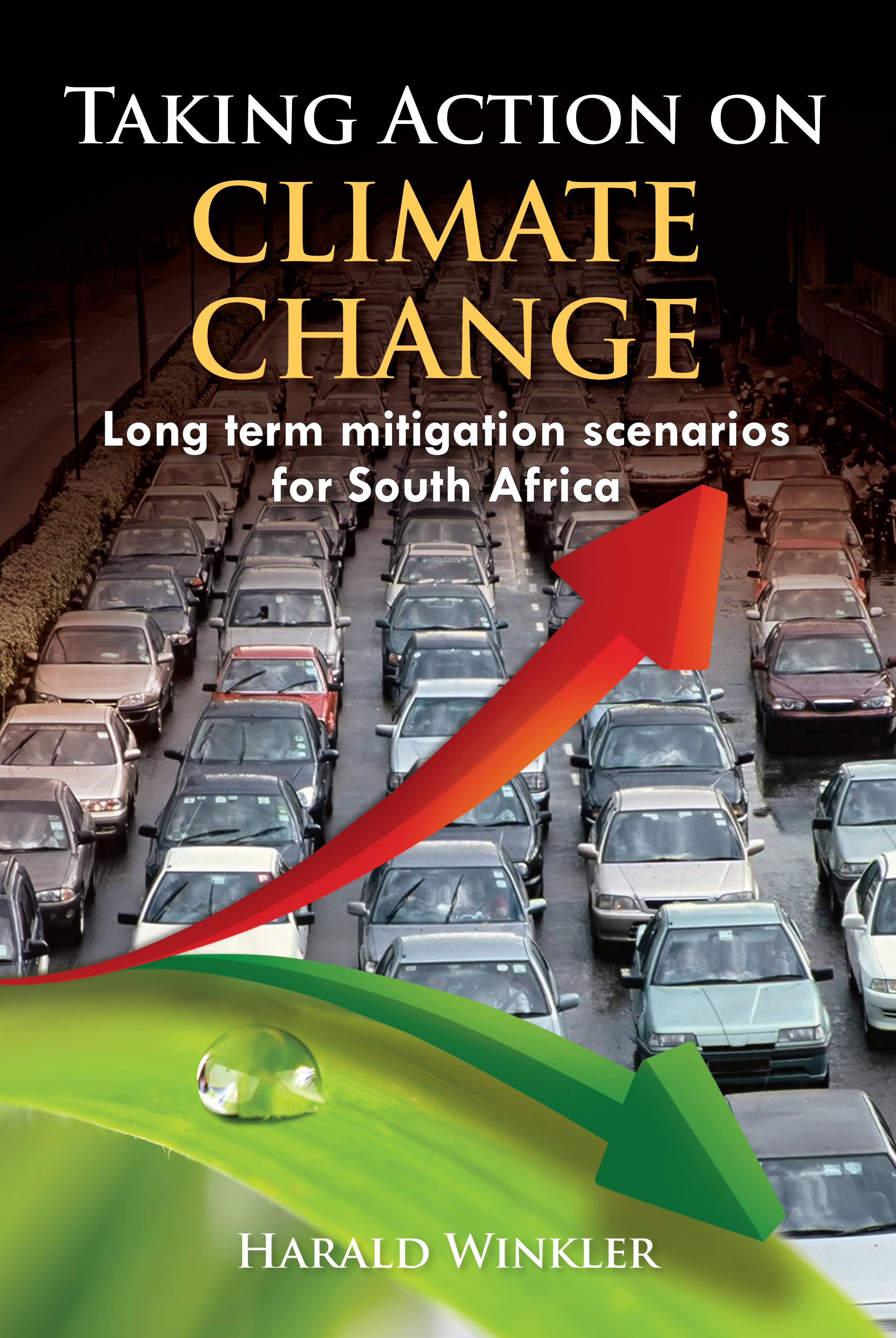

TAKING ACTION ON CLIMATE CHANGE

Long term mitigation scenarios for South Africa

HARALD WINKLER

Taking action on climate change: Long term mitigation scenarios for South Africa

by

Harald Winkler

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Acronyms, abbreviations and units

AR4	Fourth Assessment Report (of the IPCC)
AsgiSA	Accelerated and Shared Growth Initiative for South Africa
Annex I	Annex to the Convention listing industrialised and transitioning countries
ASSA	Actuarial Society of South Africa
bbl	Barrels (of liquid fuel)
CDM	Clean Development Mechanism
CFL	Compact fluorescent light
CGE	Computable general equilibrium
CH_4	Methane
CO_2	Carbon dioxide
CTL	Coal-to-liquid
DEAT	Department of Environmental Affairs and Tourism
DME	Department of Minerals and Energy
DSM	Demand-side management
FBC	Fluidised bed combustion
FGD	Flue-gas desulphurisation
GDP	Gross domestic product
GEAR	Growth, Employment and Redistribution (macroeconomic strategy)
Gg	Gigagram, 10^9 grams, a billion grams
GHG	Greenhouse gas
GJ	Gigajoules 10^9 Joules, a billion Joules
GW	Gigawatts (10^9W)
HFC	Hydrofluorocarbons
HVAC	Heating, ventilation and air conditioning
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
J	Joule, standard international unit of energy, defined as a Newton-metre, or approx. the energy required to lift a small apple one metre straight up
kW	Kilowatts (power measurement)
kWh	Kilowatt-hour
LFG	Landfill gas
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas

LTMS	Long Term Mitigation Scenarios
LULUCF	Land use, land-use change and forestry
MARKAL	Market allocation (modelling framework)
MJ	MegaJoule, 10^6 Joules, a million Joules
Mt	Megatons, 10^6 tons, a million tons
$MtCO_2$	Megatons of carbon dioxide, a million tons CO_2
MW	Megawatt, 10^6 Watt, a million Watt
MWh	Megawatthour, 10^6 Watthours, a million Wh
N_2O	Nitrous oxide
NAI	Non-Annex I (countries who are not parties listed in Annex I)
Nepad	New Partnership for Africa's Development
NER	National Electricity Regulator
NGO	Non-governmental organisation
NIRP	National Integrated Resource Plan
NMVOC	Non-methane volatile organic compounds
NO_x	Nitrogen oxides (plural, since they refer to nitrogen dioxide [NO_2] and nitric oxide [NO])
O&M	Operation and maintenance
OECD	Organisation for Economic Cooperation and Development
PBMR	Pebble Bed Modular Reactor
PFC	Perfluorocarbon
PJ	PetaJoules, 10^{15} Joules
ppmv	Parts per million by volume
PPP	Purchasing power parity
PV	Photovoltaics
PWR	Pressurised water reactor (nuclear)
RDP	Reconstruction and Development Programme
RETs	Renewable electricity/energy technologies
SBT	Scenario Building Team (working on the LTMS)
SD-PAMs	Sustainable development policies and measures
SF_6	Sulphur hexafluoride
SO_2	Sulphur dioxide
SRES	Special Report on Emission Scenarios (of the IPCC)
SWH	Solar water heater
tC	Tons of carbon
tCO_2	Tons of CO_2
TJ	TeraJoule, 10^{12} Joules
Toe	Tons of oil equivalent

TPES	Total primary energy supply
TWh	Terawatt-hours, 10^{15} Watt-hours
UNFCCC	United Nations Framework Convention on Climate Change (the Convention)
VAT	Value added tax
W	Watt (a unit of power, or capacity, one Joule per second)

Acknowledgements

This book draws to a large extent on the Long Term Mitigation Scenarios Technical Report (Winkler 2007) and its Technical Appendix (ERC 2007a). The work on the Long Term Mitigation Scenarios (LTMS) was a team effort in many ways.

Firstly, I wish to acknowledge the team at the Ministry and Department of Environmental Affairs and Tourism who led and championed the LTMS work, in particular then Minister Marthinus van Schalkwyk, Joanne Yawitch, Shaun Vorster, Peter Lukey, Tsietsi Mahema, Kelebogile Moroka and many others.

LTMS was not only research commissioned by a government department, but integrally a stakeholder process. The team at Tokiso, led by facilitator Stefan Raubenheimer and later greatly supported by Pascal Moloi, put together a remarkable process. The many members of the Scenario Building Team, from across the spectrum, are too many to name here, but I am grateful for all their commitment to engage with a complex, challenging and at times daunting process. The approval of the Scenario Document (SBT 2007) based on that intensive process stands out for me as one of the remarkable products of facilitated process and rigorous research—shaped by the willingness of thinkers from different perspectives to listen to one another and find a way forward. If everyone from large emitters through government officials to NGOs can continue to work together in this way, there is yet hope that effective action on climate change may soon be implemented in South Africa.

The LTMS reports could not have been written without the inputs from four research teams and the many researchers on them. I gratefully acknowledge the inputs from the energy modelling team, my colleagues at ERC—Alison Hughes, Mary Haw, Andrew Marquard and Bruno Merven; the CSIR team who worked on emissions in the waste, agriculture and LULUCF sectors—Rina Taviv, Marna van der Merwe, Bob Scholes and Gill Collet; Gerrit Kornelius, who showed Andrew and myself the way on industrial process emissions; to the economy-wide modellers, Kalie Pauw and Marna Kearney; and the impacts team led by Guy Midgley, Arthur Chapman, Pierre Mukheibir, Mark Tadross, Bruce Hewitson, Stephanie Wand, Roland Schulze, Trevor Lumsden, Mark Horan, Michele Warburton, Barney Kgope, Brian Mantlana, Tony Knowles, Akin Abayomi, Gina Ziervogel, Rebecca Cullis and Andre Theron. The input reports are referenced throughout this book to record their contribution to the LTMS technical work, and it was only on the basis of these inputs (Hughes et al. 2007; Kearney 2008; Kornelius, Marquard & Winkler 2007; Midgley et al. 2007; Pauw 2007; Raubenheimer 2007; Taviv et al. 2007) that it was possible for me to put together the Technical Report. I am deeply grateful for what I learned in the process and the experience of collaboration across a wide range of disciplines. Any remaining errors in the Technical Report, its Appendix or in particular this book are my own.

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My final word of thanks is owed to my friend Stefan Raubenheimer. On the back of an envelope, we conceived this approach to scenarios and then lived, breathed and worked little else for the next three years.

Chapter One

Introduction

Climate change is one of the greatest threats to our planet and to our people. South Africa is especially vulnerable to the impacts of climate change. At the same time, South Africa emits large quantities of the greenhouse gases (GHGs) that are causing climate change. In fact, this country is one of the highest emitters per capita per GDP in the world. South Africa is both a contributor to the problem and its victim.

This book outlines a unique process, the Long Term Mitigation Scenarios (LTMS) for South Africa, which was undertaken to address the challenge of reducing GHG emissions. It outlines a blend of research and process that built on South Africa's distinctive post-1994 democratic culture of consultation. The LTMS brought together business, labour, NGOs and government to remarkable levels of consensus around a set of evidence-based scenarios for reducing our greenhouse gas emissions.

Why a Long Term Mitigation Scenario process?

South Africa is an active participant in the international process of combating climate change and regulating the emissions of greenhouse gases. It is a signatory to the United Nations Framework Convention on climate change as well as the Kyoto Protocol. South Africa takes the issue of climate change very seriously and has shown leadership in the UN negotiations. In the negotiations our actions must speak as loudly as our words: we need to show leadership by example. This we can do by preparing a course of action for our country.

The link between our own emissions and climate change impacts is indirect. Compared to our own emissions, the emissions of larger economies are far more significant to the climate change impacts that South Africa will suffer. However, South Africa will not be able to influence the emissions reduction efforts of those countries without a reduction plan of its own which is respected as appropriate and real. Yet there is an indirect but very powerful connection—if we do not act, other countries are less likely to act and ultimately the negative impacts will affect everyone.

Under the Kyoto Protocol, at least until 2012, South Africa, together with other developing countries, has no binding greenhouse gas mitigation obligations. However, this is likely to change some time after 2012, and it means that at some point South Africa will be required to start cutting its emissions. South Africa is in fact already formulating plans to reduce GHG emissions.

The LTMS process, both in facilitated stakeholder dialogue and rigorous research, was South Africa's approach to preparing for this formidable challenge. Before we consider the findings of the LTMS in the rest of this book, I would like to tell the story of the process briefly.

The story of LTMS

The need for long term mitigation scenarios was identified at the first consultative conference on climate change in 2005. The conference concluded that a transparent, participatory and scientifically-informed policy development process was needed. Government ministers in March 2006 launched such the LTMS process, which concluded with outcomes agreed by a Cabinet *lekgotla* in July 2008.

The process had objectives at both national and international level:

- Nationally, to develop robust and broadly supported scenarios to lay the basis for long term climate policy.
- Internationally, to provide South African negotiators with well-founded positions for the negotiations on the future of the climate regime after 2012.

The Department of Environmental Affairs and Tourism (DEAT) was mandated by Cabinet to carry out the LTMS, which in turn asked the Energy Research Centre (ERC) to project manage the process, with the mediation firm Tokiso providing independent facilitation.

The technical work on the LTMS stood on two legs—a facilitated stakeholder process and best-available information. What made LTMS unique in the field of mitigation was that research fed into a facilitated stakeholder process, producing evidence-based scenarios. Central to the process was the Scenario Building Team (SBT), bringing together strategic thinkers from key sectors across government, business and civil society. The SBT met six times formally—in addition to many smaller meetings—from August 2006 to October 2007. Members of the SBT participated in their individual capacities, but brought their strategic understanding of their sectors to the table. The process is described more fully in a separate report (Raubenheimer 2007).

What gave the LTMS process rigour and a foundation in the best available scientific information were the four research teams: energy, led by ERC's modelling group (Hughes et al. 2007); non-energy emissions in waste, agriculture and forestry, led by the CSIR (Taviv et al. 2007); industrial process emissions, by Airshed and ERC (Kornelius et al. 2007); analysis of economy-wide impacts (Kearney 2008); and work on climate change impacts and adaptation, with a diverse team led by the SA National Biodiversity Institute (Midgley et al. 2007).

