency, measured using an EEI (energy efficiency index) for the sector. The targets are calculated by assuming an incremental improvement of the EEI.

One of the key components of the Triptych approach is in calculating the Industrial sectors' total EEI. This is done according to the formula used in a number of studies, including Groenenberg et al., 2004:

- A SEC (specific energy consumption) for a sub-sector is calculated as the total aggregate energy intensity for that sub-sector, or the energy per unit production:

$$SEC = \frac{E_{tot}}{P_{tot}} = \frac{\sum_{i=1}^n (p_i SEC_i)}{\sum_{i=1}^n p_i} \quad (1)$$

SEC_i is the specific energy consumption per unit production, per sub-sector

p_i is the production for that sub-sector

E_{tot} is the total energy used for the sub-sector

P_{tot} is the total production for the sub-sector.

- Each sub-sector has a reference SEC (specific energy consumption) which is the aggregated energy intensity for current best practices for processes in a sector;

$$SEC_{ref} = \frac{E_{ref,tot}}{P_{tot}} = \frac{\sum_{i=1}^n (p_i SEC_{ref,i})}{\sum_{i=1}^n p_i} \quad (2)$$

SEC_{ref} is the reference specific energy consumption per unit production for a sub-sector

$SEC_{ref,i}$ is the reference energy consumption per unit production

$E_{ref,tot}$ is the total reference energy for the sub-sector

- The reference SEC can be an averaged index according to the best practices in several countries or determined according to technically feasible levels
- The ratio of the energy-intensity versus the SEC is the EEI;
- The total EEI is an aggregation across the sub-sectors of the EEIs, relative to production those sectors.

This calculation can be shown as:

$$EEI = \frac{E_{tot}}{E_{ref,tot}} = \frac{\sum_{i=1}^n p_i SEC_i}{\sum_{i=1}^n p_i SEC_{ref,i}} \quad (3)$$

An EEI close to unity denotes the sub-sectors energy efficiency is close to best practice efficiencies. A high EEI denotes inefficiencies in the sub-sector. Countries that will receive heavy burdens under this allocation scheme are those with high energy use per unit production.

The sub-sectoral EEIs used in this study are taken from the study by Kuramochi 2006, that updated EEIs based on recent sectoral data. The following sectors were used:

- Iron and Steel
- Pulp and Paper
- Cement
- Petrochemical (energy use)
- Petroleum refinery (energy use)
- Ammonia production (energy use)

Targets

As the EEI is an index relative to the current best-practice efficiencies, several of the most efficient Annex I countries have EEIs of almost 1.0. The target for 2030 is and EEI of 1.0 in the Strong scenario, and this is achievable using current technology as this expresses the best available technology and not a theoretical level of efficiency. As technology advances and industries' performance improves, technology transference will enable more countries' industrial sector performance to approach current best practices, and have their EEI's approach 1.0 or below.

The following targets are made for the Industrial sector of countries under Triptych
The Medium case requires:

- 2050: The EEI of for a countries Industrial sector must be reduced to a value of 0.7, which is 70% of current sectoral best practices.
- 2100: The EEI must be reduced to 0.6, which is 60% of current best practices.

The Strong case calls for

- 2030: The EEI of the Industrial sector reduced to 1.0.
- 2050: The EEI reduced to 0.5.
- 2100: The countries EEI to be reduced to 0.25.

The target in GHG volumes is a function of the improvement in efficiency over the base case and the growth in production over the time period. This can be quantified as the amount of GHG saved per year- taking into account growth projections- due to increased efficiency until the target year.

Future industrial production is based on the IMAGE/TIMER 2.3 model implementation of the IPCC SRES scenarios that makes provisions for structural changes and growth in the sector (den Elzen, 2007). This projection is then input into FAIR to be used as the sectoral baseline for the industrial sector.

4.2.2 Domestic

In this sector, emission targets are based on per capita emissions for the following sub-sectoral activities:

- Fossil fuel combustion in residential, commercial, agricultural and transport, excluding international transport;
- F-gas emissions from sources including: refrigeration, air-conditioning, fire extinguishers, aerosols.

The assumption is made that growth in emissions from the above activities are dependent on the level of growth in the economy (measured using GDP) and population of the country. The target calls for convergence in the sectors GHG emissions per capita for all countries.

Targets

The convergence targets are measured in tCO₂ per capita per year.

The Medium case calls for:

- By 2050: Convergence of global per capita emissions of 1.5tCO₂ per capita,
- After 2050: 1.5% annual reduction in per capita emissions

The Strong case requires:

- By 2030: Convergence of global per capita emissions of 1.25tCO₂ per capita,
- After 2030: 2.0% annual reduction in per capita emissions

Emissions per capita in 2005 according to the FAIR 2.6 model were 1.6tCO₂e per capita. Emissions reduction targets are therefore quantified according to the rate of projected growth in the sub-sectors and population growth and the proposed per capita emissions.

4.2.3 Power and Electricity

The power production sector uses three points of convergence: emission levels per kWh produced; decreasing the share of oil and coal in the electricity energy mix and a decrease in demand from other sectors.

1. Convergence of emissions per kWh of electricity produced

The emissions per kWh produced by coal, gas and oil are assessed. There is a wide range in emissions per kWh electricity generated, with the fuel quality and generation technology being the significant factors. Investment into cleaner generation technology can be used to build more efficient facilities.

Targets

Under the Medium case:

- By 2050: Generation efficiencies: Coal 600gCO₂/kWh; Oil 450gCO₂/kWh; Gas 300gCO₂/kWh.
- By 2100: Generation efficiencies: Coal 400gCO₂/kWh; Oil 300gCO₂/kWh; Gas 250gCO₂/kWh.

Under the Strong case:

- By 2030: Generation efficiencies: Coal 600gCO₂/kWh; Oil 450gCO₂/kWh; Gas 300gCO₂/kWh.
- By 2050: Generation efficiencies: Coal 400gCO₂/kWh; Oil 300gCO₂/kWh; Gas 250gCO₂/kWh.
- By 2100: Generation efficiencies: Coal 200gCO₂/kWh; Oil 150gCO₂/kWh; Gas 100gCO₂/kWh.

South Africa's coal generating efficiency in 2008 was 1000gCO₂/kWh (Eskom 2008). Using current coal-generation technology, developed countries such as Denmark, Sweden and Finland are achieving emissions of 600-700gCO₂/kWh. However, developing countries such as Zambia, Brazil and Argentina's emissions are greater than 1600gCO₂/kWh (den Elzen et al, 2007b). The differences in emissions can be attributed to both the generation technology, the grade of coal used.

2. Decrease in Share of Oil and Coal

The second condition for this sector is a decrease in the proportion of electricity generated from oil and coal. The large decrease would require uptake from other sources such as nuclear, gas and renewables. Carbon capture and storage (CCS) could be an important alternative option as the aim is to lower emissions by reducing emissions intensive electricity generation from oil and coal. Due to the long life-spans of power stations, immediate action would be required for such proposals to avoid lock-in (den Elzen 2007).

Targets

For the Medium case:

- By 2050: 90% reduction in oil and coals share;
- By 2100: 95% reduction.

For the Strong case:

- By 2030: 60% reduction;
- By 2050 and 2100, the same as the Medium case.

3. Decrease in the domestic and industrial sectors electricity demand

This portion of the approach requires reductions in electricity demand from the domestic and industrial sectors relative to the baseline. This reduction would be achieved through implementation of efficiency measures. In actuality, the reduction is from the sectors that use electricity, but this approach assumes that the generation facility can influence demand.

Targets

For the Medium case an annual reduction of 1.5% from the base case is required. For the Strong case an annual reduction of 2.0% from the base case is required.

4.2.4 Fossil Fuel Production

The technology exists to reduce emissions from the production of fossil fuels significantly. Emissions from this sector take account of the decreased fossil fuel demands brought about by the increase in efficiency in the other sectors through implementation of the Triptych targets. In other words, decreases in demand in the power and electricity and industrial sectors.

Targets

In the Medium case, by 2050 a 90% decrease in emissions
In the Strong case, by 2030 a 90% decrease, by 2050 a 95% decrease in emissions.

4.2.5 Agriculture

The agricultural sector is a large source for non-CO₂ GHGs. For this sector, emissions reductions can be brought about through implementing changes in agricultural practices.

Targets

Under the Medium case, reductions in emissions are:

- For Annex I and NICs (newly industrialised countries): 40% by 2050 and 50% by 2100
- For ADCs (advanced developing countries) and LDCs (least developed countries): 20% by 2050 and 30% by 2100

In the Strong case reductions required are:

- For Annex I and NICs: 40% by 2030 and 50% by 2030
- For ADCs and LDCs: 30% by 2030 and 50% by 2050

4.2.6 Waste

Emissions from waste can be substantially reduced using existing emission reduction options. The approach calls for a reduction in per capita emissions from waste. Emission reductions are set relative to the level of per capita emissions from waste in the base year.

Targets

The target for the Medium case is 90% decrease in per capita emissions from waste by 2050.

The target for the Strong case is a 90% decrease by 2030.

4.3 Differentiated Participation

Under the Triptych 7.0 Approach, developing countries are allowed to delay their targets to a later date than their developed country counterparts. This compromise makes allowance for differentiated levels of responsibility, capacity and capability; and gives developing countries room for development. Under this approach, developing countries would be required to implement SD-PAMs measures prior to their quantified emission reduction commitments. Inclusion of the differentiated convergence component aims to make the proposal more acceptable to developing countries with development-first policies.

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5 Triptych Results for South Africa under FAIR

5.1 Baseline projections and Major drivers

The Triptych targets are based on the emission levels projected for the years 2030, 2050 and 2100. For this thesis baseline projections and results are calculated until 2030. This section describes how South Africa is represented within the FAIR 2.2 model in terms of GDP and population projections. It then goes on to introduce each of the sectors from which the targets are calculated. It gives the growth rate for each of the sectors so that this may be compared with the growth rate from the national model in the following sections.

5.1.1 GDP projections

GDP growth is based on the World Bank 2004 figures, and the growth rate a downscaling of the regional growth rate. As this is an international model, World Bank figures are used for consistency for countries' estimated GDP levels. Although using national data may in many cases be more accurate it would raise issues on the exchange rates used and reliable data is not available for all regions. Using data from an international agency therefore alleviates this concern. The growth rate for South Africa is derived from the growth level tending towards that of the rest of the region. **Figure 12** shows the two growth projections for the GDP. The one calculated as the purchasing price parity (PPP) rate, the other the with the market exchange rate (MER). The original World Bank data is in PPP. The GDP_{PPP} growth rate is steady and is about 1.2% per year.

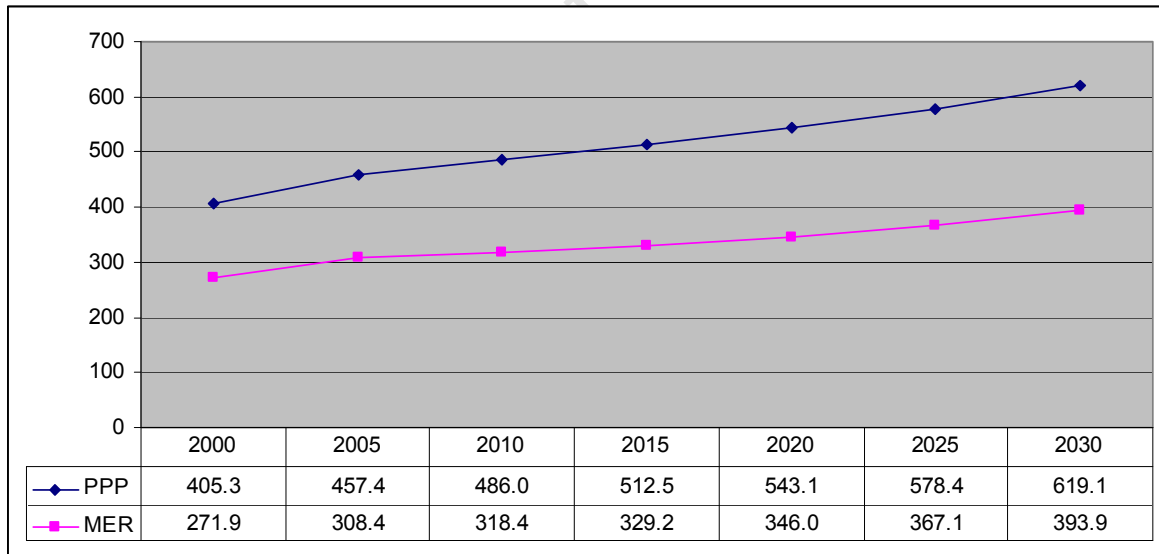


Figure 12 – GDP_{PPP} and GDP_{MER} projections for South Africa 2000 – 2030
Source: FAIR 2.6 and IMAGE 2.3 models

5.1.2 Population projections

The UN 2004 World Population Prospects data was used to create the population projection. The regional projection was downscaled by using the relative sizes of the countries within the region and assuming equal growth rates for countries in the region. **Figure 13** shows the assumed growth rate for South Africa. The sudden

change from 2000 to 2005 is caused from aligning data from two different sources. The growth rate for the population is 2% per decade, or 0.2% per year.

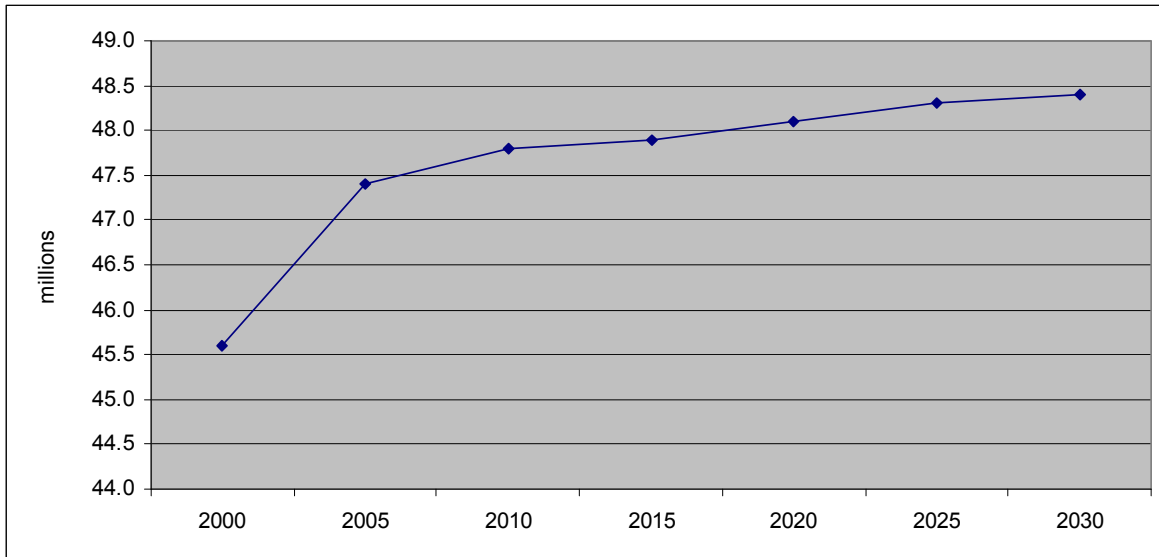


Figure 13 – Projection for population growth for 2000 – 2030
Source: FAIR 2.6 and IMAGE 2.3 models

5.2 FAIR Sectoral Baseline Results

The baseline emissions projections from FAIR are shown in **Figure 14**. The dominance of the Power and Electricity sector can be seen as well as the minor contribution of Waste emissions to the total. Baseline emissions from all sectors are seen to grow over the period. The following sections look at the growth rates for each of the sectors and elaborate on assumptions used to project them.