The research teams gathered large amounts of data to conduct energy modelling, analysis of non-energy emissions, macro-economic modelling and assessments of vulnerability and adaptation. Not every data point used or assumption made can be reported in the confines of this book. Many more are reported in the LTMS Technical Report (Winkler 2007) and its Appendix (ERC 2007a), as well as the CD-Rom accompanying this book. The research was central to defining scenarios that were more than conceptual, but arrived at projections based on the best available science.

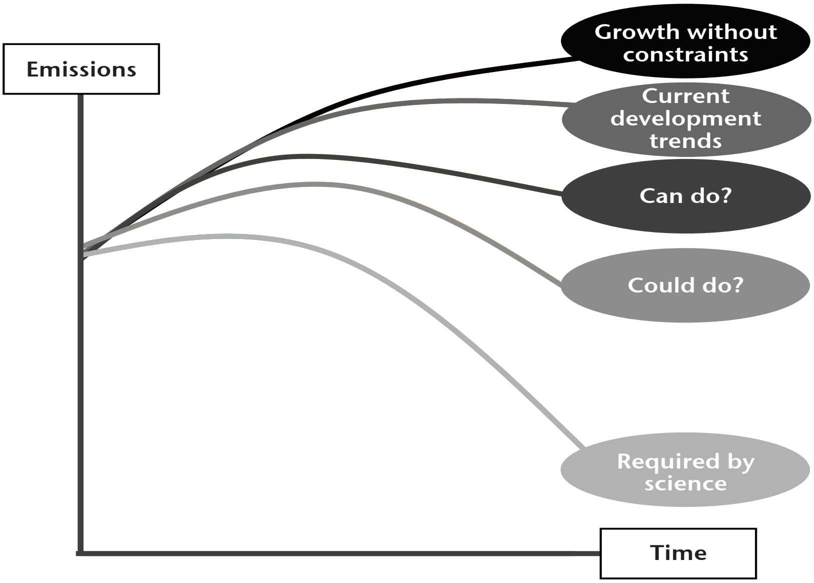

Figure 1.1: Scenario framework

Conceptually, the gap between where emissions might go if nothing was done, or Growth without Constraints (GWC) and where they need to go as Required by Science (RBS) is illustrated in Figure 1.1. The top and bottom scenarios (worst-case and best-case) create an envelope. The top scenario shows a prediction of our emissions path if South Africa adopted a growth strategy without any carbon constraint (GWC). The bottom scenario, (RBS), shows the emissions path required for South Africa to contribute to stabilising the concentrations of greenhouse gases in the atmosphere (the objective of the United Nations Framework Convention on Climate Change, the UNFCCC). Within this envelope, the focus of analysis was on action scenarios—originally called Can Do and Could Do. The SBT defined a series of possible mitigation actions which were then modelled by the research teams. In the international context, these would be nationally appropriate mitigation actions (NAMAs). In this way, Figure 1.1 provided a conceptual scenario framework which was filled in more accurately through research.

The first major research was conducted for a meeting in May 2007 and brought the first shock to the Scenario Building Team (SBT)—that 'The Gap' between the emissions created by the scenario called Growth without Constraints (GWC) and that called Required by Science (RBS) was enormous. The gap was three times the size of emissions in 2003, the base year (see Chapter 3 for details).

The shock had the effect of turning the RBS scenario into the effective goal—and all other scenarios into strategic options. When the Scenario Building Team realised that the Start Now set of mitigation options (wedges) did not close the gap even halfway, it requested further modelling of more ambitious wedges and strategic options. (The wedges are so named after the roughly wedge-shaped graphs of emission reductions.)

At this stage of the LTMS story, it is worth pausing and considering what is meant by 'scenarios'. The scenario planning approach for the LTMS process (see Raubenheimer 2007) is different from classical scenario planning approaches (Kahane 2000; Shell 2001; Van der Heijden 1996). The classical approach is to define scenarios as different stories about how the external world might evolve, and to end the process at that point. Thereafter the point is for policy-makers to define a strategy that is robust to all possible futures. The LTMS took a data-based approach to scenario development, drawing both on process and research.

The research teams were critical in providing the best available scientific information. In modelling future emissions and calculating costs, it was important for the credibility of the process that the information be as accurate as possible. While the process was essentially creative (the paths constructed could be as fanciful, or as aggressive, as we wanted, without being realistic), the results are conservative (based on good data and thus reliable for decision-making). This creative/conservative approach provided a firm basis for decision-making on a strategic direction that could be momentous for South Africa.

In short, with the support of the research teams, the SBT was able to develop evidence-based scenarios. The final meeting of the SBT, in October 2007, was remarkable in that participants from a wide diversity of backgrounds, acknowledging their differing views on specific issues, were able to sign off on a single set of documents. In the style of the IPCC, the SBT approved the Scenario Document (SBT 2007) page by page and also approved the Technical Summary (ERC 2007b), accepting the Technical Report (Winkler 2007), its Appendix (ERC 2007a) and the multiple underlying inputs, as cited above, from the research teams as representing a solid basis for decision-making. The following year, further high-level consultations were conducted by DEAT to prepare for a presentation of the LTMS results to Cabinet.

In July 2008, Cabinet agreed on an ambitious plan, driven by the aim of limiting temperature increase to 2°C above pre-industrial levels and doing a fair share in the international context.

Taking a long term view, the goal is to make a transition to a low-carbon economy, presenting this as the best option for job creation and development in a carbon-constrained future. The broader analysis of socio-economic implications of the mitigation options focused on the impact on GDP, employment and poverty—thereby ensuring that the country could choose at least some NAMAs that are also sustainable development policies and measures (SD-PAMs see RSA (2006) and Winkler et al (2002)). Cabinet stated clearly that emissions need to peak (at the latest by 2020–25), then plateau for a decade or so, and then decline. This strategic direction needs to be given more immediate effect by setting more ambitious domestic targets for energy efficiency, renewable energy and transport. Increasingly, mandatory rather than voluntary action is needed.

At the 2009 Climate Change Summit, the LTMS results were fed into a formal policy development process. The South African government as a whole has indicated that it seeks long term change, making a major transition from an energy-intensive to a low-carbon economy. Greater investment in long term research and development will be crucial on the road to a low-carbon society. The Summit statement reconfirmed that the process will 'culminate in the introduction of legislative, regulatory and fiscal packages to give effect to the strategic direction and policy by 2012' (Climate Summit 2009).

At the international level, the LTMS process made its contribution to the multilateral climate negotiations. As a developing country, South Africa was able, based on the LTMS, to make a fair and meaningful contribution to solving the challenge of global climate change. Acknowledging the aim of limiting temperature increase to 2°C was a major step for a developing country and demonstrates bold leadership. It is also fully consistent with the findings of the IPCC, which found that absolute reductions will be required of developed countries and deviations below baseline from developing countries. South Africa signalled that it is serious about negotiating on climate change. It can do so on the basis of having done its homework at the national level.

Clearly, South Africa expects all developed countries to respond with leadership, taking on legally binding, absolute reductions in their emissions. Only by all agreeing to their respective responsibilities will it be possible to achieve a long term goal, which the planet so urgently needs.

Reasons for action and concern

The reason why the planet needs action urgently is the impact of climate change. The focus of the LTMS, as the name says, is on mitigation—the reduction of greenhouse gas (GHG) emissions. But the reason for concern is the negative impacts of unmitigated climate change.

The Intergovernmental Panel on Climate Change's Fourth Assessment Report (IPCC AR4) provided the most recent and comprehensive estimate of the likelihood that human activities are causing currently observed temperature and climate change. Key conclusions by hundreds of the world's leading climate scientists were that:

> Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level. (IPCC 2007c)

And that:

> Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations. (IPCC 2007c)

Predicting the future is always an uncertain matter. But the IPCC assessment spent extensive effort in bounding the uncertainty. For the above statement, the level of certainty translates to a more than 90% probability (a 9 out of 10 chance) that human activities are responsible for the global warming observed since the 1950s. That is why the IPCC concluded that the evidence for a rise in global temperature is 'unequivocal'.

Climate change is very likely (>90%) driven by increased greenhouse gas concentrations caused by human activities. This finding itself provides some level of support for a policy response, but the urgency of the response needed is better judged on what the projected warming is likely to be, given a range of societal choices regarding fossil fuel use and land cover change, and given the costs of action—and those of inaction. These projections depend on the estimate of climate sensitivity, which is the climate response to a given rise in atmospheric CO_2 level. However, the climate sensitivity and especially its upper limit remains quite poorly defined—this means that a climate response to CO_2 increase that is much larger than the estimated median response cannot yet be excluded. A truly risk-averse strategy in response to potential climate change impacts should therefore consider fully the impacts of higher climate sensitivities, especially because certain key feedbacks to climate from the biosphere are not yet incorporated in climate models. But we find that these are lacking in the literature, and the published material that does exist contains what may be conservative estimates of impacts.

The evidence for human-induced climate change is clear and unambiguous: changes are already occurring, are generally consistent with model projections, and are likely to continue to occur for many decades to come. The global projections for a range of assumptions of climate sensitivity and societal development scenarios (excluding targeted mitigation responses) are for a rise of between 1.2°C and 5.8°C in global temperature by 2100. While the range of climate change projected is clearly uncertain even at the global level, and the potential impacts even more uncertain, it is possible to provide a careful assessment of sensitivities, vulnerabilities and risk associated with climate change at national and sub-national levels. It is possible to bound the uncertainties. It is also possible to explore potential adaptation options and estimate their possible costs in relation to the costs of inaction, though this has seldom been done comprehensively.

Modelling studies project a range of impacts in South Africa, and some of them are alarming and of immediate societal relevance, even given a business-as-usual global emissions scenario. Some of these impacts require careful consideration and risk assessment—for example, a change in available water supply in South Africa would have major implications for most sectors of the economy, but especially for urban and agricultural demands. A state-of-the-art assessment of what we know about climate impacts was one of the input reports for the LTMS (Midgley et al. 2007).

In addition, the immediate health impacts of extreme climatic events on rural livelihoods, in particular, are well established and documented.

Production and income activities are likely to be significantly affected by climate change and increased climate variability by ~2050 at least, particularly in rural areas. Similarly, in urban environments, a higher risk of frequent flooding in some cases and drought-induced water shortages in other areas will be the result of increased climate variability. A range of risks for natural ecosystems and associated economic sectors, such as nature-based tourism and rural livelihoods, has been identified. These include the risk of endemic species extinctions in biodiversity hotspots, increased frequency of natural fires, and disruption to ecosystems via species geographic range shifts and the enhanced threat of alien invasive organisms.

The summary presented in this section is a review of currently available information on observed climate trends, projected changes and the vulnerability to climate change in South Africa, based on a more comprehensive review for the LTMS (Midgley et al. 2007). Where possible, we reviewed adaptation responses per sector, and extracted the costs of adaptation and damage due to a lack of action—although examples of this level of work are currently very few. Together with the social and moral imperatives to meet international climate change commitments, the review of potential climate-induced impacts in South Africa (Midgley et al. 2007) provided additional motivation for embarking on the LTMS process.

Another reason for action is economic, a case made in compelling fashion in the Stern review on the economics of climate change. The costs of emission reduction are high, but the costs of inaction will be far higher. The costs of adaptation in a world where no mitigation took place were found to be in the order of 5 to 20 times the cost of the mitigation actions required (Stern Review 2006).

Climate change is not just an environmental issue. It goes to the very heart of the world's future economic viability, including achieving and sustaining the Millennium Development Goals. The negative impacts of climate change have the potential to undermine South Africa's development goals as well. Yet, even though the costs of action are less than inaction, the challenge is huge. The sheer scale of the mitigation solutions required is examined in the LTMS.

Chapter Two

Developing a model of GHG emissions

As the story of the LTMS made clear, research and stakeholder processes were closely interwoven. Information on greenhouse gas (GHG) emission reductions was a central input by the research team to the Scenario Building Team (SBT). In this chapter, the focus is on data that were important to the LTMS results and which elicited particular debate in the process. The chapter outlines the methodology followed—the models used in the energy sector, the analytical tools employed for other sectors, how costs were calculated and what the key drivers of emissions are. The chapter ends with a consideration of important constraints on the analysis.

Methodology for modelling emissions

The methodology for modelling emissions was divided into two major components—energy and non-energy emissions. Four-fifths of South Africa's GHG emission comes from energy supply and use (RSA 2004; Van der Merwe & Scholes 1998). The energy sector includes not only supply but also the major end-use sectors in industry, transport and commercial and residential buildings. Energy models are a powerful way to explore various alternative energy futures quantitatively.

Non-energy emissions were analysed with detailed spreadsheet analysis, with different teams addressing waste, agriculture and forestry (Taviv et al. 2007) and another focusing on industrial process emissions (Kornelius et al. 2007).

For all emission scenarios, whether energy or non-energy, the key drivers of emissions include GDP, population and technological change, among other factors.

In terms of gases, the energy model considers the three 'big' greenhouse gases—carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_20)—as well as other GHGs: carbon monoxide (CO), oxides of nitrogen (NO_x), non-methane volatile organic compounds (NMVOCs), and sulphur dioxide (SO_2). The new guidelines for GHG inventories also require reporting on three industrial trace gases (HFCs, PFCs and SF_6), though at this stage these are not accounted for in the energy model but make up a very small proportion of the country's greenhouse gas emissions.

Energy modelling

The energy modelling framework we used analysed emissions and mitigation options in the energy sector (Hughes et al. 2007). For this research, the MARKAL (short for Market Allocation) model, developed by the International Energy Agency, was selected (Loulou, Goldstein & Noble 2004). It is an energy system model, which includes demand for energy services, technologies that deliver this demand, fuels that feed the technologies and energy sources. MARKAL is an optimising model, meaning that, subject to available resources, a set of energy supply and use technologies, and a set of required energy services (such as heat for cooking) specified by the modelling team, the model determines the optimal configuration of the energy system in terms of an objective function, usually to minimise system costs subject to constraints. The model ensures that energy system requirements are met, for example that energy demand is equal to or less than supply; that a specified reserve margin is maintained; that plants for peak and base-load are distinguished; that technologies have a limited life, and others

The strength of the MARKAL model lies in allowing users to answer questions about the most cost-effective technology solutions for energy systems. It considers both fuel costs and the cost of energy technologies (Howells & Solomon 2002). Constraints on various aspects of the model, which temper the drive to least cost, can include environmental factors (e.g. emissions), limits on resource availability and dissemination rates of policies and measures. The model is demand-driven, in that it starts its analysis from projections of useful energy demand.

The cost-optimisation process is based on an assumption that investment decisions in the energy sector are made by all actors in the energy system (who are assumed to be rational cost-minimisers) and thus without careful design the least-cost option will dominate the analysis of the energy market—something not observed in practice. In reality, non-economic policy considerations and issues are taken into account by policy makers and other decision makers, such as energy security concerns, energy poverty, accounting rules or organisational culture. Model outcomes are thus constrained by bounds—upper and lower limits on investment in specific technologies applied by the modelling team. The model runs in annual time-steps, in this analysis extended to a longer than usual period, from 2003 to 2050.

MARKAL requires a large set of data, which can be divided into several kinds:

- Data on energy technologies—conversion (e.g. power plants, refineries), transportation (e.g. pipelines) and end-use (e.g. motors, lights) technologies—which would include efficiency, capital cost, life time, and environmental impacts/emissions
- Independent variables, such as GDP and population
- The structure of the energy system
- Historical data on the existing energy system.

MARKAL is typically used to construct a 'reference case' (or modellers' baseline scenario), against which other scenarios are compared. In the LTMS, this case was called Growth without Constraints (GWC). Key to GWC is the absence of any constraint on carbon. The reference case is effectively a simulation of the development of the energy system into the future, and is tightly constrained to represent a 'business as usual' scenario, generally continuing existing development trends. For instance, energy efficiency is only increased in line with historical trends. In the case of climate change, constraints can be changed to develop different mitigation scenarios (for instance, requiring a minimum or absolute percentage of climate-friendly technologies, assuming a significant increase in energy efficiency or placing a limit on emissions). The model then optimises the energy system within the parameters of these new constraints. It is then possible to compare any mitigation scenario (or intervention) to the reference scenario in terms of the total cost in the energy system and other factors, such as CO_2 emissions.

Energy models, including MARKAL, have various limitations which need to be considered when interpreting outputs. First, the structure of the energy system remains static over the modelling period. In reality over 47 years, currently unknown technologies will enter the system. These cannot be reflected, but do limit the approach. Second, MARKAL and other models simulate decision-making in a relatively simple way (usually using only a few quantitative criteria). The results are driven by the objective function, which is to minimise costs. More complex criteria (such as public resistance to nuclear power) can be approximated roughly by imposing constraints (for instance, limiting investment in nuclear power plants). Third, a specific failing of

MARKAL is its inability to account satisfactorily for peak load in the electricity sector, since although the model distinguishes between day and night (and summer, winter and intermediate periods), it does not make finer time distinctions. Thus, the model has a tendency to generate less electricity from peak-load power stations than would be the case in a real electricity system. Fourth, major drivers of energy demand, such as GDP and population, are not explicitly represented within MARKAL. Energy demands and projections are calculated outside of the model, and in the model must be met from the various technologies, fuels and energy sources.

The LTMS MARKAL model was extended to allow analysis beyond the usual energy planning horizon, up to 2050. The thirty-year version of the MARKAL model was internationally reviewed by AEA Energy & Environment. The review found that the SA energy system was well represented to provide reasonable outputs, with the characterisation of upstream, transformation/conversion and end-use sectors (industry, residential, commercial, transport, agriculture); the model was well balanced, with an appropriately detailed specification across the different sectors; most technologies were characterised properly, with use of appropriate cost and technical parameters; tracking of energy and emissions across the system ensures that model outputs can be properly interpreted; and model development appears to have been done in a logical manner, with appropriate naming conventions and documentation of core data and assumptions. Some general recommendations were made to further develop the model, without being critical to its usability. Recommendations focused on technology characteristics (future costs/technical performance), adding novel or emerging technologies; further energy conservation measures; and loosening some constraints (AEAEE 2007). In sum, the MARKAL model passed international peer review during the process.

After the conclusion of the LTMS work, a team from the World Bank conducted an overall review. It found that:

> Overall, the review team believes that the LTMS is the first of its kind in developing countries with South Africa a leader in this area. The team found that the combination of research-based scenarios with stakeholder consultation process was a pioneering effort to provide high-quality information for decision-making on climate change response strategies in South Africa. The methodologies used in the research were consistent with international best practice and the results are robust. Notwithstanding the

> potential improvements that could be made in future work, the results clearly provide the basis of best available scientific information for decision-makers. The work lays a robust basis for development of domestic sectoral implementation efforts. The energy modelling underpinning most of the analysis was found to be robust. The dynamic economic modelling should be completed as a matter of priority. Already, the existing analysis enables proactive planning for a transition to a low-carbon economy. The innovation shown in the LTMS scenarios would be worth sharing with other developing countries. (World Bank 2008)

Modelling energy demand

The energy modelling approach described above starts from projections of energy demand. The energy model used for LTMS was based on energy demand from key sectors—agriculture, commerce, industry, residential and transport. In this breakdown, mining is part of industry. The structure and major assumptions for the reference case of each of the following sectors are reported in greater detail in the LTMS Technical Appendix (ERC 2007a: section 4) and are summarised on pages 13 to 19 below from **Industrial energy demand** to **Agricultural energy demand**. Table 2.1 shows the fuel use, for all fuels combined in energy content and measured in units of PetaJoules (PJ), by sector for the Growth without Constraints case. It is these fuel use demands that are used to provide the starting point for analysis, before turning to electricity generation and liquid fuel supply.

Table 2.1: Fuel use by sector in the GWC case for selected years

Units: PJ	*2003*	*2005*	*2015*	*2025*	*2035*	*2045*	*2050*
Agriculture	122	124	150	207	285	369	413
Commerce	110	117	175	275	397	519	581
Industry	1 245	1 332	1 918	2 863	4 160	5 649	6 462
Residential	216	222	254	284	300	311	315
Transport	672	720	1 136	1 800	2 698	3 654	4 145
Total	2 365	2 516	3 634	5 430	7 841	10 503	11 915

Industrial energy demand

In the model, the industrial sector is disaggregated into three major sectors: gold mining, other mining and the rest of industry. Industry combines iron and steel, non-ferrous metals, non-metallic minerals, pulp and paper, chemical and petrochemical, food and tobacco, and other, a breakdown for energy modelling previously used in South Africa (Howells 2004; Trikam 2002).

End-use demands are split up into heating (boilers and process heating), cooling, compressed air, HVAC, facility support, lighting and a few other end-use demands. All these demands, besides boiler heat, are met with electricity. Boilers are fed with an assortment of fuels, such as coal, bagasse and heavy fuel oil, as well as electricity for electrode boilers.

How fuel use changes in industry over time is shown in Table 2.2.

Table 2.2: Fuels used in industry in the GWC scenario, selected years

Units: PJ	*2001*	*2005*	*2015*	*2025*	*2035*	*2045*	*2050*
Coal	613	710	1 023	1 592	2 464	3 530	4 137
Diesel	19	21	27	40	59	81	94
Electricity	412	470	642	962	1447	2033	2365
Gas	8.3	9.6	14	22	34	48	56
HFO	52	60	87	136	210	301	353
HRG	15	17	24	37	58	83	97
LPG	0.11	0.12	0.17	0.25	0.38	0.54	0.63
Paraffin	0.41	0.46	0.63	0.95	1.44	2.04	2.38
Bagasse	51	59	85	132	205	294	345
Biomass	35	41	59	92	142	204	239

Transport energy demand

The modelling of energy demand in the transport sector is based on previous work done at the ERC (Vessia 2006). One major difference is that, in the older version of the South African national MARKAL model, the demand for transport was given in vehicle-kilometres for specific types of vehicle. This made it difficult to simulate change from one mode of transport (e.g. private cars) to another mode of transport (e.g. buses or trains). The new model allows for more flexibility by setting the demand to passenger-kilometres for passenger transport and tonne-kilometres for freight. With this method one has to assume an occupancy or tonnage for each type of vehicle. These assumptions are given in Table 2.3.

When calculating the energy efficiency of freight vehicles it is assumed that the vehicle is full for half of the journey (i.e. half the kilometres) and empty for the other half—that is, return journeys are not used. Fuel efficiency for diesel vehicles is assumed to be 85% of the efficiency of petrol vehicles. New vehicles are assumed to have an efficiency of 90% of the given efficiency to account for city driving versus open-road driving as well as a decrease in efficiency with the increased age of a vehicle (Kwon 2006). In a study performed in Great Britain it was concluded that, while fuel consumption rates may have improved over time, this was partly offset by an increase in the average engine capacity of vehicles. Thus we use an annual efficiency improvement of 0.9% compared with the potential improvement of 1.1% if there was no change in average engine capacity (Kwon 2006). A recent study in the US showed that households do not consider fuel prices when making decisions about vehicle or gasoline purchases (Turrentine & Kurani 2007). The recent trend has been towards buying vehicles with larger engines, and fuel prices do not increase per unit for higher consumption. If fuel use and emissions are to be reduced, government may need to introduce some charges for less efficient vehicles—either on the fuel or on the emissions per kilometre.

Table 2.3: Assumptions for occupancy and load for passenger and freight vehicles

Passenger vehicles	*Occupancy (persons/vehicle)*
Diesel buses	35
Petrol taxis (minibus)	10
Diesel taxis (minibus)	10
Petrol cars	2.1
Diesel cars	2.1
Hybrid cars (diesel)	2.1
Hybrid cars (petrol)	2.1
SUVs diesel	2.1
SUVs petrol	2.1
Motorcycles	1

Diesel freight vehicles	*Load (ton/vehicle)*
Light commercial vehicle	3
Medium commercial vehicle	10
Heavy commercial vehicle	15
Petrol freight vehicles	
Light commercial vehicle	3

Another addition to the model is the inclusion of separate categories for sport utility vehicles (SUVs) and hybrid vehicles. The cost for SUVs is averaged from the cost of the following Toyota vehicles for both petrol and diesel: Land Cruiser GX, Land Cruiser Pickup, Land Cruiser Pickup Brutus and Land Cruiser Prado VX. Few data were available for sales of these types of vehicle at the time of the study, as they were new to the market. This makes it difficult to predict the growth patterns for these vehicles in the future. Research was done on the penetration rates of SUV and hybrid vehicles into foreign markets to get some idea of future penetration rates in South Africa.

The United States Department of Transport estimated that in 2004 there were 24.3 million SUVs on the road versus 137.6 million ordinary cars. In new vehicle sales, an estimated 27% of new vehicle registrations in 2002 were SUVs (Plaut 2004). In 2004 hybrid vehicle sales made up 0.52% of the market share and were forecast to reach 3% by 2011 (De Haan et al. 2006).

In South Africa the situation is somewhat different, since only approximately 5% of households could afford to buy an SUV or hybrid vehicle.[1] If each household has two vehicles, 10% of vehicles are owned by the top-income households and could potentially be SUVs or hybrids. Keeping in mind the percentage of SUVs and hybrids in new car sales in the US and the fact that the top 10% of vehicles on the road *could* be SUVs or hybrids, we assumed that, by 2035, 40% of these top 10% of vehicles will be SUVs and 10% will be hybrids. This equates to 4% of the total fleet of private passenger vehicles consisting of SUVs and 1% of hybrids. These estimates are in line with original estimates.

The demand for transportation fuels is met through various types of vehicle using an assortment of energy carriers, with liquid fuels such as diesel and petrol being the most dominant. The model has the flexibility to include bioethanol and biodiesel into the transportation fuel mix in any ratio specified. While these fuels are not currently used in South Africa on a large scale, with the growing interest in biofuels and the construction of a bioethanol plant underway at the time of the study (25 Degrees 2006), this flexibility allows the model to perform more realistic future scenarios. In the base case (GWC) it is assumed that bioethanol and biodiesel will be made available from 2008—and indeed some was introduced in that year. The biofuel strategy indicated that petrol and diesel should blend

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[1] We assume that households with an income of R18 000 per month or higher are able to afford an SUV. These households fit into LSM (Living Standards Measure) 10 as described by the South African Advertising Research Foundation (SAARF 2005).

in biofuels in ratios of 10% and 5% respectively by 2012 (DME 2006). Thereafter the biofuels ratios are assumed to remain constant.

Commercial sector demand for energy

The commercial sector's energy demands consist of cooling, lighting, refrigeration, space heating, water heating and 'other' demands that are met by various technologies using a range of energy carriers.[2]

The energy demand in this sector is calculated using the floor space for a given commercial activity and the increase in energy demand is modelled on an increasing floor space area. Floor space projections are generated using regression analyses with the GDP growth projections for various commercial buildings (warehouses, offices, etc). These are then summed up to give the total floor space projection. Total floor space projections from 2000 to 2030 based on the GDP growth (see rates on page 41 under **Gross domestic product**), and are indicated by the uppermost line in Figure 2.1. The figure also shows break-down of this growth by commercial building type.