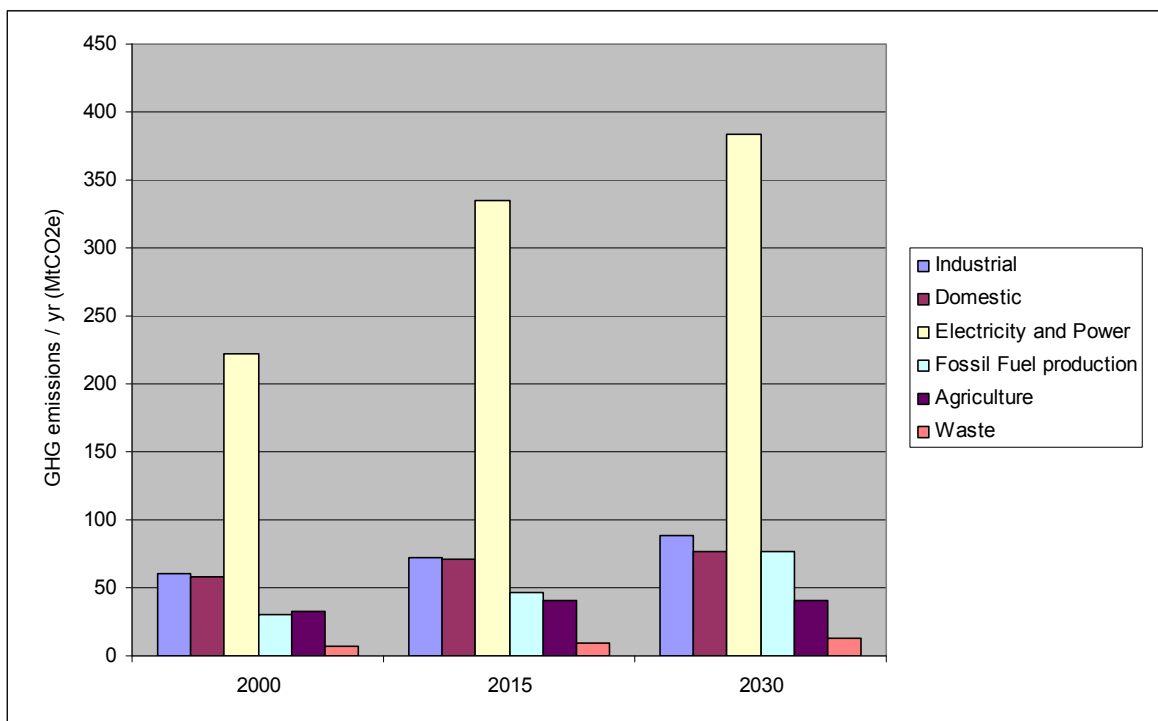


Figure 14 – GHG Baseline emissions per sector

5.2.1 Industrial Sector

The Industrial sectors calculations are one of the most data intensive as it draws on process efficiencies within the sector. The data from the sub-sectors listed in **Table 14** were used to represent the industrial sector for South Africa.

	Year	Energy intensity (GJ/t)	EEI	Production (t)
Iron and Steel	2000	44.4	2.9	8.5
Pulp and Paper	1999	74.8	3.0	2.0
Cement	2003	4.6	1.2	9.0
Petroleum Refinery	2000	8.0	2.2	25.5

Table 14 – Updated industrial energy efficiency statistics
Source: Kuramochi, 2006

According to the statistics collated in the study by Kuramochi (2006), South Africa's industrial sector has an aggregate EEI of 2.5. This EEI level will require considerable reductions, as the strong scenario calls for reductions to achieve an industrial EEI of 1.0 by 2030.

The output from the FAIR model in **Figure 14** shows baseline industrial sector emissions for the 2000, 2015 and 2030. Average growth is consistent, at a rate of 1.3% per year.

5.2.2 Domestic Sector

The growth in the domestic sectors emissions has a low growth rate of 0.9% per year in the Triptych version of the baseline. This would once again be due to the population growth and GDP projections used. The emissions for Triptych's domestic sector are a combination of emissions from energy-use in the transport, commercial, agriculture and residential sub-sectors.

5.2.3 Power and Electricity Sector

The emissions profile from the electricity sector includes public and private generation and also other transformation sectors such as refineries and coke ovens. The dominance of the power and electricity sector can be seen in **Figure 14**. Electricity growth is on average 1.8% per year from 2000 to 2030, slowing in the second half of the period.

5.2.4 Fossil fuel production

Fossil fuel production emissions growth is on average 3.1% per year from 2000 to 2030. Coal-bed methane accounts for almost all the emissions from this sector. Fossil fuel production volumes are dependent on demand for fuel and will grow with the increase in demand from economic and population growth. The model does not take into account the share of fossil fuel production associated to exports.

5.2.5 Agriculture

Emissions in this sector are related to non-energy emissions in the agriculture sector. This includes biomass burning, fuel wood burning, enteric fermentation and savannah burning. For South Africa, the main GHG for this sector are CH₄ and N₂O. The baseline emissions projection for this sector can be seen in **Figure 14**. Growth for this sector in the FAIR model is based on linear downscaling of the regional growth trends (den Elzen 2007).

5.2.6 Waste

Emissions in this sector increase by an average of 2% per year over the period 2000 – 2030. As for agriculture, emission growth is based on the historical growth trends for the region. Emissions from this sector are non-energy and comprise of GHGs from landfills, wastewater and waste incineration.

5.2.7 FAIR Composite Baseline

Combining all the different sectoral baselines gives the total baseline for the period 2000-2030. This is shown in **Figure 15**, where total emissions increase from about 410MtCO₂e in 2000 to approximately 693MtCO₂e in 2030. This is an average increase of around 1.7% per annum. The sector with the largest emissions is from the power and electricity sector, accounting for 56% of total emissions in 2030. The Long Term Mitigation Scenarios study (LTMS, 2007) baseline reaches a level of about 1000MtCO₂e in 2030, and an earlier study on Energy Policies for Sustainable Development (Winkler, H (Ed.) 2006) projects GHG baseline emissions of 600MtCO₂e by 2025, whereas the FAIR baseline projects emissions for SA to be 660MtCO₂e in 2025, a 10% variance.

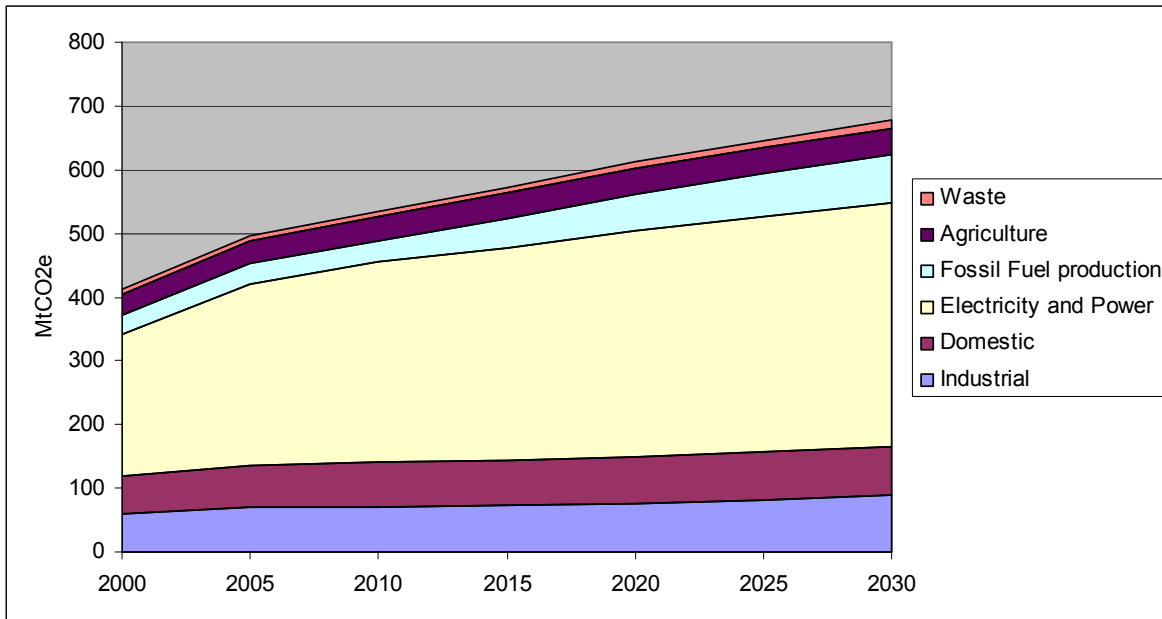


Figure 15 - FAIR baseline GHG emissions 2000-2030

5.3 Targets for South Africa under the FAIR model

The FAIR 2.6 tool was used to derive targets for South Africa under the Triptych 7.0 Approach. The aforementioned targets for the Strong and Medium scenarios were used as input parameters. The first set of targets required for the Strong case are for 2030, and the second set 2050. The Medium case requires implementation of the first set of targets by 2050. In the FAIR model, South Africa is afforded a five year delay in achieving its reduction targets due to its developing country status. This implies that its first target should be reached by 2035 in the Strong case and 2055 in the Medium case. **Figure 16** shows the FAIR baseline emissions and the Strong and Medium scenario emissions for South Africa. GHG emission reductions relative to the baseline can be seen to begin in 2015.

Under the Medium case emissions need to be reduced to 373MtCO₂e per year in 2030 from a baseline emissions level of 693MtCO₂e. In the strong case, it would need to be reduced to a level of 258MtCO₂e per year in 2030

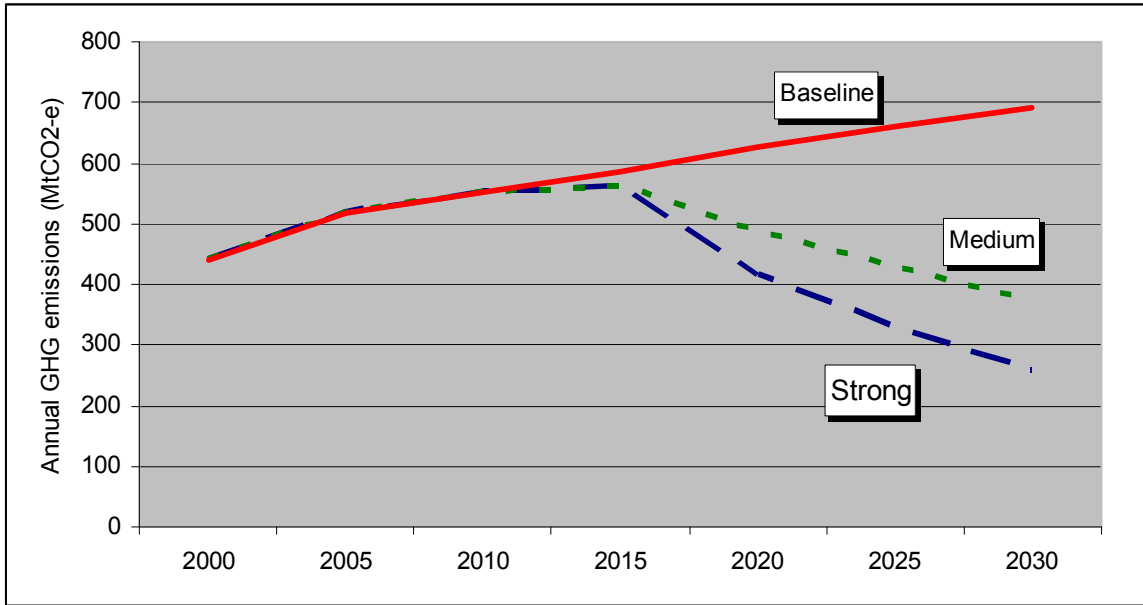


Figure 16 - South African Triptych emissions scenarios

5.3.1 Triptych 7.0 Medium Case FAIR model results

The Medium Case reaches a GHG stabilisation level similar to the 550ppm CO₂e level under the IPCC SRES B2 scenario. The initial targets are set for the year 2050, and the next set of target parameters are set for 2100.

The Medium case requires a reduction to 373MtCO₂e in 2030, down from a baseline emissions level of 693MtCO₂e, a decrease of 46%.

Figure 17 shows the sectoral break-down of the baseline profile of South Africa according to the Triptych sectors. Within each of the sectoral wedges the emission reductions targets can be seen as the wedges that begin after 2010 and have lighter patterned areas. The main reductions can be seen to originate from the power and electricity, fossil fuel production and industrial sectors. The domestic sector shows a relatively modest reduction target.

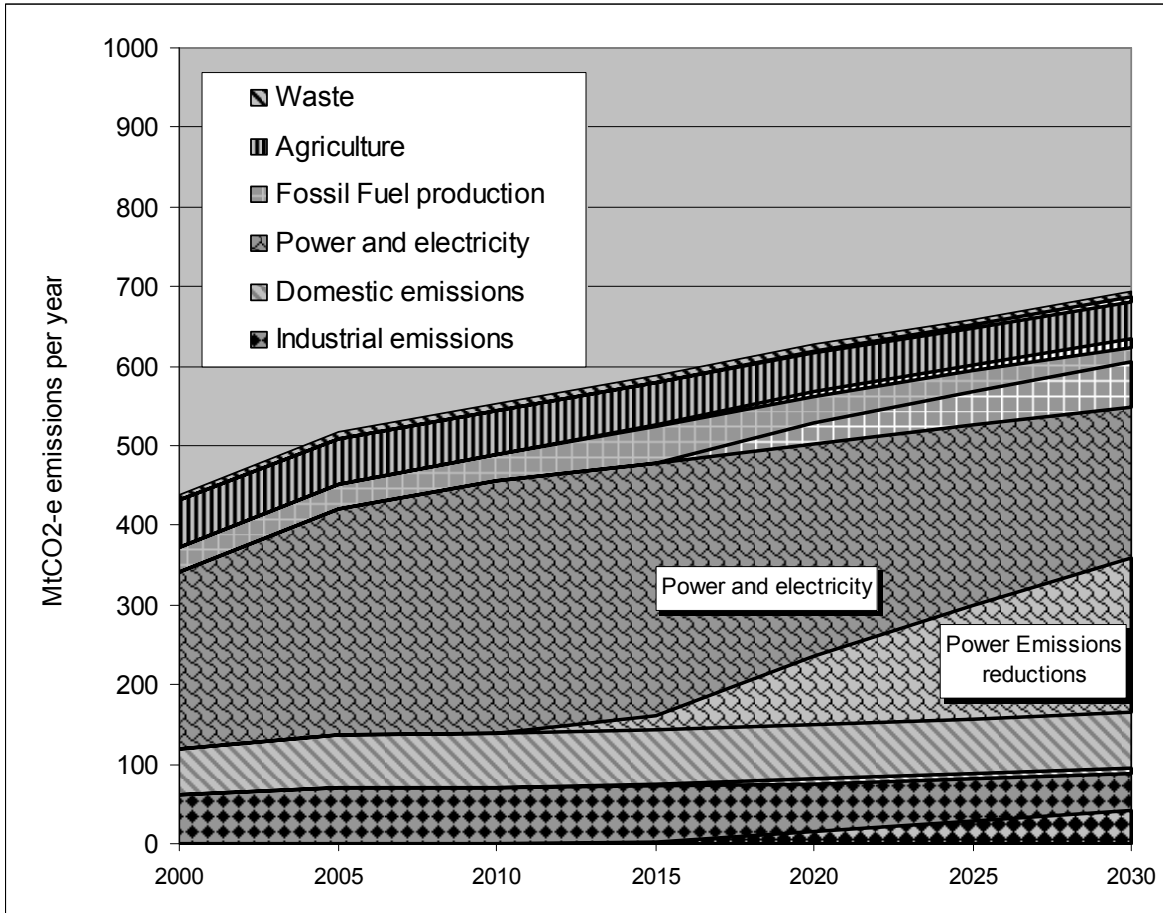


Figure 17 –Triptych 550ppm Medium case showing targeted reductions from each sector

5.3.2 Comparison of baseline emissions with targeted emissions reductions

Figure 18 shows the breakdown per sector for South Africa's baseline emissions in 2030. The power and electricity sector is seen to be the largest sector, accounting for over 50% of total GHG emissions. The emissions from the industrial, domestic, fossil fuel production and agriculture are similar in scale, and waste contributes a small percentage of South Africa's emissions.