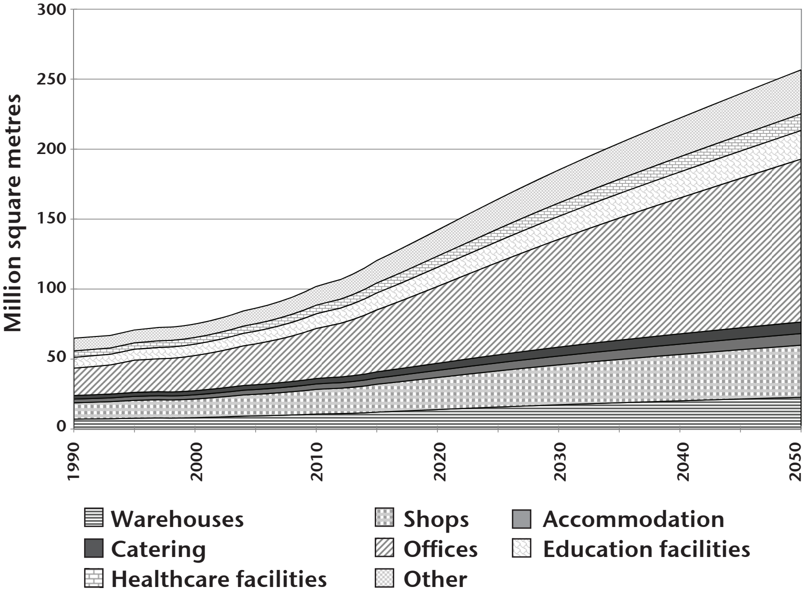

Figure 2.1: Floor space growth projection by type

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[2] Energy carriers include fuels—which are primary energy—but also electricity, which must be derived from a fuel and hence is a secondary energy carrier.

Total commercial energy demand is derived by multiplying the floor space by an average (for the GWC scenario) of 350 kWh / m^2 per year (De Villiers 2000). Seasonal variations are taken into account (for further detail, see ERC 2007a).

Residential energy demand

The vast range in residential incomes in South Africa means that the energy demand of households differs substantially. Higher income households tend to demand more energy because they use more electric appliances, whereas lower income households tend to use more traditional energy sources (Mehlwana 1999; White et al. 1997). Whether a household is situated in an urban or rural setting also impacts on the energy use and particularly on the type of fuel used to meet energy demands (Prasad 2006; Thom 2000). In many rural areas wood is available, whereas a household in a similar economic bracket in the city may be using coal. To capture these differences within the model, the residential sector is divided into six different household types (based on Winkler 2006b). Table 2.4 shows the different housing types and the number of households in each type in 2001.

Table 2.4: Household type and number of households of that type in 2001

Household	*Number of households*	*Share of all households*	*Notes and assumptions*
Urban rich electrified (UHE)	4 074 438	36.4%	Virtually 100% of rich urban households are electrified.
Urban poor electrified (ULE)	1 255 728	11.2%	Remainder of urban electrified households must be poor.
Urban poor unelectrified (ULN)	1 349 240	12.0%	Rest of urban must be non-electrified.
Rural rich electrified (RHE)	1 181 279	10.5%	Assume 84% of rich rural households are electrified.
Rural poor unelectrified (RLE)	1 095 449	9.8%	Remainder of rural electrified must be poor.
Rural poor unelectrified (RLN)	2 249 571	20.1%	Rest of rural households must be non-electrified; number of households includes the few rich rural not electrified.

Source: (Winkler 2006b)

In this study, households using the least energy are those in the bottom two quintiles of income earners (an annual per capita income of less than

R4 033). Households that fall into a 'middle class' have been included in the 'rich' category (Winkler 2006a). There are limitations to this analysis, notably that the complexity of household types is much greater. This needs, however, to be balanced against the additional complexity introduced into modelling by additional household types—due to which other studies are often simplified to a single 'residential sector'. For a national-level mitigation analysis, this disaggregation is appropriate.

Energy demand in the residential sector is categorised into cooking, lighting, space heating, water heating and other electrical demands. Originally, refrigeration and laundry were included as separate demands. However, national data are not available for such a disaggregation. Data collection in the residential sector is difficult and expensive and therefore the data on household numbers in the model are drawn from census data. Census 2001 gives numbers of households that use a particular fuel to meet a specific demand. From these numbers of households, an energy use is calculated given a fuel use per household. The factor of fuel use per household is an approximation and leads to some inaccuracies. In areas where figures look highly unlikely, an expert (Visagie 2006) was consulted and numbers were adjusted, keeping total fuel use similar to what was reported in the DME National Energy Balance for 2001.

The demand for energy increases as the population increases, to the extent that with population growth there is obviously an increase in the number of households. There is also an increase in energy demand as households become richer and thus own more appliances and require more energy. This factor is taken into account with the shifting of household types as people get richer and more urbanisation takes place.

Agricultural energy demand

In the agricultural sector, demands for heat, processing energy, irrigation, tractors, harvesters and other energy needs (all in PetaJoules or 10^{15}J) are met through various types of vehicle or machinery and fuel sources. Technologies using liquid fossil fuels (tractors, harvesters and pumps using diesel or petrol) are able to use a biofossil fuel blend. Tractors and harvesters are also able to run on pure bioethanol or biodiesel where a farmer may be producing his or her own biofuel for use in farm vehicles. The demand for energy increases in time with respect to the agricultural GDP.

Power plants

Since electricity generation accounts for some 40% of GHG emissions in South Africa (RSA 2004), the mitigation potential in the power sector is high. Consequently, the data on costs and other characteristics of new power plants were of considerable interest in the LTMS process.

The cost of a power plant is not a simple number. Various cost differences are found in the literature, sometimes reflecting different characteristics, at other times different locations. For established technologies, there are more data points, but numbers can still vary. The approach taken for the LTMS was to compare cost data used in previous work and to examine these in detail with stakeholders.

These values were derived by comparing values in previous work, including work done for the second National Integrated Resource Plan (NIRP2) (NER 2004); work underway for the third NIRP, checked by Sonwabo Damba, seconded to DME and the LTMS process (NIRP3; a study conducted by ERC for UNDESA and IAEA (IAEA) (Winkler 2006a); and various international studies (including Banks & Schäffler 2005; EIA 2006; Harmon 2000; IEA & OECD 2006; NEA, IEA & OECD 1998, 2005; NREL 1999; RAE 2004). The full range of values found in the literature is included in a spreadsheet on the CD-Rom accompanying this book. Explanations of why certain values were chosen are listed in 'Notes' columns in these tables. The general approach was to prefer local sources and to choose a number within the range of peer-reviewed studies and official plans.

All major existing Eskom plants are included explicitly in the model and smaller plants such as the hydro plants Gariep and Van der Kloof are included collectively as Eskom hydro plants. Currently mothballed coal-fired plants that are planned to come online before 2030, such as Groot Vlei and Komato, are included in the model. New plants that are under construction, such as the New Braamshoek plant and the CCGT plant planned for Coega, are also in the model. Existing municipal plants are collectively included as a single unit.

All new coal plants are assumed to have flue-gas desulphurisation (FGD). Proven technologies such as certain renewable energy technologies, clean coal technologies or Pebble Bed Modular Reactor (PBMR) nuclear technology are also included. For new technologies, a technology learning rate has been applied such that over time new technologies decrease in cost due to economies of scale and 'learning by doing'.

Table 2.5: Characteristics of new electricity-generation technologies

	Capex: pv capital expenditure (R/kW in yr–2003 R)	*Fixed O&M costs (R/kW / yr–2003 R)*	*Variable O&M costs (R / MWh / yr, R/MWh for imports–2003 R)*	*Capacity per unit (MW)*	*Expected operating lifetime (Years)*	*Efficiency (%)*	*Lead time (Years – construction lead time)*	*Availability factor (%)*	*Capacity factor (%)*
PF dry-cooled with FGD	R9 980	R125	R7.5	642	30	34.6	4	88	
Fluidised bed combustion (FBC) greenfield with FGD	R11 511	R205	R19.5	233	30	36.7	4	86	
Super-critical coal with FGD	R11 015	R227	R16.9	600	30	40.0	4	88	
Integrated gasification combined cycle (IGCC)	R10 564	R141	R19.1	550	30	46.3	5	88	
Combined cycle gas turbine (CCGT) (w/out transmission benefits) LNG	R4 171	R175	R10.6	387	25	50.0	3	85	
Open cycle gas turbine (OCGT)1	R2 753	R80	R65.9	120	25	33.0	2	85	
Imported hydro-electricity (Cahora Bassa)			R92.2			n/a			n/a

→

	Capex: pv capital expenditure (R/kW in yr–2003 R)	*Fixed O&M costs (R/kW / yr–2003 R)*	*Variable O&M costs (R / MWh / yr, R/MWh for imports–2003 R)*	*Capacity per unit (MW)*	*Expected operating lifetime (Years)*	*Efficiency (%)*	*Lead time (Years – construction lead time)*	*Availability factor (%)*	*Capacity factor (%)*
Imported hydro-electricity (Mepanda Uncua)			R161.3			n/a			n/a
Imported hydro-electricity (Inga)			R126.7			n/a			n/a
Imported coal-fired electricity (Mmamabula)			R-			n/a			n/a
Imported gas-fired electricity (Kudu)			R235.4			n/a			n/a
Central solar receiver ('power tower' with molten salt as HTF)	R22 200	R178	R0.1	100	30	n/a	3		51
Parabolic trough (thermal oil as HTF)	R22 500	R147	R0.1	100	30	n/a	3		40
Photovoltaic	R49 000	R69		5	30	n/a	2		20
Wind turbines	R7 768	R167		5	20	n/a	2		20 25
Landfill gas	R4 287	R156	R0.4	3	25	n/a	3		89

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	Capex: pv capital expenditure (R/kW in yr–2003 R)	*Fixed O&M costs (R/kW / yr–2003 R)*	*Variable O&M costs (R / MWh / yr, R/MWh for imports–2003 R)*	*Capacity per unit (MW)*	*Expected operating lifetime (Years)*	*Efficiency (%)*	*Lead time (Years – construction lead time)*	*Availability factor (%)*	*Capacity factor (%)*
New biomass co-generation	R23 000	R154	R22.9	8	30	n/a	4		68
New small hydro	R10 938	R202		2	25	n/a	1		30
PBMR (excl transmission benefits)	R18 707	R158	R6.7	165	40	40.5	4	95	
PBMR later series multi-module	R10 761	R158	R6.7	165	40	40.5	4	95	
PWR (excl trans benefits)	R15 290	R507	R25.0	874	40	31.5	4	79	
Pumped storage (Braamhoek)	R4 619	R37	R9.0	333	35	76.0	7	97	
Pumped storage (generic)	R4 822	R49	R9.0	333	40	76.0	7	97	

Transmission costs are not included in the model for either existing or new plants. However, certain types of plant that do not need to be built near a fuel source, for example nuclear power plants and gas turbines, have been given a ‘transmission benefit’ in the form of slightly reduced cost.

The lead times given are construction lead times, and do not include time required for pre-feasibility and EIA processes. The lead times including these processes may be longer, and high global demand for power plants may affect timing of actual implementation. Variable operation and maintenance (O&M) costs as inputs to the MARKAL model do not explicitly include fuel costs, but costs attached to fuels upstream have been taken into account by the model. The results therefore do report all variable costs, including fuel. Open-cycle gas turbines may use a variety of fuels (LPG, kerosene, natural gas or syngas) which differ only by fuel costs (NER 2004).

The variable O&M costs for imports are in R/MWh, not per year. This reflects an estimate of the price that would be paid for imported electricity, independently from when it was generated and from source, be it from hydro-electric, gas- or coal-fired stations.

Wind turbines have been modelled at two capacity factors—20% and 25%—at the same cost. The difference lies in the wind resource. Since the energy model would simply choose the higher capacity factor turbine if unconstrained, an upper limit has been placed on the wind turbines to reflect the number of good sites available.

The capital cost and capacity factors for solar thermal plants (the ‘power tower’ as well as the solar trough) are within the wide range of capital costs reflected in the literature (Banks & Schäffler 2005; De Vries, Van Vuuren & Hoogwijk 2007; DME 2004; EDRC 2003; IEA 2003; IEA & OECD 2006; NREL 1999; Philibert 2005; Sargent & Lundy 2003; UNEP 2006; Winkler 2006a; World Bank 1999, 2006). The values reflected in Table 2.5 are drawn from a recent study citing data on a plant to be built in South Africa near Upington (World Bank 2006: 90–91). Eskom agreed to proceed with these numbers with caution, as the plant has not yet been built.

The costs of combined cycle gas turbines (CCGT) do not include costs of regasification plant, but such costs have been included within the fuel costs, considered upstream in the model.

The exchange rate is relevant for imported capital equipment. In the model, the investment costs of power plants are first taken in dollars, and then converted by the exchange rate of R7.50 in 2003, increasing at 2% per year.

With regard to imported coal-fired electricity from Botswana, available information suggests that two phases of approximately 2230 MW each will be developed, with the first phase starting in 2011.

The efficiency of super-critical coal-fired stations raised much discussion. The value eventually used for the efficiency of super-critical coal-fired stations is 40%, within the range of efficiencies reported internationally, from 36% to 42% (NEA, IEA & OECD 2005). There is also evidence that in developing countries efficiency may be lower than international values (Chikkatur & Sagar 2006). Given these various factors, the LTMS reduces the efficiency of super-critical coal-fired stations to 38% for the first new stations built, and includes more efficient stations (at 40%) from 2030 onwards.

No ultra-super-critical plants have been modelled, since only incomplete information is available. Similarly, not enough information is available on the potential for co-generation.

Refineries

Apart from electricity, the other major energy supply sector in South Africa is liquid fuels. South Africa makes liquid fuels by three different processes: refining crude oil, converting coal and converting natural gas. Liquid fuels come from four oil refineries: Sapref, Genref, Calref and Natref; from Sasol's two coal-to-liquid plants at Secunda; and from the Mossgas natural gas-to-liquid plant at Mossel Bay.

The focus of the model is on potential new additions, assuming that the existing refineries continue to exist. All existing refineries have been included in the model as a single unit of refining capacity, with only synfuel plants separated out. New crude oil refineries are assumed to have a capacity of 300 000 barrels (bbl) per day. A new coal-to-liquid (CTL) plant has been included as an option, with 80 000 bbl-equivalent / day, as shown in the summary of key characteristics in Table 2.6.