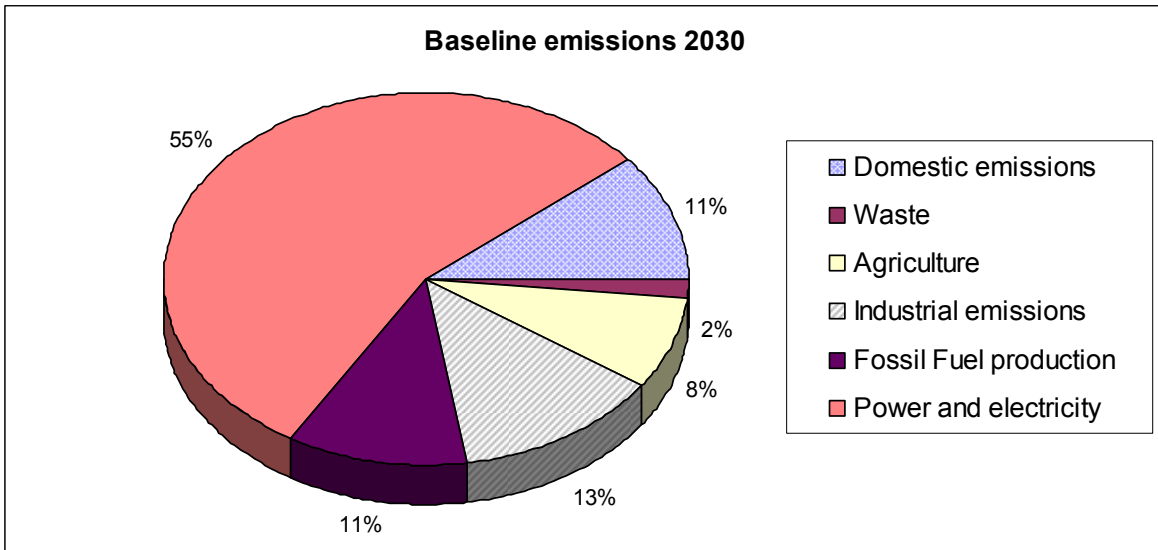


Figure 18 – Proportions of sectors accounting for baseline emissions in 2030

The percentages of the total reductions for each sector are shown in **Figure 19**. From this graph, the power and electricity and fossil fuel production sectors are seen to be burdened with proportionately heavier reduction targets than their contributions to total emissions. Conversely, the domestic and agriculture sectors have lower emission targets relative to their share of contributions to emissions.

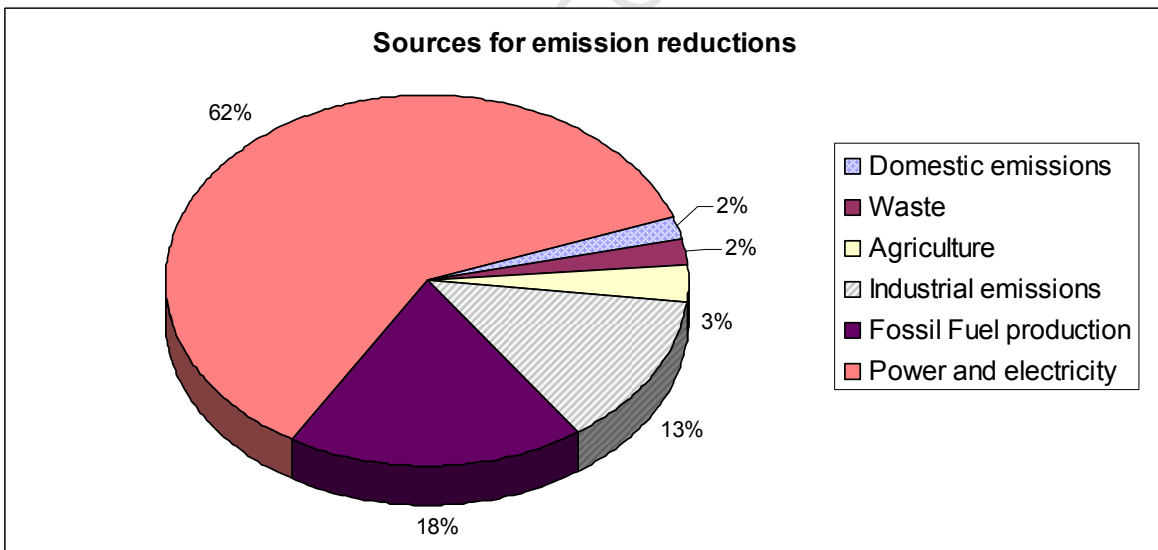


Figure 19 – Percentage of total emission reductions per sector in 2030

5.3.3 Triptych 7.0 Strong Case FAIR model results

The Strong case requires a significantly higher level of reductions from the Medium case. These reductions must therefore begin to be achieved sooner than for the Medium case. An emission reduction of 62.8% from baseline emissions levels is required under this case, reducing baseline levels of 693MtCO₂e in 2030 to 258MtCO₂e. The magnitude of targets can be seen in **Figure 20** which shows baseline emissions and wedges within the baseline areas illustrating the reductions.

The emission reductions required of the power and electricity sector are labelled in the lighter shaded area. The other sectors are represented in the same way. The main reductions can be seen to be from the power and electricity sector, with significant reductions in the fossil fuel production and industrial sectors.

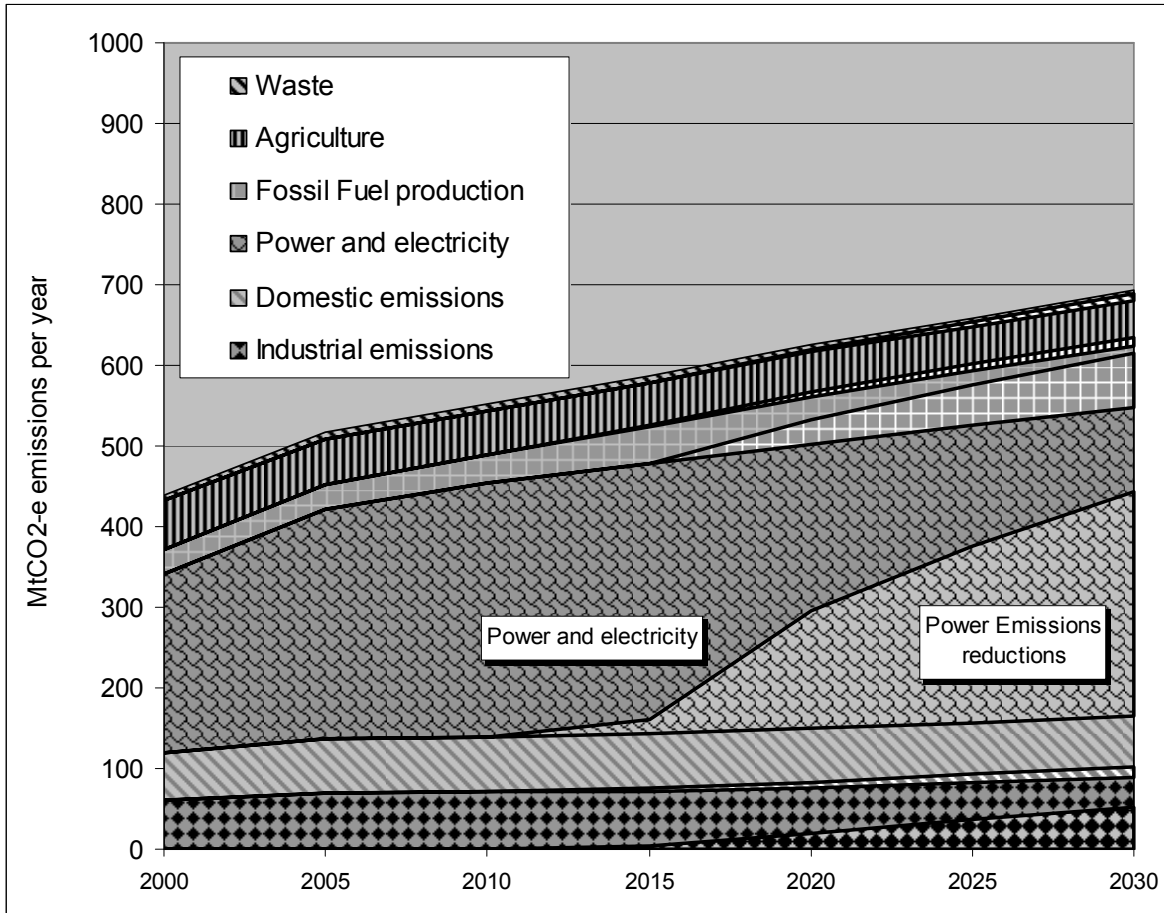


Figure 20 – Triptych 450ppm Strong case showing targeted reductions from each sector

The breakdown of emissions reductions per sector do not differ significantly from those in the Medium case, shown in **Figure 19**, with regards to the proportions of emissions burdens per sector.

5.3.4 Comparison of Triptych Strong and Medium Case FAIR model results

The Strong case calls for higher reductions than the Medium case through setting more stringent targets that are to be met by an earlier time. **Figure 21** compares the levels of emissions under the Strong and Medium cases. The Strong case targets are very stringent, and by 2030, the lower emissions resulting from these can be seen in the graph. The targets for the domestic and agricultural sectors of South Africa are modest compared to the other sectors.

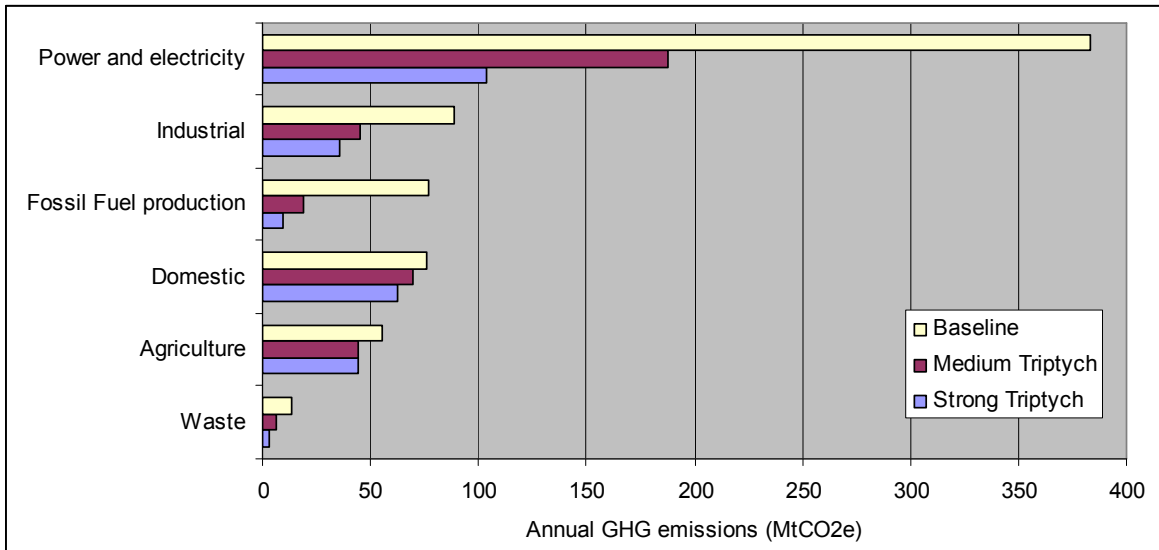


Figure 21 – Comparison of South African 2030 GHG emissions: Baseline, Triptych Medium and Strong scenarios.

5.3.5 Comparison of regions under the Strong Triptych Approach

The emission reduction patterns are compared to those of the rest of the world and other non-Annex I countries.

The overall reduction targets for South Africa and world regions can be seen in **Table 15**. This shows the BAU baseline emissions using the IMAGE 2.2 version of the IPCC SRES B2 scenario, and the emission targets for the year 2030 under the Strong Triptych case. Global emission reductions would need to be approximately half their BAU totals. Overall, the non-Annex I countries have lower emission reductions targets than the world average, requiring a reduction of 42% from BAU levels. Annex I countries on average have to reduce emissions by 64% from BAU levels. South Africa has a very high target for a developing country, of 62.8%. This is more comparable to targets for Annex I countries.

Region	Baseline (GtCO ₂ e)	Strong Triptych (GtCO ₂ e)	Reduction
non-Annex I	38.223	22.361	42.1%
Annex I	22.540	8.102	64.1%
South Africa	0.693	0.258	62.8%
World	60.493	30.463	49.6%

Table 15 - Comparison of Triptych reductions for 2030

Figure 22 shows the share of sectoral contributions to the targets for the world, Annex I and non-Annex I countries, and South Africa. South Africa's reduction target is composed mainly of reductions in the power and electricity sector (over 60% of the reduction). The portion of reductions for industrial emissions is similar to the rest of the world. Although the scale of reductions required from SA is similar in scale to that of Annex I countries, the composition of the sectoral breakdown resemble other non-Annex I countries more strongly. As a country that's energy system is strongly based on coal power, the reductions penalise South Africa more strongly than countries with cleaner energy systems. This shows how important a

technology such as CCS will be for South Africa as it endeavours to reduce emissions.

In comparison to South African emissions, the World domestic sector has a larger share of total emissions, and fossil fuel production accounts for a smaller portion of total emissions. This is indicative of the South African energy system that has a large fossil fuel production component, but does not have high per capita energy expenditure.

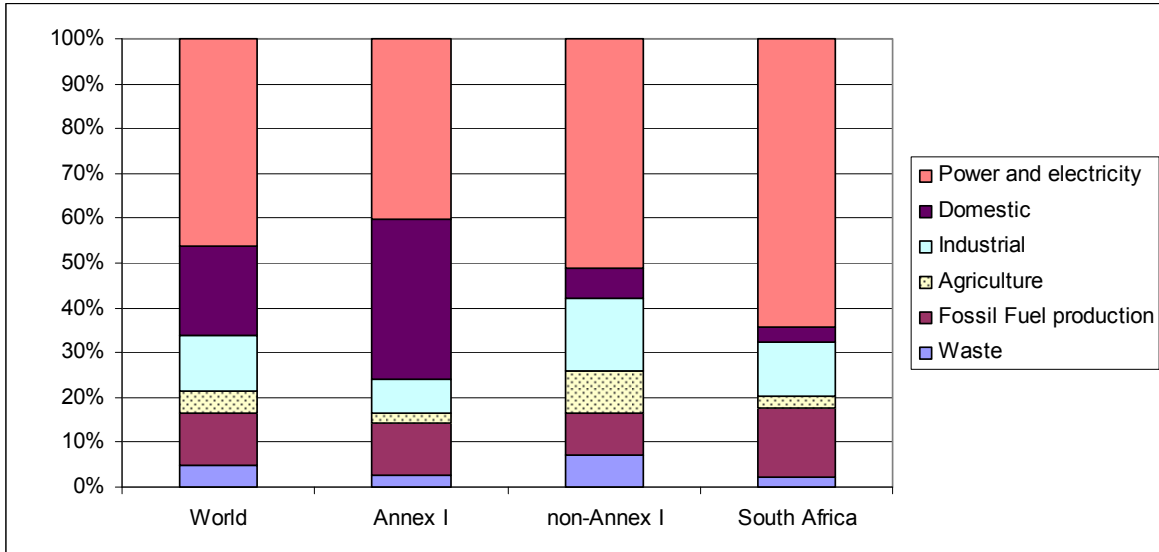


Figure 22 - Breakdown of emissions reductions per sector for 2030

6 A National Energy Model of South Africa

South Africa's National energy model is going to be used to analyse the results from FAIR 2.6. The description of the model will therefore be done with the intention of drawing out similarities between the national model and the FAIR 2.6 model. The simplified structure of the reference energy system can be seen in **Figure 23**. This figure shows the flows of the fuels from appropriation through conversion to electricity and processed fuels onto end-use demand.

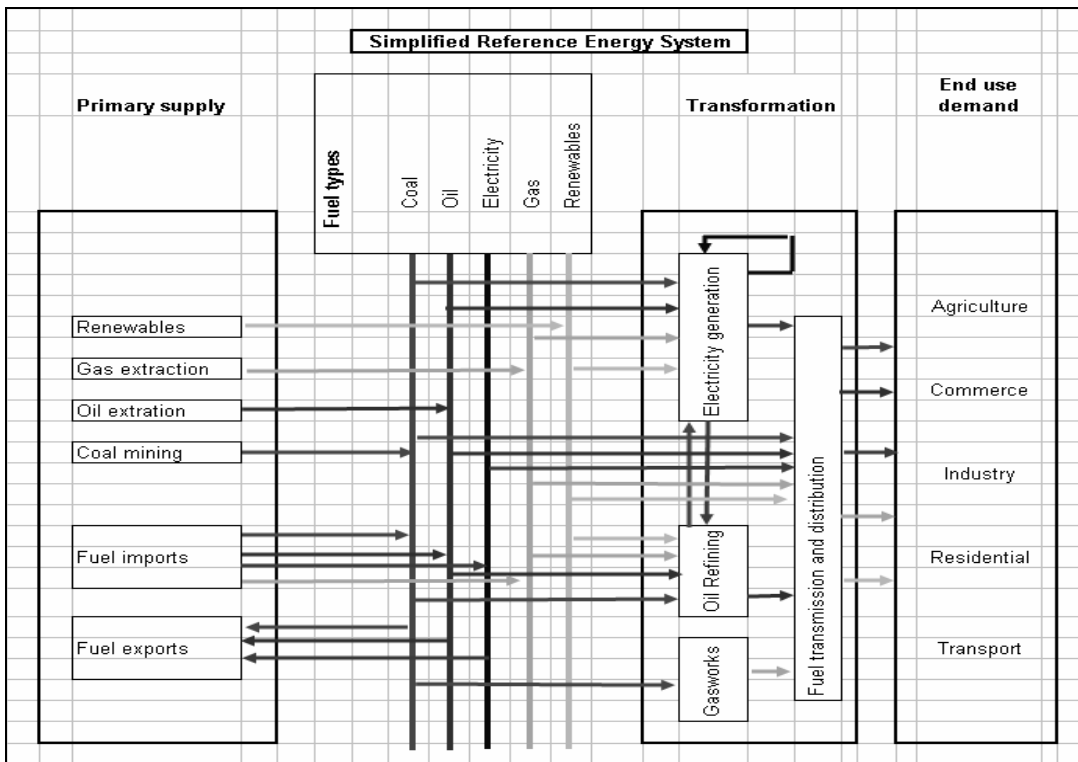


Figure 23 - Simplified Reference Energy System

Source: Energy policies for sustainable development in South Africa (Winkler et al. 2006)

An illustrative view of the South African energy system can be seen in **Figure 24**. Apart from the conversion of fuels, the thickness of the shaded areas illustrates the proportionate scale of the energy content per particular fuel type. It is interesting to note that a large proportion of SA's coal is exported, and the GHG emitted in other countries.

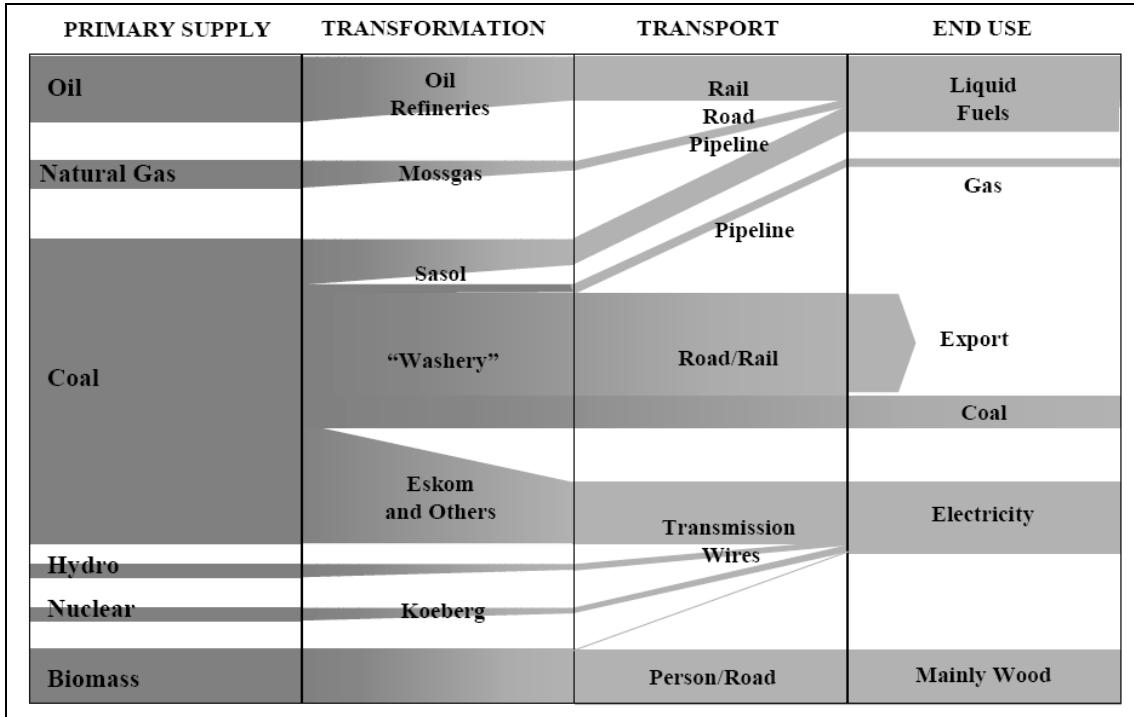


Figure 24- SA energy mix

Source: Integrated energy plan for the Republic of South Africa, DME 2003

The demand for energy is the determinant for the amount of energy production. The MARKAL model solves the projected energy system for meeting projected energy demands using a least-cost methodology. The growth in demand in the model is determined primarily by two major drivers: population growth and GDP growth.

6.1 The MARKAL Model

Research at the ERC has led to the development of a model of South Africa's energy system using the Market Allocation (MARKAL) modelling tool. MARKAL is a robust modelling tool used to explore the possibilities for future energy balances. The energy balances are derived using a least-cost optimisation architecture, based on user-defined parameters for future demand assumptions and energy costs. According to the data for growth in demand of particular fuels and services, and key drivers, such as GDP, population and exchange rates, the model is able to optimise the complete energy system. This optimisation is based on costs for energy technology, such as infrastructural capital, operating and fuel costs. These bottom-up approaches, where the energy demands are met according to a variety of supply options, allow the modellers to investigate a range of options in meeting growth projections.

This model accounts for each stage in the delivery of energy services, from sourcing of raw fuels, to processing of fuels, to conversion to energy, to delivery of the energy service. An example of the interconnections made in modelling an energy service is "passenger kilometres" in the transport sector. The source of energy for generating passenger kilometres is liquid fuel at a certain conversion rate depending on the efficiency of the vehicle. This fuel which would cost a certain price depending on the price of oil estimated and the exchange rates could be obtained from refining

imported crude oil, or having been converted using coal to liquids technology. Thus for a certain amount of passenger kilometres, that is driven by growth in population and GDP, the effects are calculated at all levels of the model. The MARKAL model is therefore a completely “vertically integrated” energy model.

This model has been developed and used in numerous projects for government agencies, using a range of assumptions, based on the latest knowledge and global trends. Recent work using the MARKAL South African energy model includes formulating long-term mitigation scenarios and assessing energy policies for sustainable development.

6.2 MARKAL Major Drivers

6.2.1 Population growth

South Africa has a one of the highest rates of HIV infection in the world. Due to the fact that there is no known cure for the disease, population figures need to take account of the increased mortality rate brought about by the virus. The MARKAL model makes use of the Actuarial Society of South Africa’s population projections (ASSA 2003) which takes into account the prevalence of HIV. The population grows from 45.5 million in 2000 to 51.9 million in 2030. Earlier studies project a higher population figure of 57 million in 2025 (Haw 2007).

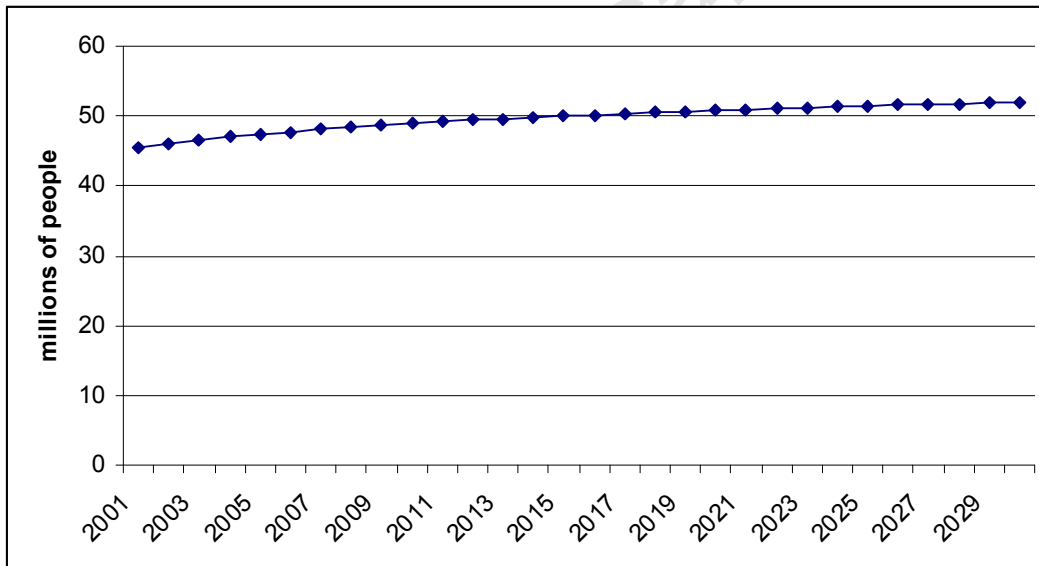


Figure 25 - Population projection
Source: ASSA 2003

6.2.2 GDP growth rate

The GDP growth rate used in MARKAL assumes a high rate of economic growth. The projection assumes that South Africa is currently going through an accelerated growth phase after which economic growth will slow down. GDP growth projections can be a sensitive topic as government targeted GDP growth that is reported can carry political motives. The GDP growth rate used is from Vessia 2006, in which growth peaks at 5.24% after 2015, following which it slows to a level of about 2%.

The growth rate is on average 5.1% over the period. This is higher than that used in the Integrated Energy Plan (DME, 2003) that averages 2.8% from 2001 to 2020. The Vessia 2006 growth rate is closer to the government targeted growth rates of between 4.5% and 6% under the Accelerated and Shared Growth Initiative for South Africa (AsgiSA 2008).

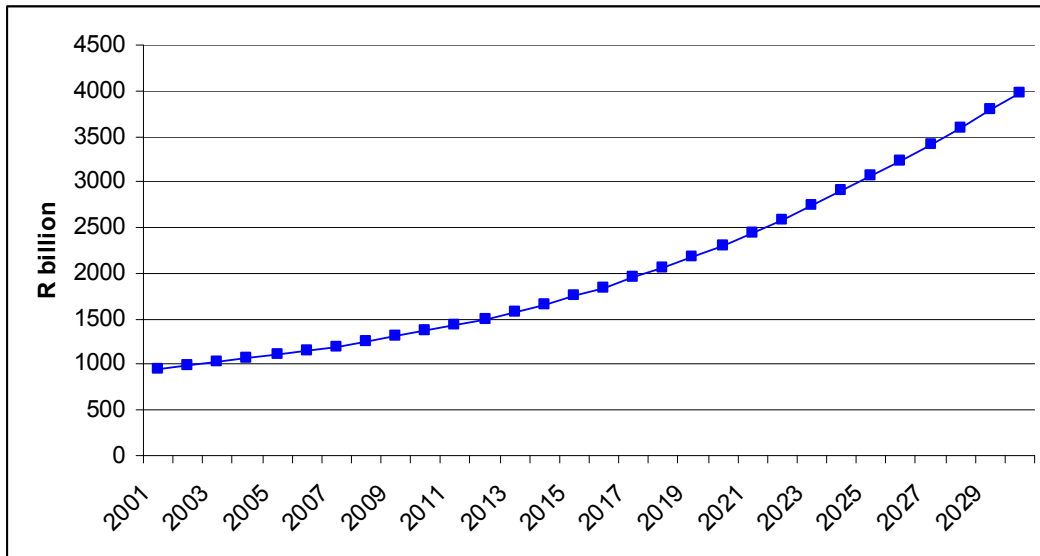


Figure 26 – GDP projections
Source: Vessia 2006

6.2.3 Future Energy Prices

The projected future fuel prices are another of the major drivers as this would determine the costs for the different energy solutions. The costs for the MARKAL model used included the following cost assumptions:

- Crude oil prices: 2001 \$55 per barrel; 2010 \$100 per barrel; 2030; \$150 per barrel. Dramatic increases in oil prices in 2008 have seen crude oil set to reach \$150 within the year. These sudden changes are not accounted for in the models used in this project.
- Liquid fuels: price based on crude oil prices as above
- Coal prices: R56 per ton in 2001 to R118 per ton in 2030.
- Uranium prices increase at half the rate of coal prices from R2.50 per GJ in 2001. (Winkler et al 2008).

The next section will look at the comparability of the sectors and will apply the Triptych rules to the South African model where appropriate for comparative purposes.

6.3 Comparison of FAIR and MARKAL Major drivers

The population and GDP assumptions used in the model greatly affect the growth projections for energy and development, and consequentially the GHG emissions from these activities. This section compares the sets of assumptions used for the FAIR and MARKAL models.

6.3.1 Population

The FAIR and MARKAL population projections differ from one another. The national population projection has been given more attention in its derivation than the FAIR projection. The FAIR projection is a downscaled version of a regional projection. The MARKAL version has a higher population growth rate of 4.5% as opposed to FAIR's 2.0% per decade. This will affect the growth projections for the sectors in FAIR as they are based on population sizes.

	MARKAL	FAIR	Difference
	(million)	(million)	(% MARKAL)
2000	45.5	45.6	-0.24%
2005	47.7	47.4	0.66%
2010	49.1	47.8	2.73%
2015	50.2	47.9	4.51%
2020	51.0	48.1	5.62%
2025	51.6	48.3	6.34%
2030	51.9	48.4	6.81%

Table 16 - Comparison of MARKAL and FAIR population projections

6.3.2 GDP projections

There is a larger difference in GDP projections than for population projections. The magnitude of variation can be seen in **Table 17** that shows both MARKAL and FAIR projections. The exchange rate estimate is taken from Haw and Hughes 2007, that uses an exchange rate of R7.50 in 2003 as the base rate and increases the R / \$ exchange rate by 2% a year. The year 2000 exchange rate value is thus derived from this.

	MARKAL GDP	FAIR GDP (MER)	Exchange estimate	FAIR	Difference
	(R billion)	(\$ billion)	(R / dollar)	(R billion)	(% MARKAL)
2000	948.7	271.9	7.07	1922.1	-102.6%
2005	1146.6	308.4	7.80	2405.4	-109.8%
2010	1428.9	318.4	8.62	2744.4	-92.1%
2015	1844.3	329.2	9.51	3130.8	-69.8%
2020	2443.6	346.0	10.50	3633.1	-48.7%
2025	3237.7	367.1	11.59	4254.3	-31.4%
2030	4178.9	393.9	12.80	5041.3	-20.6%

Table 17 - Comparison of MARKAL and FAIR GDP projections for South Africa

The growth rate of the MARKAL GDP projection is 3% per year over the period. After taking consideration of the estimated exchange rate, the FAIR GDP average growth rate is 3.26% over the period which is higher than that of the national model. However the Triptych calculations do not make use of the Rand value, and the GDP growth rate in US \$ terms is 1.25%. The GDP_{PPP} has an average annual growth rate of 1.2% over the period. This rate is used for calculating growth in a number of the sectors. Converting the MARKAL projected GDP at a growth rate of 5.1% from

Rands to US dollars yields a growth rate of 3%, which is used by MARKAL to calculate growth in demand and emissions.