The new bioethanol plant under construction in Bothaville in the Free State has been included explicitly in the model. Plans are in place for another seven such plants to be constructed in the Free State, North West and Mpumalanga.

Refineries can be set up to produce outputs in different ratios. The outputs for different refineries are reported in Table 2.7 by energy output.

Table 2.6: Key characteristics of refineries

	Capex: PV capital expenditure (million R / PJ in year 2003 R)	*Fixed O&M costs (R / GJ / year (2003 R)*	*Variable O&M costs (R / GJ / year (2003 R)*	*Expected operating lifetime (Years)*	*Capacity factor (%)*
Crude oil					
Petrol-intensive 300 000 bbl/day	66	9.4	1.9	25	92%
Diesel-intensive 300 000 bbl/day	66	9.4	1.9	25	92%
Generic 300 000 bbl/day	66	9.4	1.4	25	92%
Gas-to-liquids	[2003 R/GJ]				
New GTL based on PetroSA	148.70	10.94	11.45	25	0.93
Coal-to-liquids	[2003 R/GJ]				
New CTL based on Sasol	272.16	9.45	3.43	25	0.96
Maize-to-ethanol	159.83	33.360	40.773	25	0.96
Biodiesel					
Large biodiesel plant	52.91	6.00	9.70	25	0.96
Small scale biodiesel plant	234.9	18.21	29.71	25	0.82

Table 2.7: Output splits of different existing refineries

Oil refinery		*GTL output split*		*CTL output split*	
Diesel	31.5%	Diesel	24.0%	Diesel	20.9%
Fuel oil	23.6%	Fuel oil / alcohols	8.2%	Fuel alcohols	12.4%
Jet fuel	8.9%	LPG	6.9%	Jet fuel	2.2%
LPG	1.7%	Paraffin	9.9%	LPG	1.9%
Paraffin	2.9%	Petrol and aviation gas	51.0%	CH_4 rich gas	2.9%
Petrol	30.7%			Paraffin	2.2%
Refinery gas	0.7%			Petrol and aviation gas	57.5%
				H_2 rich gas	0.0%

The output splits or product slates for new refineries are assumed to be different from existing ones, as the demand for fuels shifts towards diesel.

Table 2.8: Output splits for new refineries

	Generic new	*Diesel-intensive*	*Petrol-intensive*	*New CTL*
Avgas	0.3%	0.3%	0.3%	
Diesel	34.9%	42.6%	34.5%	73.0%
HFO high sulphur	21.4%	11.4%	11.4%	
Jet fuel	7.9%	11.0%	11.1%	
Illuminating paraffin	3.0%	3.0%	3.0%	
LPG	1.8%	2.4%	1.9%	3.4%
Petrol	30.7%	29.3%	37.8%	23.6%

Industrial process emissions

In addition to the substantial emissions from use of energy in industry combustion (see **Industrial energy demand** on page 13), industrial processes result in emissions not attributable to energy use. The non-energy emissions are reported in this section. They have been analysed separately in the LTMS. The following industries are considered in this respect:

a. **mineral products**: cement production; lime production and dolomite use;
b. **chemicals**: ammonia production; nitric acid production; carbide production; and other chemicals;
c. **metals**: iron and steel; ferro-alloys;
d. **mine emissions**: coal mining; and
e. **synfuels specific emissions**: methane emissions; concentrated CO_2 streams; expanded coal-to-liquids production.

Table 2.9 reports industrial process emissions and the relevant base year. Industrial process emissions were modelled using a spreadsheet extrapolation from the base year in each case (Kornelius et al. 2007). Since no updated figures were available for GHG emissions from non-energy industrial processes, these were derived from the national GHG inventory figures for 1990,[3] and estimated for the base year by either applying the relevant 1990 emissions factor to the annual growth rates of the industries concerned, or modifying the emissions factor according to relevant technology developments in the industries between 1990 and 2003. The base year for each industry differed slightly due to the availability of production data (Kornelius et al. 2007). In addition to this, some figures in the Inventory for 1990 were found to be inaccurate or absent, and were re-assessed.

Except for a few (pre-2009) short-term variations described in Table 2.9, all industries except coal and synfuels have been assumed to grow at the same rate as the GDP rate used in the MARKAL model (see drivers under **Gross domestic product**, page 41). The coal and synfuels industries are likely to grow at the same rates as these industries do in the Growth Without Constraints (GWC) scenario in the energy model. Several new CTL plants are built in the GWC case in the model, and growth in the coal industry is determined by growing demand for coal as feedstock for electricity and liquid fuels. Emission factors will probably remain constant, with the following exceptions:

- **Synfuels**: new CTL plants are assumed to have methane capture, and thus there will be no methane emissions.
- **Aluminium**: for new production capacity (built after 2003), emissions of PFCs are significantly reduced, resulting in the total emissions factor dropping from the 2003 value of 0.00232 Gg per ton of production for existing capacity to 0.00128 Gg / ton of aluminium produced for additional capacity.

The mitigation options have been limited to six sectors: synfuels, coal mining, aluminium, cement, iron and steel and ferro-alloys. The options were selected as the outcome of local consultation and a survey of local and international literature, including the previous GHG inventory (Van der Merwe & Scholes 1998) and the associated country studies used in preparation of South Africa's Initial National Communication (RSA 2004); the Technology Needs Assessment (CSIR 2006; DST 2007) and the IPCC guidelines (IPCC 1996, 2006).

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[3] At the time of the LTMS study, the inventories for 1990 and 1994 compiled by Van der Merwe and Scholes (1998) were the most recent years available. The National Inventory Report, including an inventory for 2000, had reached final draft stage, but was still undergoing peer review in mid-2009 (DEAT 2009).

Table 2.9: Industrial process emissions data

Industry	*Inventory year*	*Base year*	*Inventory year production — tons of product*	*Base year production — tons of product*	*Inventory year emissions — Mt CO_2-eq*	*Base year emissions — Mt CO_2-eq*	*Inventory year emissions factor—kg CO_2-eq per ton product*	*Base year emissions factor — kg CO_2-eq per ton product*	Growth in emissions
Cement production	1990	2003	8 450 000	9511469	7.859	6.798	930	715	MARKAL elasticity
Lime production	1990	2002	1 862 000	1700000	1.49	1.36	800	800	MARKAL elasticity
Limestone/ dolomite use	1990	2002	2 340 000	3 393 000	1.06	1.425	453	420	MARKAL elasticity
Ammonia production	1994	2003	762 000	775 000	-	1.892	2 450	2 450	MARKAL elasticity
Nitric acid production	1990	-	274 659	-	-	1.595	-	-	MARKAL elasticity
Carbide production	1990	2006	269 000	70 000	0.293	0.076	1 090	1 090	MARKAL elasticity
Iron and steel production	1990	2003	6 256 961	7 800 000	10.011	12.494	1 600	1 600	MARKAL elasticity
Ferro-alloy production	1990	2004	1 796 700	3 931 000	2.698	5.618	1 501	1 429	MARKAL elasticity

→

Industry	*Inventory year*	*Base year*	*Inventory year production — tons of product*	*Base year production — tons of product*	*Inventory year emissions — Mt CO_2-eq*	*Base year emissions — Mt CO_2-eq*	*Inventory year emissions factor—kg CO_2-eq per ton product*	*Base year emissions factor — kg CO_2-eq per ton product*	Growth in emissions
Aluminium production	1990	2004	175 500	865 000	0.761	2.01	2 320	2320/1500	0 until 2007, then 80%, then MARKAL elasticity from 2008
Coal mine methane	1990	2003	-	MARKAL	-	6.55	29	29	MARKAL output
Synfuels concentrated CO_2	1990	2003	-	-	23	23	-	-	MARKAL output
Synfuels point-source methane	1990	2003	-	-	3.738	3.738	-	-	MARKAL output

Non-energy emissions in waste, agriculture and land use

Emissions from sectors other than energy account for about one-fifth of South Africa's total greenhouse gas emissions (RSA 2004; Van der Merwe & Scholes 1998). While not the major source of our emissions, they still represent a substantial proportion. Non-energy sectors considered in LTMS include:

a. waste (solid waste treatment, waste water treatment);
b. agriculture (enteric fermentation, manure management, reduced tillage, burning of sugar cane residues); and
c. other land use (wild fire, savanna thickening, afforestation).

Three of the non-energy sectors (waste, agriculture and land use) were analysed by a team from the CSIR (Taviv et al. 2007). Analysis for industrial process emissions, which deals with non-energy emission in industry, was assessed by Kornelius et al. (2007), as described on page 27 under **Industrial process emissions**.

The non-energy sector consists of a number of very diverse activities and these were analysed by a set of predictive models. The analysis of non-energy emissions therefore could not be conducted through a single model, but in a series of spreadsheets. Local and international literature was assessed to select the mitigation options available in the non-energy sector. The most relevant studies are described for each sector, in addition to the major ones (DST 2007; IPCC 1996, 2006; Van der Merwe & Scholes 1998).

Agriculture has significant mitigation potential (IPCCs Fourth Assessment Report (IPCC 2007a: chapter 8).

International experience, notably the US experience as reported in a publication entitled *Agriculture's role in greenhouse gas mitigation* (Paustian et al. 2006) has provided a point of reference for the role that agriculture can play in GHG mitigation in South Africa. Agriculture has been included as one of the key sectors in South Africa's technology needs assessment for climate change, based on a ranking of priority sectors (DST 2007).

Agricultural mitigation measures often have synergy with sustainable development policies, as many explicitly influence social, economic and environmental aspects of sustainability. Many options also have co-benefits, such as improved efficiency, reduced cost, environmental co-benefits, as well as trade-offs (e.g. increasing other forms of pollution), and balancing these effects is necessary for successful implementation (IPCC 2007b: chapter 12).

Agriculture is included not so much for the scale of emissions but for the other benefits that mitigation in this sector can deliver. Agriculture accounted for about 10% of total emissions (Van der Merwe & Scholes 1998).[4] The particular mitigation actions examined in LTMS are manure management, enteric fermentation and low-tillage agriculture.

Most of the mitigation options considered are based on the reduction of methane (CH_4) emissions. Since CH_4 has a much shorter lifetime in the atmosphere than CO_2 does (about 12 years compared to 120 years for CO_2), and its 100-year global warming potential is 25 times higher[5] on a mass basis than for CO_2 (IPCC 2007c), it is considered an excellent candidate for mitigation, since its stabilisation in the atmosphere can be achieved much sooner than is the case for CO_2.

The selection of the areas where additional research and the acquisition of new data are critical is based on the relative importance of the sector in terms of mitigation potential and relative size of the error that results from the uncertainty associated with the existing calculations. This is tabulated in Table 2.10.

The two columns on mitigation potential in Table 2.10 make it clear that there is large potential for reducing emissions through:

- enhancing sinks by fire control and savanna thickening;
- solid waste management; and
- enteric fermentation.

Although existing models have been used where possible, some models and calculations have been updated in cases when new information became available to allow for more accurate modelling. Even if the model calculations have a large level of error (50 to 100%) the resulting error will be only about 1% of the total emissions for 1990.

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[4] At the time of the LTMS studies, GHG inventories were available for two years, and agriculture accounted for 11.6% (1990 inventory) and 9.3% (1994), hence about 10%. Subsequently, the inventory for 2000 is being compiled, and the share has declined further to 4.9%; this inventory was still undergoing review in mid-2009. Greater increase in non-agricultural emissions and changes in data assessed may be two factors that explain the declining share.

[5] The global warming potential of methane was amended to 25 in the fourth assessment, but for CDM projects the previous value of 21 from the second assessment is still used until the new numbers are adopted by parties for use under the Convention and its instruments.

Table 2.10: Uncertainty associated with sector emissions and accuracy of existing models (based on the total national emissions for 1990 of 347 346 Gg CO_2-eq)

Sector	*1990 emissions* (Mt CO_2-eq)	*% of total (%)*	*2003 emissions*	*Average (2003–2050)*	*Mitigation potential (%)*	*Mitigation potential (2003–2050)* (Mt CO_2-eq)	*Uncertainty %*	*Error* (Mt CO_2-eq)	*Error (% of national emission) (%)*
Agriculture	22.34	6.43							
Enteric fermentation	19.25	5.54	18.13	18.11	36.06	6.53	50	3.26	0.94
Manure management	2.17	0.62	1.87	2.00	49.46	0.99	50	0.49	0.14
Agricultural soils (reduced tillage -80% adoption)	14.53		–4.72	–3.95	–52.73	2.08	100	2.08	0.60
Waste									
Solid waste (S5)	7.53	2.17	13.92	16.32	55.12	9.00	50	4.50	1.30
Land use									
Fire control and savanna thickening (sequestration)			–3.29	–0.55	–1740.55	9.49	50	4.74	–1.37
Afforestation (sequestration)			–5.42	-4.08	-103.28	4.21	50	2.11	–0.61

Source: (DEAT: National Communication report RSA 2004)

The potential reduction in the use of fertilisers is an important mitigation option in developed countries. However, in South Africa, the amount of fertiliser used per hectare is already relatively low and therefore the mitigation potential is considered as limited.

Costs of mitigation

The methodology so far has focused on GHG emissions, one of the results parameters of critical interest in the LTMS process. The other key parameter is cost. The broad questions informing the LTMS process include 'What will it cost?' There are different ways of answering this question. A key result of the LTMS study was to establish, based on best available estimates, the cost of reducing a ton of GHG emissions—called the mitigation cost. This is the *unit* cost of mitigation, and LTMS followed a well-established methodology in calculating these. The units for this central measures of cost in LTMS are rands per ton of CO_2-eq.

Other cost measures would include total costs, the upfront investment requirement, the costs of delay, the broader socio-economic costs or the cost as a share of economic output. The limitation of unit costs is that they do not give a sense of scale. To express the overall costs, a methodology for costs was developed, expressed as a share of GDP. This approach relates overall costs to the overall size of the economy, leaning on work done on the economics of climate change (Stern Review 2006). The costs can also be expressed as a share of the costs of the overall system in which they arise, for example as an increase in the costs of the energy system.

Both the above measures apply to direct costs, for example the difference in costs between building a wind farm rather than a coal-fired power station. But the wind farm uses different inputs from coal (more steel, less coal) and thus affects other parts of the economy. Economy-wide modelling is the tool used to seek to include the indirect effects—that is, the direct difference of costs of coal versus wind, and also the difference in input costs. It is also important in providing a basis for considering potential impacts on the poor, by considering not only the impact on GDP but also job creation and income distribution. The methodologies for each approach are laid out in the following sections.

Mitigation cost methodology

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

The approach can be summarised[6] as follows:

- The lifecycle costs[7] of the mitigation options and baseline have been calculated by discounting all of the costs of these options to a present value.
- These lifecycle costs are then levelised, discounting them and expressing them in rands per year.
- The cost-effectiveness analysis is based on the difference in the levelised lifecycle costs of the mitigation option and the baseline option (levelised annual cost), divided by the average annual reduction in emissions. The costs of the baseline minus the costs of mitigation option are the incremental cost.
- The cost-effectiveness analysis should exclude taxes and subsidies, external costs, depreciation and interest payments but include private costs or costs which can easily be quantified. Implementation costs should be included.

In the energy model, LTMS replicates this approach, using MARKAL result parameters—that is, the parameters that the MARKAL model generates as output. Thus, unlike in the approach above, costs and emissions reductions do not relate to a specific project, but *to the modelled system as a whole*. Thus, a) the cost parameter used from MARKAL is the total system cost, not the cost of a specific part of the energy system, and b) emissions are similarly emissions for the whole system. The lifecycle costs are thus replaced by the total system costs.

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

[7] Lifecycle costs include, but are not limited to, capital costs and O&M costs (see **Modelling energy demand** to **Refineries** pg 13–25.).

Thus, the cost-effectiveness of a particular mitigation action, or the Mitigation Cost (MitC) is the annual Levelised Incremental Cost (LIC).

The MARKAL parameter which is used to derive the discounted system costs is U.ANNADJTOTCOS, an annual real undiscounted cost of the total energy system in the model for a particular year, excluding taxes and subsidies. Thus, to calculate the total discounted system cost, the values for U.ANNADJTOTCOS for the years 2003 to 2050 is discounted using an appropriate discount rate (in this case, for four discount rates: 0%, 3%, 10% and 15%) for the baseline, and for the mitigation action. U.ANNADJTOTCOS does not include taxes and subsidies. Thus, to calculate the LIC, the discounted cost of the baseline and the mitigation action is calculated from U.ANNADJTOTCOS for each case, and then levelised for the total period. LIC is the difference between the levelised costs (LC) of the baseline and the mitigation action, thus,

$$\text{LIC} = \text{LC}_{\text{mitigation action}} - \text{LC}_{\text{baseline.}}$$

The LIC is then divided by the annual average Emissions Savings (ES), or

$$\text{MitC} = \text{LIC} / \text{ES},$$

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

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

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

Non-energy modelling uses the same fundamental methodology, although a significant difference is that each sectoral model compares emissions and costs only within that sub-sector, for example emissions in agriculture with and without low tillage.

Costs as share of GDP or system costs

The LTMS research team examined the literature expressing mitigation costs as unit costs (following, for example, Azar & Schneider 2002; Halsnaes, Callaway & Meyer 1998; Nordhaus 1993). For an overall assessment, however, information about mitigation costs as a share of GDP needs to be included. Generally, mitigation costs as a share of the total economy have been found to be higher in developing than in developed countries.

The mitigation costs as a share of GDP have been used more recently in the Stern Review on the economics of climate change (Stern Review 2006). The Review estimated that 'the annual costs of stabilisation at 500–550 ppm CO_2-eq to be around 1% of GDP by 2050—a level that is significant but manageable'. It contrasted this with the costs of inaction, suggesting that 'BAU [business-as-usual] climate change will reduce welfare by an amount equivalent to a reduction in consumption per head of between 5 and 20%' (Stern Review 2006: Executive Summary pp. x and xii).

While the impact study does not provide a comprehensive monetisation of the damage costs of climate change, it suggests that there would be some costs. The 1% of GDP level can be used as an externally given threshold of an acceptable cost of mitigation. Whether this level should be 1% or some other level would ultimately be a political judgement on what costs are manageable for our country.

The methodology used to calculate share of GDP needs to deal with the fact that mitigation costs change over time. The mitigation costs are discounted (at a range of discount rates) in the R / tCO_2-eq reported in the energy and non-energy modelling. The approach taken to calculating the share of GDP starts with the difference in total energy system costs—that is, the incremental costs of the mitigation 'wedge' minus the costs of the base case, GWC. These costs are reported by MARKAL for each year. The incremental costs are divided by the GDP for the same years, giving a share of GDP per year. Since the percentages change over time—as mitigation cost difference and GDP both change—the average (mean) of the shares is taken. The averaged share of GDP is reported in percentages.

Using a similar methodology, the aggregate mitigation costs are compared to the total energy system costs. Since the energy system is smaller than the economy, its costs are smaller and mitigation costs expressed as a share of these smaller numbers are typically higher.

Economy-wide modelling

Economy-wide modelling makes it possible to assess the direct and indirect costs of mitigation throughout the economy, A dedicated study (Pauw 2007) investigated the economy-wide implications of climate change mitigation scenarios, focusing on changes in production and GDP (value added), employment and income distribution. For some aspects, a Social Accounting Matrix was used as well. A dynamic CGE approach to economy-wide modelling was conducted (Kearney 2008) subsequent to the conclusion of the main technical work, to validate the results and seek to address the limitation of the comparative static approach in the initial study.[8]

Energy efficiency scenarios

Industrial, commercial or transport energy efficiency can be explained in simple terms as a reduction in demand for energy per unit of output produced. Savings in energy use per unit of output will cause production costs and hence consumer prices to decline. Other producers using output from that industry will also benefit (costs decline). End-use consumption will increase demand due to a decline in prices, which causes further economic gains to be realised, both in terms of output, employment and general welfare gains for households.

The **simulations** implemented various percentage reductions in energy use per unit of input, and were compared in the comparative static framework.

- **Industrial energy efficiency**: This includes efficiency in the use of electricity and coal (thermal efficiency) in the mining and manufacturing sectors.
- **Commercial energy efficiency**: This includes efficiency in the use of electricity in the trade, transport and general business services sectors.
- **Transport energy efficiency**: This includes efficiency in the use of petrol and diesel (petroleum) in the transport sector. The analysis excludes private transport.

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[8] Readers interested in the details of the methodology for economy-wide modelling are referred to Pauw (2007) and Kearney (2008) for the dynamic CGE approach.

Structural change (IO/SAM-multiplier and CGE)

Investments in production capacity in cleaner energy supply processes will cause structural shifts in the long run. This occurs once initial investment flows have been converted to changes in capital stock employed in production processes. In the energy context, this implies a relative increase in production capacity towards less carbon-intensive processes, for example biofuels in petroleum, and nuclear or renewable energy in electricity.

Different production processes differ in terms of intermediate input use, value added (labour intensity, skill intensity and wages) and production costs; hence structural shifts will have various upstream and downstream effects in the economy. This requires the following adjustments in the Social Accounting Matrix (SAM):

- **Petroleum sector**: Split petroleum (liquid fuels) into processes representing crude oil refineries, coal-to-liquids, gas-to-liquids and biofuels.
- **Electricity sector**: Split electricity into processes representing coal-fired plants, nuclear energy, renewable energy (wind, hydro and other renewables) and gas turbines.

Increased capacity has been modelled in a comparative static framework. Increasing the total supply of a commodity (petroleum or electricity) by increasing production capacity (capital stock) will distort the market and causes prices to fall (see, for example, Davies & Van Seventer 2006). This is not desirable, hence the LTMS considers *relative* changes in production capacity within a sector.

This approach keeps the demand side constant and does not deal with 'dynamic' issues such as labour force growth, population growth, capital accumulation rules and so on. The subsequent study took a dynamic approach (Kearney 2008).

The simulations in the comparative-static framework consider:

- **A biofuels scenario in the petroleum sector**: This is a mitigation action with greater reliance on biofuels in the final liquid fuels mix.
- **Renewables and nuclear intensive scenarios for the electricity sector**: These are mitigation actions with greater reliance on nuclear or renewable energy in the final electricity supply mix.

These simulations are used to analyse different strategic options generated in the LTMS process (see Chapter 6, page 171 with results reported under **Economy-wide implications of strategic options**). From a methodological point of view, a number of important issues need to be clarified up front. Although essentially forward looking, the modelling exercise focuses on selected short-term economic consequences of mitigation scenarios only and does not attempt to make general economic forecasts. In a meeting as part of the LTMS process with a range of economists, the consensus was that results should be reported in the shorter term—in the context of this study, up to 2015, not 2050. Furthermore, the outcomes described in this section could well be overwhelmed by other economic events that are not dealt with, such as mineral price booms, exchange rate fluctuations, rapid changes in technology and other policy measures introduced during the forward-looking period of observation. Like all models, economy-wide models are abstractions of reality, and make assumptions—such as behavioural rules that assume perfect competition—that are not a true reflection of reality. In practice, any exogenous change, mitigation scenario or otherwise, will set in motion a range of adjustment processes and only a limited number of them, those that are captured by underlying economic theory and economic data, are captured.

Nevertheless, economy-wide models offer an improvement on a simple back-of-the-envelope calculation and policy-makers gain a better understanding from them. The marginal costs of undertaking such analysis have, in the past ten years or so, been reduced considerably in South Africa and a number of modelling frameworks are currently available, one of which has been tested extensively for the National and Provincial Departments of Agriculture and this framework is used here for the exercise described in this section.

In the comparative static analysis, increased investment in one period does not increase capital stock in the next, since the model does not account for time and investment is exogenous. The dynamic variant allows for capital stock to be updated in the model, so that increased investment enhances the productive capacity of the economy over time.

Drivers of emissions and costs

The modelling methodologies outlined above all require data and assumptions. While great care was taken in the LTMS process to report on data and assumptions explicitly, considering every single data entry becomes unintelligible. Rather, a focus on a set of key drivers is warranted—on factors that are understood to have significant implications for results.

Gross domestic product

GDP projections

Together with population, GDP is one of the biggest drivers of energy use. To the extent that economic output translates into increased income, there is higher consumption by more affluent people. Energy consumption patterns change as they move to cleaner, more convenient fuels (usually electricity), acquire more appliances and demand more energy. In long term modelling of energy and greenhouse gas (GHG) emissions, per capita income is often the major development indicator.

The task of projecting GDP growth is difficult, as decisions on growth rates are often considered politically biased (governments would like to project a continuously high GDP growth when others consider this unlikely to occur). GDP growth is seldom, if ever, exponential over a long time period. However, this is the way that most energy models describe GDP growth—as a single growth rate. Evidence from other developed regions shows that GDP growth typically increases, reaches a peak and then declines. The world has witnessed high periodic economic growth in many countries. For instance, a per capita GDP growth rate of 3.5% per annum was achieved in Western Europe between 1950 and 1980. Similarly, high per capita GDP growth rates were achieved in the developing economies of Asia. Per capita GDP growth rates of individual countries have been even higher—8% per annum in Japan over the period 1950 to 1973, 7% in Korea between 1965 and 1992, and 6.5% per year in China since 1980 (IPCC 2000). Consistent with previous analysis, Øvyind Vessia (2006) has suggested that South Africa might be considered to be in an acceleration phase. This would be consistent with AsgiSA targets of economic growth increasing from recently relatively low values around 2.5%.

Vessia (2006) looked at historical GDP growth in South Africa, compared it to trends in other countries and developed a time-dependent GDP projection (called GDP-E) which initially increases quite steeply but then returns to a stable, lower growth. This was the GDP growth pattern used for LTMS. The assumptions served as a first approximation for moving away from modelling GDP as a simple exponential growth trend. Dedicated future studies on GDP projections could certainly improve on these assumptions.

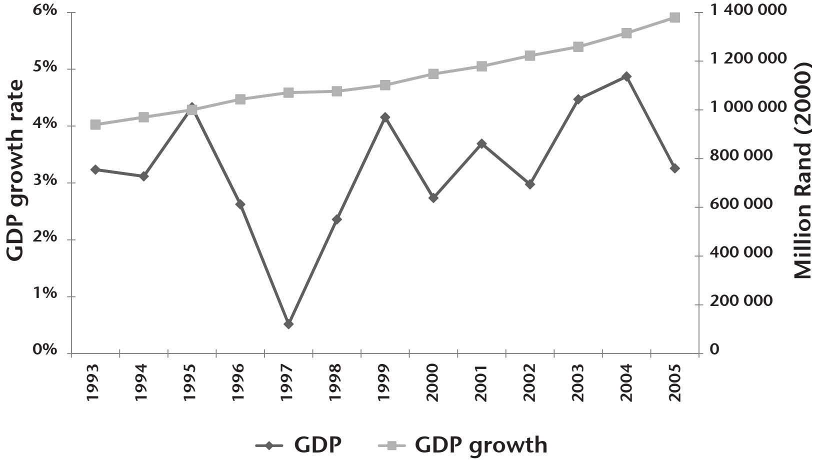

Figure 2.2: Annual GDP and growth rate for South Africa 1993–2005

Source: (Based on data in StatsSA 2006)

Over the 12 years prior to 2005, GDP growth in South Africa has fluctuated between 0.5% and 5% but has shown a positive trend as illustrated in Figure 2.2. Targets for GDP growth rates have been set as part of the Accelerated and Shared Growth Initiative for South Africa (AsgiSA 2006; National Treasury 2005). The SBT in the LTMS processes suggested that such a band should be used, but sensitivity to growth rate conducted (see Chapter 7, page 196, under **Sensitivity to GDP**).