The MARKAL GDP figures for 2000 and 2005 are more reliable than the FAIR figures. The growth rates used to project the MARKAL GDP are based on South African growth targets set by the government. The FAIR projections are based both on historical data and downscaled regional projections, but not on country-level targeted growth levels. Noting the massive changes in the global economy in 2008, both sets of projections may need revision.

Considering the differences in both the GDP and population projections, FAIR will have lower sectoral growth projections where the projections are based on population or economic growth. Differences between the MARKAL and FAIR model projections are to be most accentuated in sectors that use growth rates of both population and GDP to derive emissions projections.

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7 Using FAIR results on SA National Energy Model

South Africa's target under the Strong and Medium cases in the Triptych Approach calls for large reductions which as a developing country would require considerable effort and resources. This section will investigate the results of applying the Triptych Approach results from the FAIR model to South Africa's national.

This section compares the data from the FAIR implementation of Triptych and associated sectors with similar sectoral groupings from MARKAL for 2000 - 2030.

7.1 MARKAL Baseline:

The sectors in the MARKAL model are based on energy sectors, whereas the FAIR sectors include non-energy emissions and are an expansion from the three sectors used in the original Triptych proposal. The composite baseline graph in **Figure 27** shows baseline emissions increase from 420MtCO₂e in 2003 to about 970MtCO₂e in 2030.

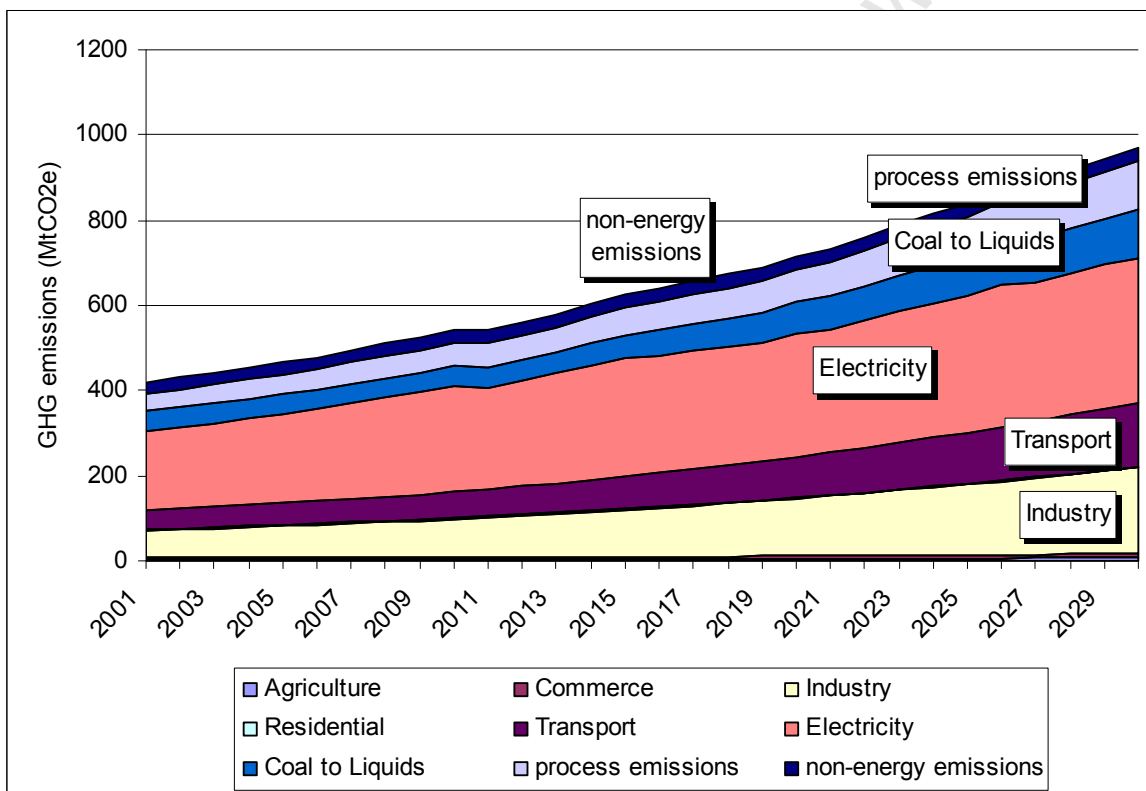


Figure 27 - MARKAL baseline emissions from the energy system

The emissions profile from MARKAL begins at a similar level to the FAIR model in 2001. However growth in the MARKAL model is higher with emissions reaching a higher level by 2030. This can be attributed to the differences to growth projections for both the population and GDP as described in Section 6.3. The projections are higher for both of these major drivers.

To compare the two models effectively, several MARKAL sub-sectors will be combined to be compared with the FAIR sectoral groupings. For example, the

agriculture and commerce sectors in MARKAL relate to energy-emissions and should therefore be included with the residential and transport sub-sectors to make the equivalent “domestic” sector.

7.2 FAIR and MARKAL baseline projections

7.2.1 Total GHG emissions

The MARKAL model shows growth from 420MtCO₂e per year in 2001 to 960MtCO₂e in 2030. This is an average annual growth rate of 2.9% which is a direct result of the GDP assumptions made. The FAIR models emissions increase from 410MtCO₂e in 2000 to 693MtCO₂e in 2030, an average increase of 1.7% per year. This is significantly lower and is also a result of the population and GDP growth assumptions made.

Figure 28 shows that although the emissions in 2000 are lower, growth in the MARKAL projection is higher and exceeds the FAIR projection in 2015. By 2030, the MARKAL projection is 28% higher than the FAIR projection by 2030. This is due to the higher growth projections from the South African national model.

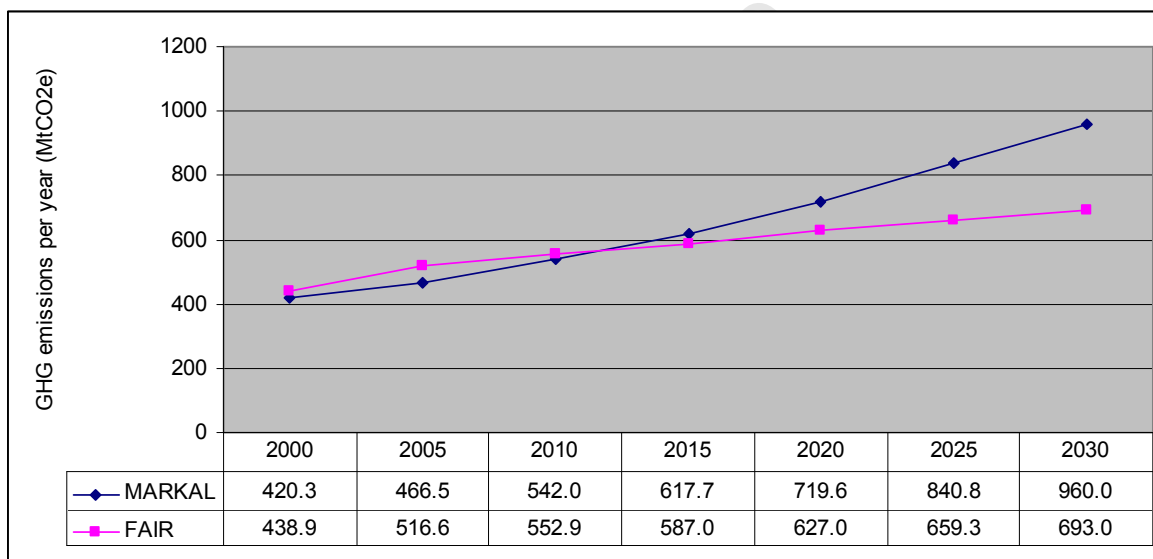


Figure 28 - FAIR and MARKAL GHG baseline projections

7.2.2 Industrial Sector comparison

The MARKAL model has a much higher growth rate for industrial sector emissions than the FAIR model. This can be seen in **Figure 29**, with the MARKAL emissions increasing on average 3.9% and the FAIR emissions from the sector at about 1.3% per year.

Using the GHG emissions growth per year of the MARKAL model, the Triptych target would require a higher level of emissions reductions. Using an EEI of 2.5 as the baseline EEI and having the target of 1.0 in 2030 would require a 60% decrease in emissions. The Triptych target for the MARKAL emissions profile would therefore require a reduction of 121MtCO₂e from the base case, in 2030.

The FAIR version would require a reduction of 53MtCO₂e in the same year with the level of projected emissions.

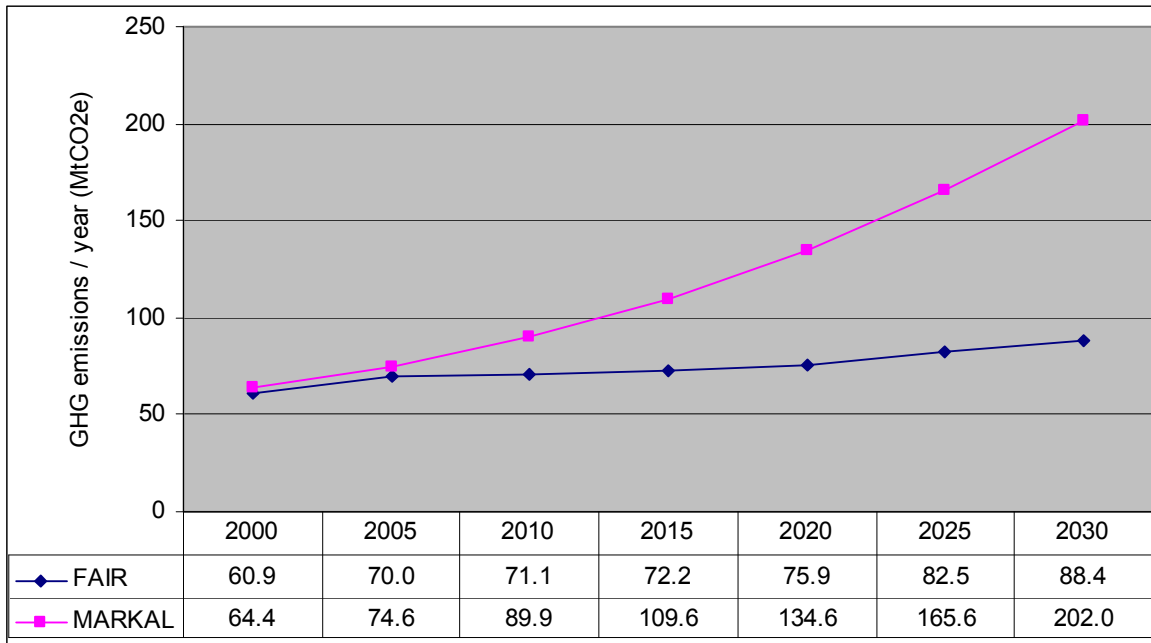


Figure 29 – Base case MARKAL and FAIR Industrial sector emissions

7.2.3 Power and Electricity Sector comparison

The electricity and power sector from FAIR and MARKAL follow similar growth trends. The growth rate for the FAIR version is 1.9% per year and the growth for the MARKAL version is 2.0% per year.

The reduction in the electricity and power sector relies on reductions in shares of coal and oil, reduced electricity demand, and increased efficiency. The Triptych reduction as calculated in the FAIR model can be scaled to approximate the reduction for the MARKAL data. Following that the FAIR model implemented a 73% reduction in the FAIR baseline emissions, the same reduction percentage is applied to the MARKAL data. This results in a reduction of 242MtCO₂e and the target level of emissions of 89.5MtCO₂e.

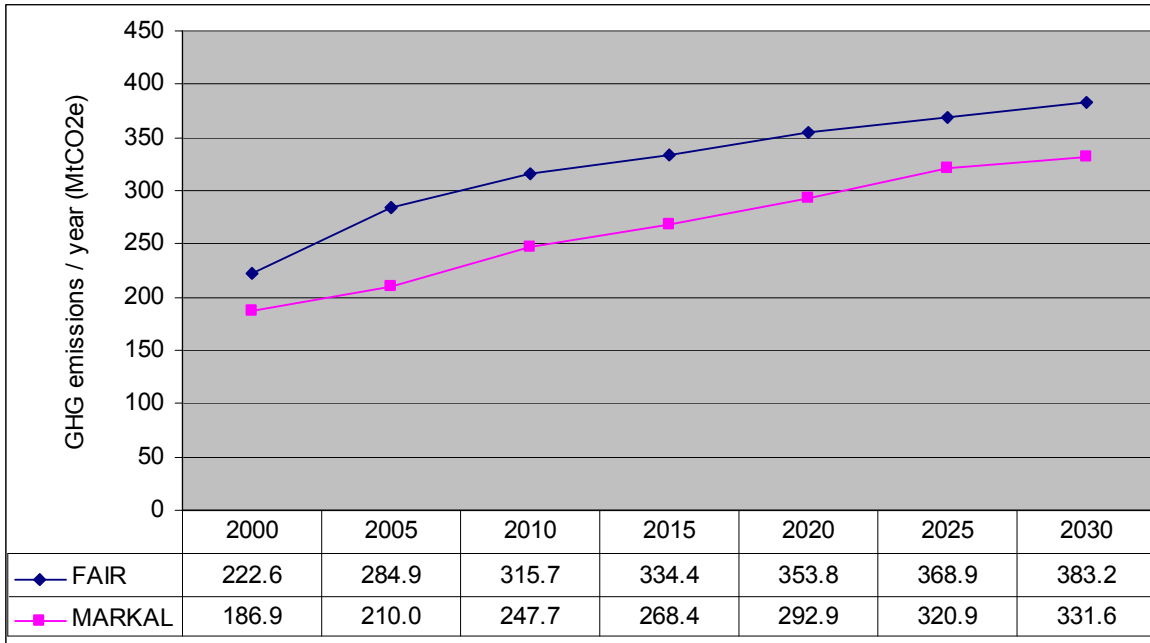


Figure 30 – Baseline projections for the power and electricity sectors

7.2.4 Domestic Sector comparison

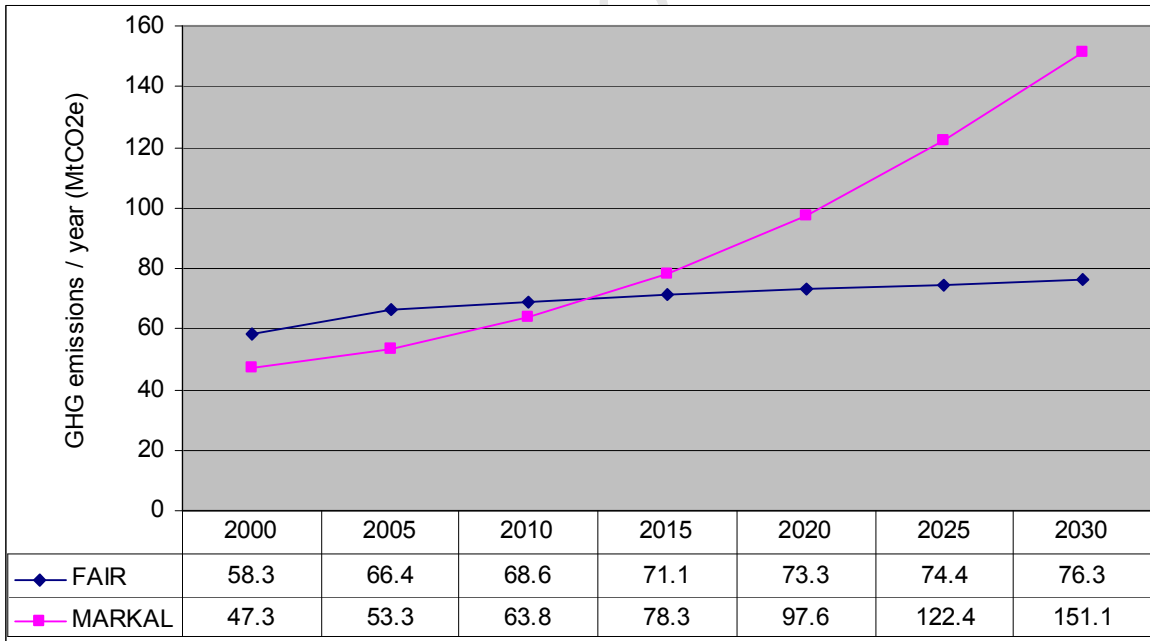


Figure 31 – GHG emissions for the domestic sectors for 2000-2030

The domestic sector is a combination of residential and transport emissions, and includes energy emissions from the agriculture and commercial sectors. The domestic sector baselines differ significantly, with the FAIR baseline following the low growth of its population projection. The MARKAL projection has a higher average growth rate of 4.1%.