Figure 2.3 shows this trend and the GDP growth, as well as Vessia's projection of GDP growth to 2060. The current growth trend is extended to 2015 and 2016 in which the peak growth at 5.24% will be reached, after which growth will decrease to a more stable lower level of approximately 2% annual growth.

Hence the GDP growth projections in Figure 2.3 have been adjusted to peak at 6%.[9] In the longer term future (from 2030 to 2050), the GDP growth rate is assumed to start flattening out around 3%. The growth rate in the initial years lies slightly above the trend line, but the actual data points vary substantially between 1993 and 2005.

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[9] The original work was done by Vessia (2006), but has been adjusted here based on SBT3 discussions.

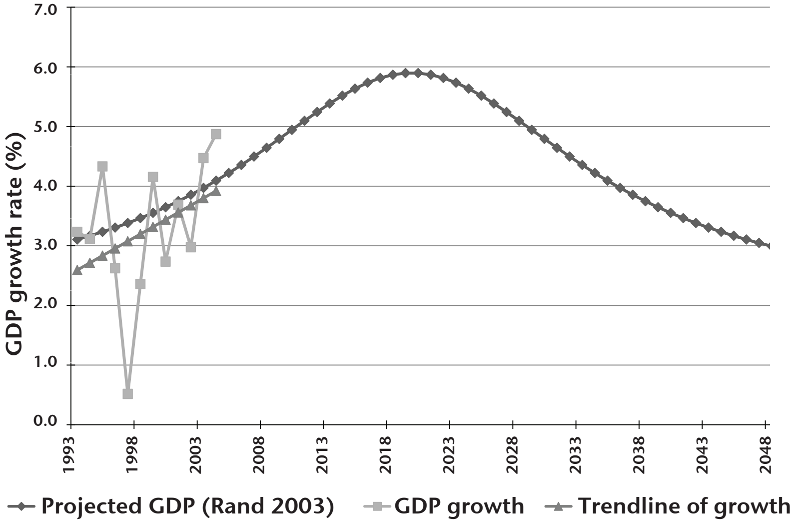

Figure 2.3: South Africa's GDP growth rate, trend line and projected GDP growth

GDP composition

Change in GDP is at best an imperfect measure of economic growth and GDP is certainly only one measure of overall economic activity. The composition of the economy, a factor highly relevant to GHG emissions, is not reflected in GDP as such but rather relates to the composition of GDP. This issue was discussed in a small group meeting held by the LTMS researchers with economists in July 2007. The discussions led to a revision of the growth rates that had implicitly been assumed in energy modelling, shifting from those in the top panel in Figure 2.4 to the revised lines shown in the bottom panel of that figure. The following explanation introduces this change.

The indices used in an economy-wide model are a basis for the development of long term mitigation scenarios in the future energy system. These indices play a fundamental role in linking the basic drivers of the model (GDP projections) with projected growth in energy demand in specific sectors. A better understanding of sectoral growth trends has two outcomes for energy modelling: (1) more realistic 'business as usual' case results, and (2) policies can be modelled which will shift the GDP to a less energy-intensive basis. These policies promise to be among the most significant mitigation policies, with considerable sustainable development co-benefits, but, without a better understanding of sectoral growth, it is unclear what impact these will have on the energy system and the broader economy.

For the purposes of the energy model, the energy system is divided into five areas: industry, commerce, transport, residential and agriculture. The growth rates initially assumed are shown in Figure 2.4, indexed to 100 in the base year to enable all sectors to be shown on the same scale.

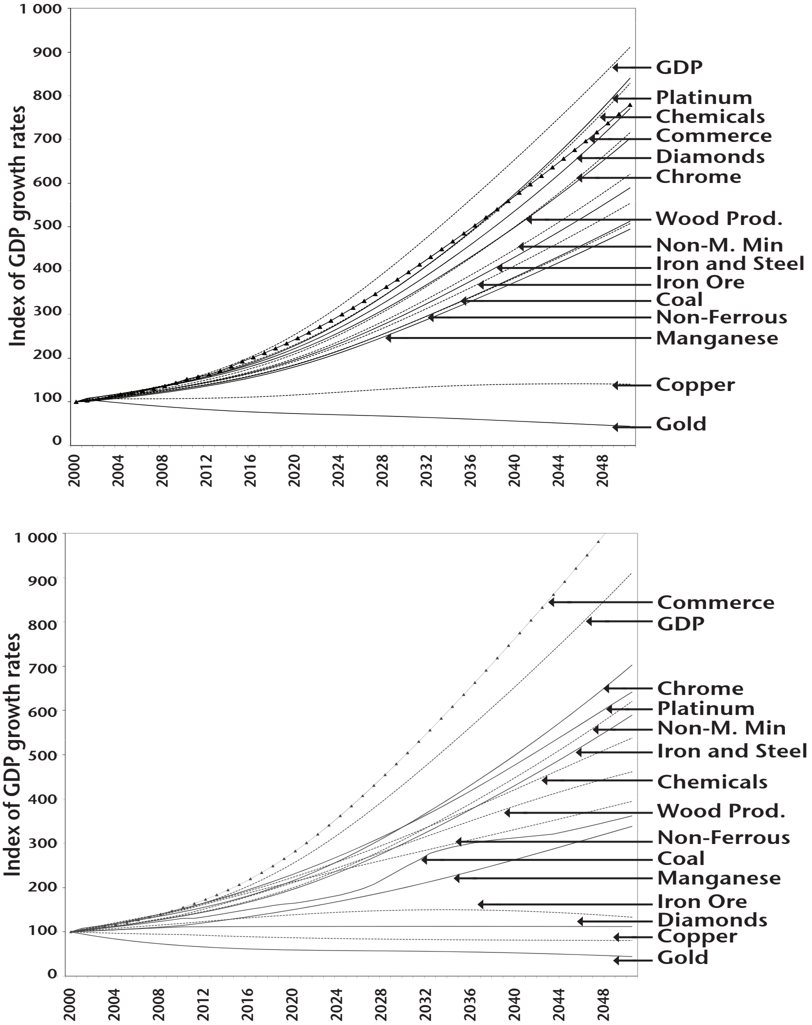

Figure 2.4: Sectoral growth projections, old (top) and revised projections (above)

Growth shown relative to an index = 100 in year 2000, unitless

The majority of the economy is represented by the commercial sector, which represents services sectors. However, the most energy-intensive portion of the economy is the industry sector, which for the purposes of the energy model includes the mining sector.

Because of the energy-intensive nature of many of the industries within the industry sector, energy demand is disaggregated into a number of categories, and separate sectoral growth indices are applied to each of these categories. It is vital for these growth rates to be as plausible and accurate as possible, since they play a large part in determining the plausibility of the energy model as a whole.

A more intuitive representation of sectoral growth is given in Figure 2.5, which shows how the composition of GDP will change over time, given the assumed growth rates. Clearly, the mining sector declines in contribution to the economy, while the services sector grows.

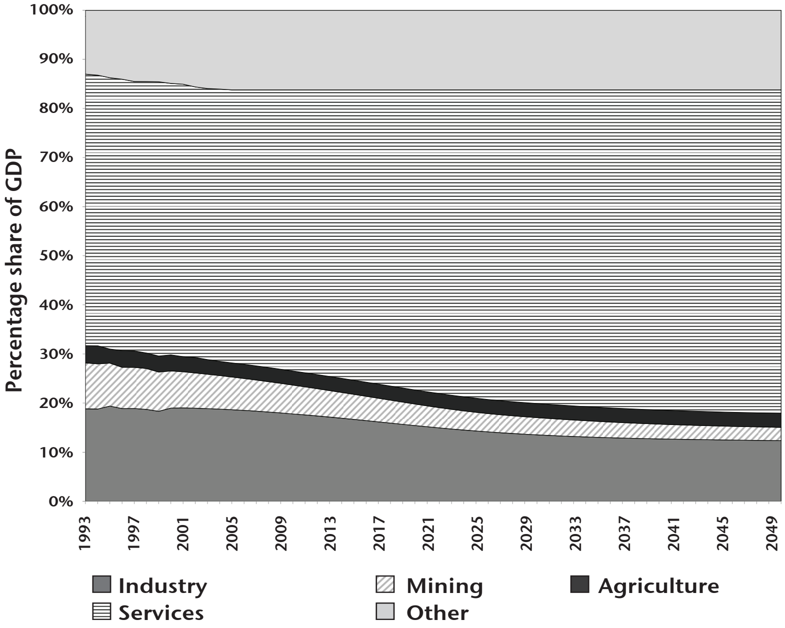

Figure 2.5: Composition of GDP, all sectors

Population projections

Population projections are a topic of much debate in South Africa, given the high rate of HIV. Population is a key driver for GHG emissions. No model can perfectly simulate this population growth as there are too many unknown variables. Nevertheless, a study by Professor Dorrington of the University of Cape Town Commerce Faculty for the Actuarial Society of South Africa was well respected for its population projections with the influence of HIV/AIDS (ASSA 2002). This was the model used for the LTMS. Figure 2.6 shows the simulated population growth over the study period.

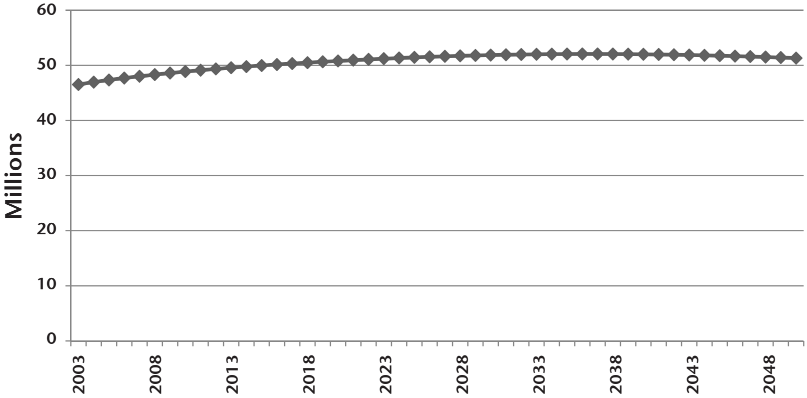

Figure 2.6: Population projection from ASSA model, 2001–2050

Discount rate

The discount rate is a critical factor influencing any analysis of economic effects over time. For calculating costs over time, the discount rate used is probably the most important single factor.

Discount rates effectively express a time preference for money—money right now is preferred to money in the future. Yet, in another perspective, high rates literally discount future expenditure, and hence costs to be borne by future generations. The merits of different assumptions about the discount rate raised considerable debate in the context of the Stern Review (Arrow 2007; Baer 2007; Nordhaus 2007; Stern & Taylor 2007).

Analyses considering the long term future (as with the LTMS process) should include consideration of a range of discount rates, including lower ones. The IPCC notes that two factors need to be taken into account:

> For mitigation effects, the country must base its decisions at least partly on discount rates that reflect the opportunity cost of capital. … In developing countries the rate could be as high as 10%–12%. (IPCC 2001: 466)

These rates do not reflect private rates of return, typically between 10% and 25%. The second perspective is based on equity in a long term context.

Weitzman (1998) surveyed 1 700 professional economists and found that (a) economists believe that lower rates should be applied to problems with long time horizons, such as those being discussed here, and (b) they distinguish between the immediate and, step by step, the far distant future. The discount rate implied by the analysis falls progressively, from 4% to 0%, as the perspective shifts from the immediate (up to five years hence) to the far distant future (beyond 300 years).

It is good practice to consider more than one rate, to provide policy-makers with some guidance on how sensitive the results are to the choice of discount rate. 'A lower rate based on the ethical considerations is, as noted above, around 3%' (IPCC 2001: 467). For the LTMS research, a sensitivity analysis was built into the reporting of detailed results, with discount rates at different levels: 15%, reflecting a value closer to commercial rates of return; 3%, to reflect the long term nature of the climate problem; and an intermediate value of 10%, sometimes used for public investment in the South African context. For the summarised results, the results based on the 10% discount rate were reported. The discount rates are applied to real prices, and nominal rates would be higher.

Technology learning

Technology is an important driver of energy development, and technology costs change over time. One of the most important factors shaping the results of energy models are the assumptions they make about technology learning (Energy Innovations 1997; Fisher & Grubb 1997; IEA & OECD 2000, 2006; Repetto & Austin 1997)—the extent to which technologies get cheaper over time.

The two central explanatory factors why new technologies get cheaper over time are learning-by-doing and economies of scale. Empirical data on learning for energy technologies have been gathered (IEA & OECD 2000; Junginger, Faaij & Turkenburg 2004; Laitner 2002; Nemet 2006; NREL 1999; Papineau 2006; World Bank 1999). Learning curves show the decline in costs (c / kWh for electricity generation technologies) as cumulative electricity production doubles.

A technology will grow until it reaches a maximum global capacity, bounded by some constraint, such as the stock of fuel it uses, suitable sites and others. Using these maximum global potentials, the growth of technologies can be represented in the form of a logistic equation—that is, one that does not increase exponentially forever but slows as it approaches an upper limit and eventually flattens out. If global cumulative capacity approaches an upper limit, the rate of growth in installed capacity will slow, and consequently learning would slow accordingly. Where no estimates of maximum global potentials could be found in the literature, the assumed levels as reported in the third column of Table 2.11 were used.

A range of technology learning rates was considered by the LTMS researchers and presented to the SBT. Table 2.11 shows the learning rates for new electricity-generating technologies, based on the process undertaken by the working group, informed by comparisons of learning ratios from a range of studies. The values chosen for the LTMS study are always within the range cited in the peer-reviewed literature.