Under the Triptych approach, the target for the domestic sector is a per capita target of 1.25tCO₂e per capita per year. In 2030, the MARKAL domestic GHG emissions are 151.1MtCO₂e (**Figure 31**) for a population of 51.9 million, a 2.9MtCO₂e per capita emission per year. The Triptych target of 1.25MtCO₂e in 2030 would therefore require the sectoral emissions to decrease by 86.2MtCO₂e to 64.9MtCO₂e, a 57% decrease. The Triptych target is the same for both the FAIR and MARKAL projections, but the reduction required is higher for the higher MARKAL baseline.

7.2.5 Fossil Fuel production Sector comparison

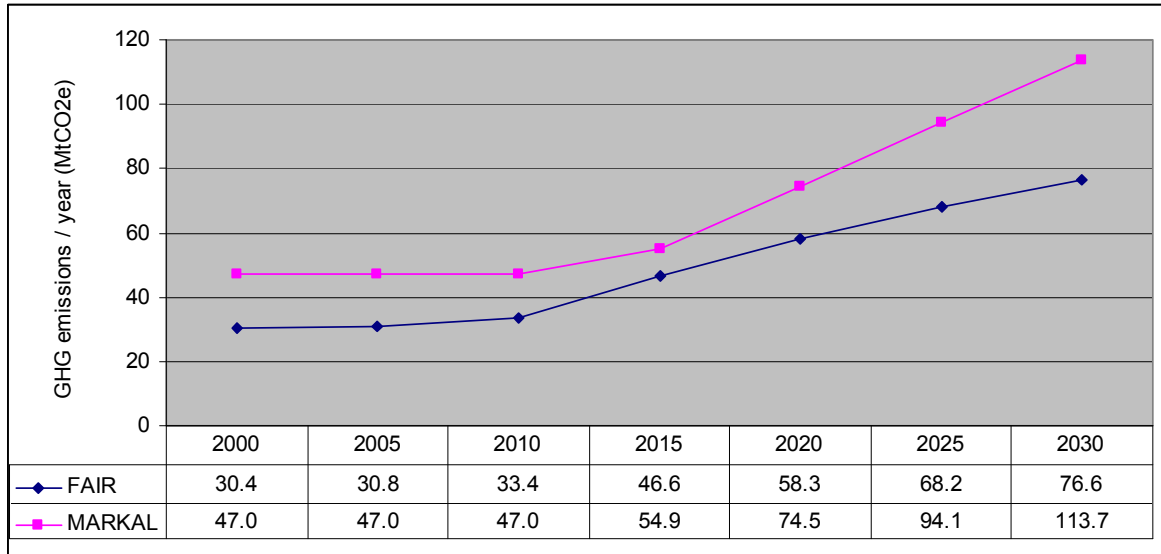


Figure 32 – GHG emissions projections for fossil fuel production sector

Fossil fuel production projections show similar growth rates for FAIR and MARKAL, though the FAIR emission projections is about 33% less than the MARKAL projection in 2030.

The Triptych approach calculates a targeted reduction of emissions of 90% from the baseline emissions. The target also takes into consideration the reduced demand from the other sectors that make use of fossil fuels. The FAIR implementation calculates an 88% percent decrease by 2030 and 97% by 2035. Applying an 88% decrease to the MARKAL baseline yields, a targeted level of emissions of 14MtCO₂e, a reduction of 99MtCO₂e.

7.2.6 Agriculture and Waste Sector comparison

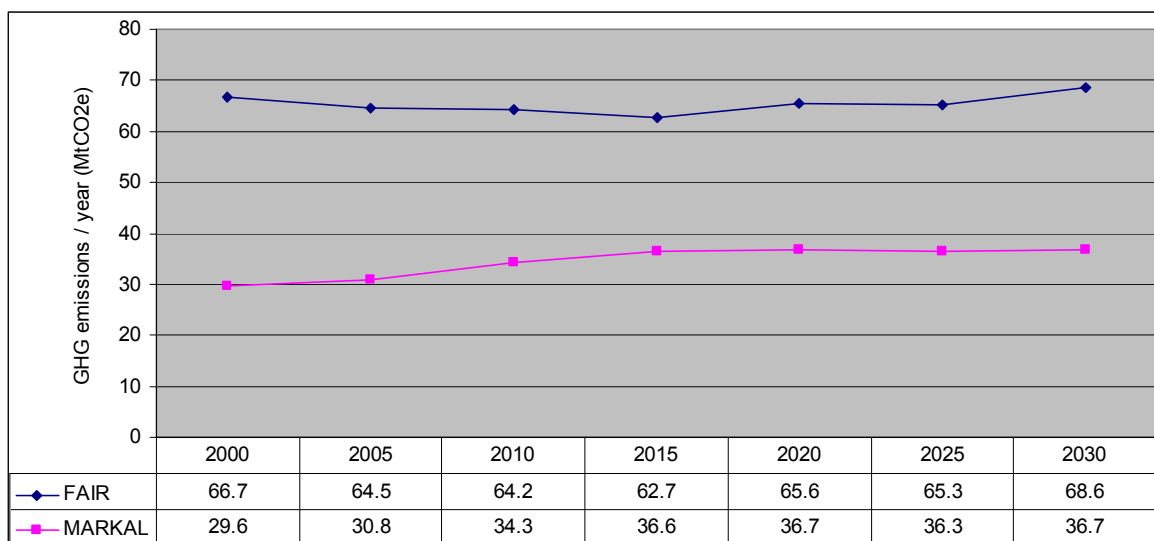


Figure 33 – GHG emissions projections for Agricultural and Waste non-energy emissions

The MARKAL projection is lower than the FAIR projections.

The FAIR model waste and agricultural sectors have a combined targeted reduction of 69.5%. Applying the same reduction to the MARKAL projection yields a targeted level of 9.5MtCO₂e, which would be a 21.7MtCO₂e reduction.

7.3 Triptych targets for MARKAL projections

Using the comparative magnitudes of the FAIR and MARKAL baselines, a series of Triptych targets are derived for the MARKAL data. These can be seen in **Table 18** that shows both the FAIR baseline and targets for the Strong and Medium cases, and then the baseline and targets for MARKAL. Detailed calculations can be seen in Appendix B.

	FAIR			MARKAL		
	Baseline	Triptych Strong	Triptych Medium	Baseline	Triptych Strong	Triptych Medium
Triptych Sector	MtCO ₂ e	MtCO ₂ e	MtCO ₂ e	MtCO ₂ e	MtCO ₂ e	MtCO ₂ e
Industrial	88.4	35.6	45.5	202.0	81.3	103.9
Domestic	76.3	62.3	70.0	151.1	66.9	75.2
Power and Electricity	383.2	103.4	188.1	331.6	89.5	162.8
Fossil Fuel Production	76.6	9.2	18.7	113.7	13.6	27.7
Agriculture	55.4	41.4	49.9	19.5	14.6	17.6
Waste	13.2	3.3	6.2	17.1	4.3	8.1
Total	693.0	258.1	372.9	835.1	271.2	393.4

Table 18 - FAIR and MARKAL Triptych targets

The targets for MARKAL from **Table 18** are derived as follows:

- Industrial – MARKAL targets are based on the reduction relative to the baseline as reflected in the FAIR targets. A 59.8% reduction in the Strong

case and a 48.5% reduction in the Medium case. The reductions are based on the improvement in the EEI level, so this method assumes the same EEI value for the MARKAL data.

- Domestic – MARKAL target is based on the 2030 per capita emissions level extracted from the FAIR target. In 2030 it is 1.28tCO₂e per capita for the Strong case and 1.45tCO₂e per capita for the Medium case. The MARKAL population projection is used to calculate the target. The MARKAL model projects a population of 51.9m people in 2030, and the FAIR model 48.4m. Using the Medium case 70MtCO₂e target from FAIR for 2030 and applying this to the MARKAL population, figure, the MARKAL Medium case adjusted target for 2030 is 75MtCO₂e.
- Power and Electricity – The target is based on the percentage reduction for the combination of the three conditions pertaining to fuel mix and efficiency improvements. For the Strong case this equates to a 73% reduction in 2030 and for the Medium case a 50.9% reduction. This method uses the FAIR fuel mix and generation efficiency data.
- Fossil Fuel production – The target for MARKAL uses the relative reduction from the FAIR case and applies the same ratio to the MARKAL data. For the Strong case emissions must be reduced to 12% of baseline levels in 2030 and for the Medium case to 24.4% baseline levels.
- Agriculture – The agriculture target follows the Triptych Approach requirements for developing countries to decrease emissions by 30% by 2030 for the Strong case, and a decrease of 20% by 2050 for the Medium case. The reduction in 2030 is 25.2% due to the delayed participation. The reduction for the Medium case is 9.9%.
- Waste- Emission reduction targets for this sector are per-capita emission reductions. The per capita reduction is calculated using the population projection for FAIR, and instituted using the MARKAL baseline and population projections. The Strong case calls for a 75% reduction in per capita levels by 2030 (90% target with delayed participation) and the Medium case a 47% reduction by 2030.

The application of the Triptych Approach to the MARKAL dataset serves to investigate the scale of the difference in results when using the international FAIR model and the national model data. Although there are differences between the sectoral targets, the combined target levels do not differ significantly across the models as seen in the total column in **Table 18**. The MARKAL targets for the Strong and Medium cases are greater than the FAIR targets by 5% and 5.5% respectively. The larger difference is in the reductions required to reach the targets. As the MARKAL model has a higher growth trajectory the reductions needed are substantially higher. For the Strong case the MARKAL reduction relative to the base case is 565MtCO₂e in 2030 as opposed to the FAIR simulated 438MtCO₂e. This is a 127MtCO₂e difference, or 15% of the MARKAL baseline emissions. Under the Medium case the difference is similarly great, 125MtCO₂e and 15% of MARKAL baseline emissions.

These differences are a result of the different growth trajectories used and if the MARKAL growth rate were closer to that of FAIR or vice-versa, the gap between the reductions required would close accordingly. An approach of approximating the targets using a range of growth trajectories would go towards solving this issue. As

the IPCC SRES report recommends using the entire range of scenarios for developing projections, a similar such recommendation could lead towards increasing the scope of commitments.

Naturally, as time goes by the true GDP growth rate and population growth rates will come to pass, and the reductions required would change along with updated information. However, realising the important role of the growth projections in establishing the targets implies that there should be an allowance for variations in the growth rates.

Having compared the FAIR 2.6 model with the MARKAL model for South Africa, these can be compared to the other climate regimes analysed in the literature review. The results can be compared according to their baseline projections, future target levels under the regimes and associated percentage reductions. This will be done for both the 450ppm and 550ppm cases.

7.4 Comparison of Triptych Targets to Other Climate Regimes

A comparison of the Triptych targets under FAIR 2.6 and MARKAL to those of the other climate approaches can be seen in **Table 19**. The percentage reduction relative to the baseline has been shown as the baseline projections for 2030 are different under FAIR 2.2, FAIR 2.6 and MARKAL. The comparison does show however that for a 450ppm CO₂e stabilisation scenario, reductions for South Africa under Contraction and Convergence, Multi-stage and Triptych require significant reductions relative to the baseline (63%-71%), with the South-North proposal commitment requiring less effort.

Under the 550ppm stabilisation scenarios, the level of effort under the different approaches ranges from 42.7% (South-North) to 54.6% (Contraction and Convergence). The FAIR 2.6 Triptych case at 45.4% reduction is not much higher than the South-North case, although with the lower baseline figures, the absolute emissions allowed in 2030 is significantly lower than the FAIR 2.2 South-North scenario.

For both the 450ppm and 550ppm cases, the South-North approach has the highest emissions allowance at 484MtCO₂e and 546MtCO₂e for 2030. The FAIR 2.2 Triptych approach has the lowest level of emissions allowance followed by the MARKAL calculation, and then the Contraction and Convergence case. It can be seen that the baseline emission projections go towards determining the target level required. Adjusting the baseline levels of population and GDP growth will change the baseline projections for the different scenarios. The percentage reduction relative to the base case may differ significantly like the 550ppm Triptych case which differs by 7% between the FAIR 2.6 and MARKAL versions.

From this comparison, it can be seen that the South-North approach requires the lowest reduction from South Africa, and the Multi-stage and Contraction and Convergence are slightly higher than the Triptych targets (about 5%). This again highlights that the low level of energy efficiency in South Africa penalises South Africa, and suggests that this issue needs addressing regardless of the post-2012 climate regime selected.

Regarding the methodologies used in determining the targets, the Triptych target was by far the most detailed in its target derivation. For the other three approaches, targets are derived using a baseline projection, and setting targets for a country depending on what category it falls under. These approaches may seem 'unfair' to some countries due to the simplified way in which countries are grouped into categories, without deeper consideration into the factors driving development and emissions growth in those countries. Inclusion of additional indicators in the Multi-stage approach showed that it was possible to make the approach more "fair" but did not go as far as the Triptych in suggesting where the emission reductions should come from.

From the derivation of the Triptych targets, it was seen that the approach used a stringent methodology to set targets based on efficiency and per capita targets. Although the approach does not mandate the techniques used to achieve the targets, they illustrate where the focal points should be to improve the emissions levels in a country. Furthermore, the approach can be negotiated according to certain sectors, or aspects of the approach. Countries dependent on coal-fired generation could negotiate a less stringent target for 2050, or developing countries could negotiate a longer delay in the provision for staged participation in the approach. Shortages of reliable sectoral data for the Triptych approach will be a major challenge in "getting it right" for each and every country, but with allowances for adjustments, the Triptych approach or a derivation thereof, could be the basis of a post-2012 regime. The collaborative effort on comparing the national and international model is therefore valuable in showing the similarities and pointing out areas where the data-sharing between models can benefit one another.

	Baseline	450ppm	450ppm	550ppm	550ppm
Climate Regime	MtCO₂e	MtCO₂e	% reduction	MtCO₂e	% reduction
FAIR 2.2					
C & C	953.3	289.7	69.6%	432.7	54.6%
Multi-stage	953.3	271.3	71.5%		
South-North	953.3	484.0	49.2%	546.3	42.7%
FAIR 2.6					
Triptych	693.0	255.2	63.2%	378.4	45.4%
MARKAL					
Triptych	835.1	270.1	67.7%	395.3	52.7%

Table 19 – Comparison of emission targets for South Africa under different Climate Regime Approaches

8 SD-PAMs and Climate Change mitigation

Sustainable Development Policies and Measures (SD-PAMs) are a development-centred approach to mitigating climate change by reducing GHG emissions. The policies and measures proposed all have additional developmental benefits to their implementation aside from the reduction of GHG emissions. In implementing SD-PAMs, the direct benefits are achieving development objectives such as job-creation, increased energy security and reductions in local pollution levels.

The Bali Action Plan (UNFCCC 2007) calls for an increase in GHG mitigation activities, and Paragraph 1b(ii) calls for "Nationally appropriate mitigation actions by developing country Parties in the context of sustainable development." The IPCC WG III report (IPCC 2007) acknowledges that development-first GHG mitigation policies better serve some countries needs. Winkler 2007 demonstrates the GHG emissions reduction co-benefits of taking early action in moving towards sustainable development pathways.

A number of possible SD-PAMs exist for South Africa, as described in *Energy policies for sustainable development in South Africa: Options for the future*, Winkler et al. 2006. The majority of SD-PAMs discussed in this section are extracted from the work continued at the ERC on this research area. The SD-PAMs have been modelled in the national energy model, and thus are primarily energy-related policies. The SD-PAMs used in the following section of the thesis were summarised and used in the collaborative workshop on international allocation models and national energy models hosted by the ERC in 2007 and 2008. The purpose of collecting the SD-PAMs from *Energy Policies* (2006) and the *LTMS* (2007) was to assess South Africa's self-assessed capacity for climate change mitigation through SD-PAMs. The potential for mitigation through SD-PAMs can then be compared to the targets under the international regimes.

8.1 Summary of a selection of SD-PAMs

The SD-PAMs are modelled within the national energy model as separate cases so that the effects of implementing the policies independently may be quantified. The following section gives brief descriptions of the assumptions made in modelling the SD-PAM cases and the resulting GHG emissions reductions. It also lists some of the sustainable development goals that can be achieved through these policies and the associated costs or cost-benefits from implementing the policies.

The MARKAL model is used to calculate SD-PAMs implementation costs and GHG mitigation potential. A list of the GHG emission reductions is given in **Table 20**. The emission reduction potential is calculated in MARKAL by adjusting a Base case to incorporate each of these SD-PAMs individually. The adjustments made to the base case, for each SD-PAM, are described in the following section. The emissions potential for these can't be added as such, as running those in parallel would influence each other and the overall mitigation potential. Combining and running the policies together is detailed in Section 8.2.

A list of the local sustainable development benefits of the SD-PAMs is given in Table 23 which follows the detailed descriptions of each SD-PAM.

	Saving in 2030
SD-PAM name	(MtCO₂e)
Industrial Energy Efficiency	97.5
Increased Renewable Energy	67.7
Imported Hydro-electricity	33.2
Increased Electric Vehicles	30.8
Imported Gas for electricity	14.4
Increased passenger vehicle efficiency	14.3
Increased share of hybrid vehicles	11.0
Transport mode shift	10.2
Residential Energy Efficiency	10.0
Commercial Energy efficiency	9.8
Increased Biofuels	4.0

Table 20 – List of SD-PAM policies and associated GHG reductions achievable in 2030
Source: Analysis in MARKAL in a model of the South African energy system

8.1.1 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 calculated reduction for 2030 is 97.5MtCO₂e with the potential to save a cumulative total of 1231MtCO₂e until 2030.

This is a net negative cost option, so that efficiency measures implemented reduce costs and emissions. For every tonne of CO₂e saved implementing energy efficiency measures, R95 is saved. Industrial energy efficiency has the potential to mitigate the largest amount of CO₂ of the SD-PAMs investigated.

8.1.2 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. Although the savings for improvements to commercial energy efficiency seem relatively low when compared to industry, the influence of implementing efficiency measures and influencing corporate involvement is large.

The emission reductions relative to baseline in 2030 are 9.8MtCO₂e. The mitigation costs for this scenario are negative and for each R1000 saved through implementing efficiency measures, the associated saving in GHG is 2.1tCO₂e.

8.1.3 Residential Energy Efficiency

In this scenario, final energy demand is decreased by 10% in 2015 for residential energy and extended on to 2030.

The modelling results put emission reductions at 10MtCO₂e in 2030. Once again this efficiency measure is a net negative option and for each R1000 saved in efficiency gains GHG emission mitigation is 2.247 tCO₂e.

Most of the energy savings come from improvements to heating and water heating systems, with a smaller portion derived from residential lighting. Improving the efficiency of residential energy use is economical and delivers socio-economic benefits such as lower fuel bills and more efficient heating.

8.1.4 Renewable energy

Renewable energy supply is to supply 10,000GWh (36PJ) to SA's energy supply in 2013, and by 2030 will contribute 27% of the supply. The 10,000GWh target is in accordance with the DME's medium-term renewable energy target as stipulated in their White Paper on Renewable Energy, 2003. The White Paper notes that this would equate to replacing 1667MW of generation capacity.

Emission reductions in 2030 will be 67.7 MtCO₂e, with an average mitigation cost, of R71 / tCO₂e over the period (2000-2030).

By the end of 2030, solar tower generation makes up approximately two-thirds of the installed renewable energy generation capacity, and solar trough generation the other one third. The contribution from wind power is minimal in the model. This assessment assumes that costs of solar generating technology are reduced significantly over the foreseeable future making it a strong and viable electricity option for South Africa.

8.1.5 Biofuels

Under this scenario biofuels are blended together with petrol and diesel. By 2013, the blend fractions are petrol blended with 8% ethanol and diesel with 2% biodiesel. By 2030 this is increased to 20% ethanol in petrol and 5% biodiesel in diesel.

By 2030 there is a modest reduction in emissions of 4.0MtCO₂e.

This is also a net negative cost option, and for each R1000 saved from implementing the policy, an associated 0.96tCO₂e is saved.

The benefit gained from the modest reduction in GHG emissions must be assessed against the decrease of agricultural crops grown for food.

8.1.6 Imported Hydro

The share of imported hydro power is increased significantly, with imports of 17TWh in 2015 increasing to 40TWh in 2020 and continuing to increase thereafter. This policy assumes that electricity becomes available for imports from the development of generation and transmission for the large-scale hydro-power facility Grand Inga in the DRC.

The emission reduction in 2030 under such a policy would be 33.2MtCO₂e where the imported hydro replaces coal-fired generation.

This scenario has net negative costs and for each R1000 saved implementing the policy, GHG emissions savings amount to 275tCO₂e.

8.1.7 Imported gas and increased CCGT

This policy promotes the use of imported natural gas as generation feedstock. New 1950MW combined-cycle gas turbine generation facilities are constructed in 2015, 2020 and 2025 using the imported gas as feedstock.

The emission reductions in 2030 are 14.4MtCO₂e. The average mitigation cost for this policy is R338 /tCO₂e.

The policy was modelled with gas replacing coal as a mitigation option, but with the low cost of coal, the increased gas scenario is a costly mitigation option.

8.1.8 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 the lower improvement rate of 0.4% per year in the base case.

Emission reductions from this policy amount to 14.3MtCO₂e for 2030. The mitigation costs for this scenario are negative and for each R1000 saved in the policy there is an associated savings of 0.366 tCO₂e.

The improvement in light vehicle efficiency has associated fuel and infrastructure savings.

8.1.9 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.

Emission reductions are 79MtCO₂e in 2030 (relative to the baseline).

The mitigation costs for this scenario are negative and for each R1000 saved in the policy there are associated GHG emissions savings of 0.176tCO₂e.

Increasing the share of public transport for passenger kilometres results in significant savings in fuel and infrastructure. It would also, more importantly aim to improve public transport for the vast majority of commuters, and improve the overall transport system of the country.

8.1.10 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% under whole scenario

The emission reductions achieved amount to 11MtCO₂e in 2030 relative to baseline levels.

The mitigation costs are high for this policy at R643 per tCO₂e. The efficiency of hybrid vehicles leads to substantial savings over the period, but at substantial costs due to the significantly higher price for hybrid vehicles over normal passenger vehicles.

8.1.11 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 has lower emission levels.

The emission reduction in 2030 is 30.8MtCO₂e, with this policy also being a net negative cost option. For each R1000 saved under this policy, a corresponding saving of 0.544tCO₂e is made.

8.2 Combining and running the SD-PAMs cases

Run individually, each of the SD-PAM cases has the potential to mitigate a certain amount of GHGs. If all cases are run in conjunction however, the reduction changes due to the sectors affecting one another, due to changes in demand. Table 21 shows the combined cases of running the SD-PAMs. The table shows the cumulative totals for introducing and running combinations of policies.

The combined case results, as shown in Table 21 shows the overall mitigation potential to be 249MtCO₂e in the year 2030. This reduction is 30% of the BAU case from the baseline in the MARKAL energy model of South Africa.

SD-PAM name	Saving in 2030 (MtCO₂e)
Imported Gas & Increased CCGT	14.4
Imported Hydro Electricity	47.9
Renewable Energy	100.6
Industrial Energy Efficiency	194.8
Residential Energy Efficiency	197.9
Commercial Energy Efficiency	199.8
Increased Biofuels	203.8
Combined Transport Case	242.8
Improved Light Vehicle Efficiency	249.0
CUMULATIVE TOTAL	249.0

Table 21 - Combined run of SD-PAMs and cumulative mitigation potential

The effect of the residential and commercial energy efficiency cases is seen to be a great deal lower than when modelled individually. This is due to the cleaner electricity supply due to increased imports and renewable energy.

The SD-PAMs involving vehicles and transport modes were combined in one case, as they are parts of an integrated transport system. The combined transport case included: transport mode shift, increased electric vehicles and increased hybrid vehicles. The emissions reduction from the combined case also has a total lower than the individual policies.

The sequence in which the SD-PAMs appear in Table 21 was the order in which they were implemented in the model. The emissions savings attributed to the energy efficiency measures would be larger if implemented before the cleaner electricity policies and measures. It should therefore be considered that the combined cases main function is to obtain the total reduction possible if all the cases are run.

8.2.1 The cost of implementing SD-PAMs

The cost of implementing the combined case of SD-PAMs is net negative, due to most of the cases being net-negative cost options.

Table 22 shows that for a 3% discount rate the annual levelised cost savings for the period 2001- 2030 is R21.8 billion. This amounts to a saving or an average saving in GDP of 1.01% over the period.

This points out that implementing the SD-PAMs has a net-positive gain for the South African economy and it would be beneficial to implement the policies. Table 22 also shows the results using higher discount rates of 10% and 15% for the period.

<i>Discount rate</i>	<i>3%</i>	<i>10%</i>	<i>15%</i>
Incremental Annual Cost (R millions)	-21,806	-8,899	-4,455
Annual CO ₂ eq saving (Mt/yr)	95		
Cost effectiveness (R/t CO ₂ eq)	-229	-93	-47
% of GDP	-1.01%		

Table 22 - Costs for SD-PAM implementation for the period 2001-2030

Source: Own analysis using SA national model, ERC spreadsheets

University of Cape Town

8.3 Sustainable Development benefits of the SD-PAMs

Each of the aforementioned policies has potential to bring about strong sustainable development benefits. These range from reductions in air-pollution, to job-creation, to increased energy security for South Africa. A list of these benefits can be seen in Table 23.

<i>Policy – name</i>	<i>Local SD benefits</i>
Industrial Energy Efficiency	Lowers the demand for extra generating capacity, improve industrial competitiveness, improved industrial efficiency
Commercial Energy Efficiency	Reduces pollution, slows growth in energy demand, reduces urgency for increased capacity, raises public awareness, and promotes job creation.
Residential Energy Efficiency	Alleviates energy poverty, decreases local air pollution (total suspended particulate solids) through reduced use of coal, and improves health.
Renewable Energy Generation	Decreases CO ₂ per capita, increased investment in renewable options and strengthens energy security, less local pollution, lower fuel costs
Biodiesel / Biofuels	Job creation, and increase in fuel specific agriculture, small reduction in local pollutants, less imported crude oil, promotes job creation and economic growth.
Imported Hydro	Reduces local air pollution and lowers the need for more domestic power generating capacity, improves energy mix.
Imported Gas & increased CCGT	Lowers demand for coal generating capacity, and lowers air pollution.
Improve Light Vehicle Efficiency	Improves local air pollution, slows growth in demand for petrol, reduce fuel imports, increase fuel exports.
Transport Mode Shift	Improves local air pollution, slows growth in demand for diesel and petrol, reduce fuel import, increase exports, significant improvements in traffic
Hybrid Vehicles	Reduces local air pollution, slows growth in demand for diesel and petrol, lowers fuel imports
Electric Vehicles	Significantly reduces local air pollution, decrease import of crude oil, increases petrol exports as diesel makes up bigger share.

Table 23- Sustainable development benefits of the SD-PAMs

From the above list, each of the SD-PAMs is shown to offer benefits apart from GHG mitigation.

SD-PAMs have been shown to have significant climate change mitigation potential. Quantification of the GHG mitigation potential showed that individually, and collectively, these policies will not only decrease GHG emissions but offer co-benefits such as local pollution reduction and job creation. Some of these policies would require co-operation and development in external agencies, such as the policy requiring increased imported hydro. Others will need stringent national policy implementation such as those requiring changes in modes of transport, fuels and efficiency increases in the various sectors. The overall gain in GDP from implementing SD-PAMs further motivates for the adoption of these policies and measures.

9 Discussion

From the results it is apparent that the different international climate regimes all require different levels of reductions for South Africa. Naturally the approaches with the lower global stabilisation targets required higher levels of reduction for South Africa. Those approaches that favour developing countries, like the South-North approach require lower reductions from South Africa, than a emissions per-capita approach like Contraction and Convergence.

It was found that the representation of South Africa within the FAIR 2.6 model was not identical to South Africa's own economic and population growth projections. This is not unusual as the assumptions made by international models would not take special account of factors such as countries own targeted GDP growth rate or immigration policies that would affect the population size. Due to the already extensive data demands needed for creating country-level international climate allocation models, it cannot be expected for the international model to match that of the national model. What is relevant though is the extent to which the targets may differ under different assumptions of the major drivers.

The major drivers for the national and FAIR 2.6 models were compared with one another, and the differences noted. The baseline for the Triptych target generated under FAIR 2.6 was then compared sector by sector to the MARKAL baseline of the national model. Differences were identified, with the major differences being attributed to the growth assumptions made.

It was found that although the growth assumptions were different in the two models, the Triptych target for both of them were similar. However, due to the high growth expected under the MARKAL model, the amount by which emissions would need to be scaled back according to that growth would be significantly larger than the forecasts made under FAIR 2.6.

Low growth estimates lower the baseline emission projections, reducing the required level of effort and higher growth estimates increase the level of effort required to reach reductions targets. Of course the actual effort will depend on the growth that takes place in reality.

On meeting the GHG mitigation targets, it was seen that SD-PAMs have the potential to meet a portion of the reductions required and offers, in most cases, a low-cost and socially-beneficial approach to meeting the challenges of climate change. Depending on the target level for GHG concentrations, SD-PAMs could fulfil much of the obligation, and along with other mitigation options, South Africa, could reach its future climate targets at a relatively low cost. This section discusses the potential that SD-PAMs have in meeting the Triptych targets.

9.1 Comparison of Triptych with SD-PAM Climate Regimes

The total emissions reductions possible through implementing SD-PAMs were compared to the requirements under the Triptych 7.0 Medium case. The Triptych targets for 2030 are derived from six sectors. The SD-PAMs can be categorised according to which sectors they pertain to. This categorization can be seen in Table 24 along with the total emission reduction in those sectors. The emissions given for

each policy is the additional amount by which introducing each of the policies reduces overall emissions in a combined policy scenario. The SD-PAMs discussed in this paper do not relate to the fossil fuel production, agriculture and waste sectors as defined under Triptych 7.0.

SD-PAM name	Saving in 2030 (MtCO ₂ e)
Power and Electricity Sector	100.6
Imported Gas & Increased CCGT	14.4
Imported Hydro Electricity	33.5
Renewable Energy	52.7
Industrial Sector	94.2
Industrial Energy Efficiency	94.2
Domestic Sector	54.2
Residential Energy Efficiency	3.1
Commercial Energy Efficiency	1.9
Increased Biofuels	4.0
Combined Transport Case	39.0
Improved Light Vehicle Efficiency	6.2
TOTAL	249.0

Table 24 - SD-PAMs divided according to Triptych sectors

9.1.1 Electricity and Power Sector

In the Triptych approach, the electricity and power sector calls for a reduction in emissions according to three points of convergence: emission levels per kWh produced; decreasing the share of oil and coal in the electricity energy mix and a decrease in demand from other sectors.

The Triptych Medium scenario, which has a 550ppm CO₂e stabilisation level, calls for the following changes to the power sector by 2050:

- Improvement in generation efficiencies: Coal 600gCO₂/kWh; Oil 450gCO₂/kWh; Gas 300gCO₂/kWh.
- A 90% reduction in the share of oil and coal used to generate power;
- An annual reduction in electricity demand of 1.5% from the base case is required.

Under these conditions, the target for 2030 is 50% of the BAU emissions. The BAU emissions are 383MtCO₂e in 2030, the target is 195MtCO₂e, and the reduction required in 2030 is 188MtCO₂e.

The three SD-PAMs identified as belonging to the electricity and power sector are the Renewables, Imported Hydro and Imported gas cases. The total GHG mitigation potential for these three policies in the year 2030 from the combined case is 100.6MtCO₂e, with BAU emissions of 331MtCO₂e. The emissions level after implementing SD-PAMs would be 230.4MtCO₂e, about 20% higher than the Triptych target level of 195MtCO₂e. The electricity SD-PAMs policies are therefore promising in the degree to which they are able to meet the electricity and power sector target for the Triptych medium scenario in 2030.

9.1.2 Industrial Sector

The Industrial sector in Triptych has targets set according to the level of efficiency of the sector. This is measured using the energy efficiency index (EEI) metric which rates efficiency against current best practices in that sector. South Africa's aggregated EEI is approximately 2.5 (Kuramochi, 2006). The Medium Triptych case calls for an improvement in EEI to 0.7 by 2050, which is about 70% of global best practice for the sector.

In the FAIR model, the BAU emissions are 88MtCO_{2e} in 2030, the target is 43MtCO_{2e} and the reduction required is 45MtCO_{2e}.

The Industrial energy efficiency SD-PAM has the potential to reduce a large amount of GHGs at low cost. The possible reduction is 94.2MtCO_{2e} in 2030. However, the BAU emissions for the sector are 202MtCO_{2e} in 2030. The Industrial energy efficiency baseline emissions for the Industrial sector would therefore be 108MtCO_{2e} in 2030, which is significantly higher than the 43MtCO_{2e} target.

The SD-PAMs results for the industrial sector shows that it is possible to reduce industrial emissions by about 45% by 2030 through implementing energy efficiency measures. It is thus possible for the industrial sectors portion of the target to be achieved through implementing SD-PAMs.

9.1.3 Domestic Sector

The Domestic sector contains residential energy-use, commercial energy-use and transport. It also includes energy-use from agriculture. The Medium Triptych case calls for a reduction in emissions per capita for this sector, to 1.5tCO_{2e} per capita per year by 2050.

The resulting reduction in FAIR for the Medium case for South Africa in 2030 is 8%. The target level is 70MtCO_{2e} and the BAU level is 76MtCO_{2e}, therefore a reduction of 6MtCO_{2e} is needed.

A number of SD-PAMs exist for this sector; increased electric and hybrid vehicles, biofuels, a shift in transport modes, residential and commercial energy efficiency. The total mitigation potential for these policies is 54.2MtCO_{2e}. A combination of transport policies contribute greatly to the emission reduction target. The BAU for the equivalent sector is 151MtCO_{2e}. The emissions level reached through implementing the policies would therefore be 97MtCO_{2e}.

Although there is a difference in baselines, the SD-PAMs presented exceed the reduction in GHG emissions required for the domestic sector in the Triptych approach. The Triptych approach targets an 8% decrease in the domestic sector emissions, and a combination of SD-PAMs for the sector could potentially mitigate 36% of domestic sector emissions.

9.1.4 Overall Effectiveness

Although the targets under the Triptych Approach are calculated according to sectoral improvements, the overall targets are total reduction targets. The Triptych targets calculated under MARKAL are used to compare the overall target, as the SD-PAMs are implemented in the same model.

The Baseline emissions in 2030 are 835MtCO₂e. The emissions reduction target for the Strong Scenario is 565MtCO₂e below the baseline emissions level, a targeted level of 270MtCO₂e in 2030, which is less than half of the predicted GHG emissions for 2010. Referring to **Table 12** and **Table 13**, the mitigation costs for this could be as high as 5.5% of GDP.

The reduction target for the Medium Scenario is 395MtCO₂e, a 439MtCO₂e reduction from the base case. This target is almost at the 1995 levels of GHG emissions of 399MtCO₂e (according to **Table 12**). Although higher than the Strong Scenario, to reach this level would still require very strong government action on climate change.

The total emission reduction possible through implementing SD-PAMs is 249MtCO₂e, which is about 57% of the Medium Scenario's and 44% of the Strong Scenario's required reductions.

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10 Conclusions and Recommendations

The process of carrying out this study yielded a number of conclusions that will be discussed in this section.

Doing analysis on South Africa's required level of commitments under the Multi-stage, Contraction and Convergence and South-North Dialogue proposals showed that South Africa under the Contraction and Convergence and Multi-stage approaches is given stringent goals that would be challenging to fulfil. This was not surprising for the Contraction and Convergence approach as it was shown that South Africa has a comparatively high per capita emissions level for a developing country. However for the Multi-stage approach South Africa was categorised as a developing country that is on the cusp of joining the ranks of Annex I countries. Considering the challenges that lay ahead of South Africa, a Multi-stage proposal that system that uses additional indicators, such as governance and HDI would reflect better the countries capability to adopt mitigation responsibilities. The South-North dialogue proposal is more lenient towards South Africa in attributing attainable climate targets, taking into account both responsibility and capacity.

The Triptych approach has been used in previous allocation scheme discussions and was used to divide up GHG mitigation goals amongst EU states. Therefore there is a possibility of it being used as a workable method of allocating burdens, albeit in a much extended and expanded version from the original version. The FAIR model used for the Triptych 7.0 climate regime proposal was found to have a number of points of intersection with the MARKAL national energy model of South Africa, such that the FAIR and MARKAL models could be compared at a sectoral level. The Triptych approach calculates the GHG emission reduction target with sectoral divisions similar to those used to represent the SA energy system in MARKAL. Using FAIR 2.6 to calculate South Africa's Triptych target yielded similar results as for the other climate regime proposals in that South Africa had similar reduction targets to that of Annex I countries. An advantage of the Triptych approach is it gives a breakdown of the sectors that are responsible for the stringent targets, highlighting those where large reductions are possible. The sectors in South Africa where largest reductions are called for are: the power and electricity, the fossil fuel production and industrial sectors.

The comparison between the MARKAL model and FAIR 2.6 model demonstrated that differences between GDP growth and population projections resulted in different baseline projections for all the sectors. The Triptych approach was therefore applied across to the MARKAL model, so that the sectoral targets could be determined for the MARKAL representation of South Africa. The MARKAL model, with its higher growth projections, called for larger reductions in GHG emissions relative to the baseline. The absolute targets for both the 450 and 550ppm CO₂e stabilisation cases were less than 5.5% different to calculated in FAIR 2.6. This result was not entirely expected as the baseline projection for the MARKAL model is over 20% higher than the FAIR 2.6 projection, with different growth trajectories and population levels. The anchor point is that the analysis using MARKAL data was done for on the year 2030; some of the reductions are for per-capita emission levels and for the large sectors, large emission reductions are required.

The SD-PAM analysis showed that implementation of such policies and measures have numerous benefits and advantages. The GHG mitigation potential from implementing a selection of SD-PAMs could reduce South Africa's GHG emissions by 30% from the BAU case which is about half of the amount required under the Triptych proposal. The contributions of the SD-PAMs to their respective sectors showed that although there were a number of them, they all belonged to only the power and electricity, industrial and domestic sectors. There were no SD-PAMs that could be categorised in the fossil-fuel production, waste or agriculture sectors. Considering that the size of the required reduction under the fossil-fuel production sector, it would be beneficial to develop possible SD-PAMs for this sector. The costs for the SD-PAMs approach are also in its favour as implementing those policies listed would lead to a GDP saving of 1.01% at a 3% discount rate for the period leading up to 2030.

The following recommendations can be made for future work:
More studies may be carried out on this topic depending on how discussions under the Bali Action plan proceed. As the future regarding the post-2012 climate regime becomes clearer it is important to keep updating such studies according to the latest developments.

The results of this study may be compared with the South African position regarding a post-2012 climate regime and see how it may contribute to future negotiations. Presenting the work to the Department of Environment and Tourism may be a starting point, or presenting the results of this paper for publication. The Triptych 7.0 approach could be incorporated into MARKAL as a specific scenario. This would be useful as it could easily be updated if other parameters pertaining to the model change over time, such as growth rates and population statistics. The comparison work done between SD-PAMs and the Triptych approach revealed that although many of the SD-PAMs could be categorised according to the sectors used in Triptych, the large reductions under the fossil-fuel production sector did not have an SD-PAM counterpart. Consideration or investigation of potential SD-PAMs in this sector is recommended. Furthermore, considering the benefits of the SD-PAMs considered, it is recommended that the SD-PAMs approach is taken further to consider additional policies and measures with sustainable development benefits that could go towards achieving GHG mitigation. Recycling is such a policy which has clear and significant sustainable development benefits, could save large amounts of energy, provide jobs, and decrease the amounts of waste produced. Finally it is recommended that actions regarding implementation of SD-PAMs proceed as soon as possible, as it is recognized that many of them are negative-cost options, have development benefits and could contribute significantly to any future climate change mitigation strategy.

Considering the findings and conclusions reached in this thesis it would be in South Africa's best interests to begin implementing the SD-PAMs policies as it will benefit the country's economy and go towards achieving climate change mitigation goals which would go towards fulfilling potential requirements for South Africa under the UNFCCC and its Protocol.

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Appendix A

Box TS-1: The Main Characteristics of the Four SRES Storylines and Scenario Families

By 2100 the world will have changed in ways that are hard to imagine - as hard as it would have been at the end of the 19th century to imagine the changes of the 100 years since. Each storyline assumes a distinctly different direction for future developments, such that the four storylines differ in increasingly irreversible ways. Together they describe divergent futures that encompass a significant portion of the underlying uncertainties in the main driving forces. They cover a wide range of key "future" characteristics such as population growth, economic development, and technological change. For this reason, their plausibility or feasibility should not be considered solely on the basis of an extrapolation of *current* economic, technological, and social trends.

The A1 storyline and scenario family describes a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into four groups that describe alternative directions of technological change in the energy system. Two of the fossil-intensive groups were merged in the SPM.

The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines.

The B1 storyline and scenario family describes a convergent world with the same low population growth as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

After determining the basic features and driving forces for each of the four storylines, the team began modelling and quantifying the storylines. This resulted in 40 scenarios, each of which constitutes an alternative interpretation and quantification of a storyline. All the interpretations and quantifications associated with a single storyline are called a scenario family

Source: IPCC Special Report on Emissions Scenarios, 2000

Appendix B

Calculation of Triptych Targets under MARKAL

Industrial Sector

Targets based on reduction according to EEI

Strong Triptych Target

FAIR Baseline: 88.4MtCO₂e in 2030 @ EEI of 2.9

FAIR Strong Triptych: 35.6MtCO₂e in 2030 @ EEI of 1.3

EEI reduction = 55%

Emission reduction = 59.8%

Applying a 59.8% reduction to MARKAL Baseline:

MARKAL Baseline: 202.0MtCO₂e in 2030

$202.0\text{MtCO}_2\text{e} \times (1-59.8\%) = 81.3\text{MtCO}_2\text{e}$

Medium Triptych Target

FAIR Medium Triptych: 45.5MtCO₂e in 2030 @ EEI of 1.6

EEI reduction = 45%

Emission reduction = 48.5%

Applying 48.5% reduction to MARKAL Baseline:

MARKAL Baseline: 202.0MtCO₂e in 2030

$202.0\text{MtCO}_2\text{e} \times (1-48.5\%) = 103.9\text{MtCO}_2\text{e}$

Domestic Sector

Targets based on per capita levels

Strong Triptych Target

FAIR Strong Triptych: 62.3MtCO₂e @ population of 48.4m = 1.29tCO₂e per capita.

Applying to MARKAL population: 51.9m x 1.29tCO₂e per capita = 66.9MtCO₂e

Medium Triptych Target

FAIR Medium Triptych: 70.0MtCO₂e @ population of 48.4m = 1.45MtCO₂e per capita.

Applying to MARKAL population: 51.9m x 1.45tCO₂e per capita = 75.2MtCO₂e

Power and Electricity

Targets based on a combination of percentage reductions

Strong Triptych Target

FAIR Baseline: 383.2MtCO₂e in 2030

FAIR Strong Triptych: 103.4MtCO₂e in 2030

Emission reduction = 73%

Applying 73% reduction to MARKAL baseline:

MARKAL Baseline: 331.6MtCO₂e in 2030

$331.6\text{MtCO}_2\text{e} \times (1-73\%) = 89.5\text{MtCO}_2\text{e}$

Medium Triptych Target

FAIR Medium Triptych: 188.1MtCO₂e in 2030

Emission reduction = 50.9%

Applying 50.9% reduction to MARKAL baseline:

$331.6\text{MtCO}_2\text{e} \times ((1-50.9\%)) = 162.8\text{MtCO}_2\text{e}$

Fossil Fuel Production

Percentage reduction of baseline emissions

Strong Triptych Target

FAIR Baseline: 76.6MtCO₂e

FAIR Strong Target: 9.2MtCO₂e

Emission reduction: 88%

Applying 88% reduction to MARKAL baseline:

MARKAL Baseline: 113.7MtCO₂e

$113.7\text{MtCO}_2\text{e} \times (1-88\%) = 13.6\text{MtCO}_2\text{e}$

Medium Triptych Target

FAIR Medium Target: 18.7MtCO₂e

Emission reduction: 75.6%

Applying 75.6% reduction to MARKAL baseline:

$113.7\text{MtCO}_2\text{e} \times (1-75.6\%) = 27.7\text{MtCO}_2\text{e}$

Agriculture

Percentage reduction of baseline emissions

Strong Triptych Target

FAIR Baseline: 55.4MtCO₂e

FAIR Strong Target: 41.4MtCO₂e

Emission reduction: 25.2%

Applying 25.2% reduction to MARKAL baseline:

MARKAL Baseline: 19.5MtCO₂e

$19.5\text{MtCO}_2\text{e} \times (1-25.2\%) = 14.6\text{MtCO}_2\text{e}$

Medium Triptych Target

FAIR Medium Target: 49.9MtCO₂e

Emission reduction: 9.9%

Applying 9.9% reduction to MARKAL baseline:

$19.5\text{MtCO}_2\text{e} \times (1-9.9\%) = 17.6\text{MtCO}_2\text{e}$

Waste

Per capita emission levels

Strong Triptych Target

FAIR Baseline: 13.2MtCO₂e

FAIR Strong Target: 3.3MtCO₂e

Emissions per capita: 3.3MtCO₂e @ population 48.4m = 0.068tCO₂e

Applying to MARKAL population: 51.9m x 0.068tCO₂e = 4.3MtCO₂e

Medium Triptych Target

FAIR Medium Target: 6.2MtCO₂e

Emissions per capita: 6.2MtCO₂e @ population 48.4m = 0.083tCO₂e

Applying to MARKAL population: 51.9m x 0.083tCO₂e = 8.1MtCO₂e

	FAIR			MARKAL		
		Triptych	Triptych		Triptych	Triptych
	Baseline	Strong	Medium	Baseline	Strong	Medium
Triptych Sector	MtCO2e	MtCO2e	MtCO2e	MtCO2e	MtCO2e	MtCO2e
Industrial	88.4	35.6	45.5	202.0	81.3	103.9
Domestic	76.3	62.3	70.0	151.1	66.9	75.2
Power and Electricity	383.2	103.4	188.1	331.6	89.5	162.8
Fossil Fuel Production	76.6	9.2	18.7	113.7	13.6	27.7
Agriculture	55.4	41.4	49.9	19.5	14.6	17.6
Waste	13.2	3.3	6.2	17.1	4.3	8.1
Total	693.0	258.1	372.9	835.1	271.2	393.4

Table 25 - FAIR and MARKAL Triptych targets

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