Table 2.11: Learning rates for electricity-generating technologies

Energy technology	*Range of learning rates in the literature **	*Maximum level this technology can reach globally (GW)*	*Learning rate, this study*
Wind	5-40%	2 000	19%
Solar photovoltaic	17–68%	500	25%
			35%
Solar thermal, parabolic trough	5–32%	500	15%
Solar thermal, power tower	5–20%	500	20%
Geothermal			
Small hydro	5%		5%
Tidal	5%		5%
Super-critical coal	3–7%	3 072	4%
Integrated gasification combined cycle			
Fluidised bed combustion			
Natural gas combined cycle	4–7%	3 773	5%
Advanced water reactors, nuclear			
* The full range (from the minimum to maximum value we found in the literature) is reported in the second column. See spreadsheet on CD-Rom for fuller ranges of costs in literature			

Carbon capture and storage (CCS) costs could also be expected to benefit from learning. Given our energy economy's dependence on coal, CCS needs to be considered as a mitigation option. However, CCS is not an electricity-generating technology and hence is not listed. The costs of CCS have been added to the costs of power plants. Estimates of future costs as assessed by the IPCC from the international literature (IPCC 2005b) were used in considering CCS as a mitigation option, together with initial work on CCS in South Africa (Engelbrecht et al. 2004; Mwakasonda & Winkler 2005). As with any other technology, its impacts on local sustainable development should be carefully assessed.

The approach to learning for the PBMR differs in that production is not so much global as national (although China is also developing a PBMR-like reactor). The reference plan for NIRP 2 indicates that the first greenfield PBMR (base) will be built 'earliest end 2013' (NER 2004: 6). With a first unit in 2013, the cost reductions might begin in 2014. NIRP 2 explicitly indicates that technology learning is taken into account—'after several multi-modules have been deployed, a cheaper multi-module' (NER 2004: 26). Appendix 3.7 further indicates that '70% of the potential cost improvement may be realised by the 3rd eight-pack station' (p. 22). The costs of the first multi-module (excluding transmission benefits) are given as R18 707 / per installed kW. Costs for the later 'series' multi-module are given at R10 761 / kW (NER 2004: 28, Table 8). The LTMS study assumed that the 32 modules would be built over a period of 12 years; that is, completed by 2025.

The SBT adopted the approach to technology learning, the rates in Table 2.11 and the above approach to PBMR costs on the basis of the work by the working group. On the PBMR costs, it was accepted that a range of costs need to be considered and therefore a scenario should also look at other costs based on the closest equivalent technology.

Exchange rate forecasting

South Africa's exchange rate has been volatile in the recent past. The year-on-year inflation differential between South Africa and the advanced economies, as well as the average annual depreciation or appreciation of the rand (a negative figure indicates an appreciation), has varied over time. South Africa follows a flexible exchange rate regime, which allows exchange rates to be determined by the supply and demand for the currency (Pauw 2006).

These factors, together with expectations of investors, make it difficult to predict future exchange rates. One approach is to use inflation differentials. The inflation rate of South Africa has been significantly higher than that of the developing world during the past 35 years.

In future, South Africa's inflation rate could reasonably be expected to remain stable at fairly low levels, with many believing that inflation targeting will be successful in maintaining levels of between 4% and 5% per annum. At the same time, however, given the large degree of income inequality and skills shortages in the South African economy, it is unlikely that we will see the inflation rate dropping to lower levels comparable to those of industrialised countries. The inflation rate in the industrialised or OECD countries is likely to be around 2% per annum in the foreseeable future. This implies an inflation differential of between 2% and 3% in the long run between South Africa and the industrialised countries, many of which are our trading partners (personal communication, George Kershoff, Bureau of Economic Research, University of Stellenbosch). Following historical trends, it is therefore likely that the South African exchange rate will continue its steady decline in value, although not at the relatively high rate of around 6.4% seen in the past 35 years. Exchange rates have been applied only to imported capital equipment, notably power plants, refineries and imported fuels, which are quoted in US dollars. They could in future be applied to major industrial equipment as well, based on data availability.

Table 2.12: Projected Rand–Dollar exchange rate over the study period

2003	R7.50
2005	R7.80
2010	R8.62
2015	R9.51
2020	R10.50
2025	R11.59
2030	R12.80
2035	R14.13
2040	R15.61
2045	R17.23
2050	R19.02

The strength or weakness of the South African rand compared to international currencies is another factor that could influence model outputs. Since the investment costs of most power stations as well as imported fuels such as crude oil are quoted in US dollars, the fluctuating rand–dollar exchange rate could have a large influence on the model results and the total costs of certain scenarios. The exchange rate is a highly volatile factor and very difficult to predict. For this study an exchange rate of R7.50 to the US dollar in 2003, increasing by 2% per year is assumed (Pauw 2006). Table 2.12 shows the projected exchange rate of the South African rand to the US dollar from 2003 to 2050.

Future energy prices

It was well understood from the outset of the LTMS process that predicting future fuel prices is virtually impossible. Different theories come up with very different results. The only thing that is certain is that, whatever the prediction, it will almost definitely not be the real price in future. Yet, to model mitigation actions and scenarios, some assumptions need to be made.

Oil prices

Liquid fuels constitute the largest end use of energy in South Africa. Predicting future prices of these fuels is a key parameter. Projections for the crude oil price had, at the time of the LTMS study, been adjusted upward by the IEA, OECD and EIA respectively. The oil price in 2003 was on average $30 per barrel (EIA 2006), but it increased sharply in 2004–05. Even though the real oil price for 2030 was lower than 2006 levels, all major projections suggest these levels.

The possibility of a further synthetic fuel plant was included in the model. It was considered in the Growth without Constraints scenario (but note the issues of water raised below).

For the reference case, LTMS projected oil prices from $30 per barrel in the base year (2003) to $97 / bbl in nominal terms ($55 / bbl in real terms) (in 2030), and extrapolated at the same rate beyond.

Gas prices

Prices were assumed to rise from around R28 per GJ in 2003 to R140 per GJ in 2030 (IEA 2006) (R46 / GJ in real terms, or $6.5 / MBtu). After 2030, it was assumed that the increase continues at the same rate as 2003–2030.

Coal prices

The domestic coal price for electricity generation assumed in previous studies (about R3 / GJ) is too low and a higher price of R6 / GJ is used in the LTMS. Domestic coal prices are expected to increase, as resources become more difficult to extract. Coal prices might increase further, according to Ernst Venter of Kumba, as it is likely that during the next few decades coal could be in much shorter supply.[10]

Coal prices are assumed to rise from around R3 / GJ in 2003 to R6 per GJ, in 2030 after which they increase further.

Emission factors

The study generally used IPCC default emission factors for greenhouse gases (IPCC 1996; 2006). In the energy model, emission factors are attributed to the primary energy carriers at the point where the fuel is combusted. For example, emissions from petrol are calculated from the petrol used by a vehicle and not from the crude oil leaving a refinery. In that example, excess emissions from the refining process itself are attributed to the refinery. Coal being burnt in power stations has emissions factors associated with it, but these are not placed on electricity as a carrier.

Emission factors are needed to convert energy consumption (in energy units, PJ or GJ) to emissions. The Intergovernmental Panel on Climate Change (IPCC) default emission factors (in tC / TJ, or tCO_2 / TJ) were used for emissions of CO_2, CH_4, N_2O, NO_x, CO, NMVOC and SO_2 (IPCC 1996: Tables 1-2, 1-7, 1-8, 1-9, 1-10, 1-11 and 1-12 respectively).

The default emission factors of nitrous oxide are given in IPCC (1996) Table 1-8. For the sectors assessed in LTMS, they vary only by fuel, with 1.4 kg N_20 per TJ of coal; 0.1 for natural gas; 0.6 for wood; and 4 kg N_20 / TJ of wood, charcoal and other biomass.

Following IPCC methodology, local emission factors or adjustments to defaults based on local conditions are used. For carbon dioxide from other bituminous coal, 26.25 tC / TJ is used instead of the IPCC default of 25.8 tC / TJ. This adjustment is based on direct measurements at a South African coal-fired power station (Lloyd & Trikam 2004). The higher emissions are consistent with the lower calorific value of South African sub-bituminous coal at 19.59 MJ / kg, whereas the IPCC default value is for 25.09 MJ / kg coal. Further measurements at more stations in future may lead to a submission of a South Africa-specific emission factor to the IPCC. The above list already includes important local air pollutants (SO_2, NO_x and NMVOC), but not particulate matter.

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[10] Presentation at Fossil Fuel Foundation indaba, October 2006.

Table 2.13: Default emission factors for carbon dioxide

	tCO_2 /TJ
Crude oil	73.3
NGL	63.1
Petrol	69.3
Jet paraffin	71.5
Other paraffin	71.9
Diesel	74.1
RFO	77.4
LPG	63.1
Ethane	61.6
Naphtha	73.3
Bitumen	80.7
Petroleum coke	100.8
Anthracite	98.3
Cooking coal	94.6
Other bit. coal	94.6
Coal electricity generation	96.3
Natural gas	56.1

Source: (IPCC 1996: Table 1-2)

Table 2.14: Default emission factors for methane

<table>
<tr><th colspan="2"><i>kg CH_4 / TJ</i></th><th></th><th><i>Coal</i></th><th><i>Natural gas</i></th><th colspan="2"><i>Oil</i></th><th><i>Wood</i></th><th><i>Char-coal</i></th><th><i>Other biomass</i></th></tr>
<tr><td colspan="2"><i>Energy industries</i></td><td></td><td>1</td><td>1</td><td colspan="2">3</td><td>30</td><td>200</td><td>30</td></tr>
<tr><td colspan="3"><i>Manufacturing and construction</i></td><td>10</td><td>5</td><td colspan="2">2</td><td>30</td><td>200</td><td>30</td></tr>
<tr><td rowspan="5"><i>Transport</i></td><td>Aviation</td><td></td><td></td><td></td><td colspan="2">0.5</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Road</td><td></td><td></td><td></td><td>Petrol</td><td>Diesel</td><td></td><td></td><td></td></tr>
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<tr><td>Railways</td><td></td><td>10</td><td></td><td colspan="2">5</td><td></td><td></td><td></td></tr>
<tr><td>Navigation</td><td></td><td>10</td><td></td><td colspan="2">5</td><td></td><td></td><td></td></tr>
<tr><td rowspan="4"><i>Other</i></td><td>Commercial</td><td></td><td>10</td><td>5</td><td colspan="2">10</td><td>300</td><td>200</td><td>300</td></tr>
<tr><td>Residential</td><td></td><td>300</td><td>5</td><td colspan="2">10</td><td>300</td><td>200</td><td>300</td></tr>
<tr><td rowspan="2">Agr, forestry and fishing</td><td>Stationary</td><td>300</td><td>5</td><td colspan="2">10</td><td>300</td><td>200</td><td>300</td></tr>
<tr><td>Mobile</td><td></td><td>5</td><td colspan="2">5</td><td></td><td></td><td></td></tr>
</table>

Source: (IPCC 1996: Table 1-7)

Biofuels do not have emissions associated with them in this study, since they are regarded as carbon neutral. Taking into account up- and downstream emissions, biofuel production may show in some cases that biofuels have substantial emissions (Von Blottnitz & Curran 2007). This is supported by American studies for ethanol on maize that show a positive-carbon balance.

Constraints

Constraints in energy modelling

Even though one of the two LTMS scenarios is called Growth without Constraints (GWC, see Chapter 3, page 60, **Growth without Constraints**), various constraints are applied in energy modelling, including physical constraints and constraints on resource availability (e.g. coal, uranium, helium, water, land and others). There are constraints reflecting, for example, fuel shares for meeting a particular energy demand, or penetration rates of different technologies.

This section provides further information on constraints applied in the energy modelling (Hughes et al. 2007). The constraints included are resource constraints, 'build' constraints and so-called activity ratios.

Resource constraints apply where there is a limit on the availability of a resource. In MARKAL, these are typically applied as upper, fixed or lower limits on technologies using a resource (a BOUND [BD] in MARKAL nomenclature). Bounds were placed on the amount of capacity (GW) of power plants that could be built—the table of values is included on the CD-Rom accompanying this book.

Even if the energy resource is available, other constraints could apply and be considered. One such constraint would be on the amount of capacity that was assumed could be built in a single year, modelled as a build constraint. International supply constraints on delivering technologies have been mentioned in this regard, or the human and institutional capacity might limit the ability to build more than a certain amount per year. Table 2.15 shows the constraints for building of power stations applied in GWC.

A build constraint was also applied to new CTL plants in the GWC scenario, of 26 PJ per year.

Table 2.15: Build constraints (IBOUND(BD)) on power stations

Unit: GW (capacity built / year)		*2003*	*2005*	*2015*	*2025*	*2035*	*2050*
Camden PF station	UP	0.3800	0.3800	0.3800	0.3800	0.3800	0.3800
Grootvlei PF station	UP	0.5650	0.5650	0.5650	0.5650	0.5650	0.5650
Komati A PF station	UP	0.3030	0.3030	0.3030	0.3030	0.3030	0.3030
Komati B PF station	UP	0.3030	0.3030	0.3030	0.3030	0.3030	0.3030
New Braamhoek pumped storage plant	UP	0.9990	0.9990	0.9990	0.9990	0.9990	0.9990
Solar thermal parabolic trough	UP	1	1	1	1	1	1
Solar thermal power tower	UP	1	1	1	1	1	1
New integrated gasification combined cycle	UP	0	0	1.13	1.88	2.25	2.25
New super critical coal with FGD	UP	0.0000	0.0000	2.2500	3.7500	4.5000	4.5000
New PWR station	UP	0.0000	0.0000	0.8500	1.5500	1.9000	1.9000

The year in which new technologies can start may also be thought of as a constraint. Starting dates depend on lead times of new electricity-generation technologies (see Table 2.5). The earliest starting dates assumed to be possible for refineries are those in the following list, from a 2006 perspective:

- bioethanol refinery—existing/under construction; 2007
- crude oil refinery—new generic 300 000 b/d; 2012
- crude oil refinery—new petrol-intensive 300 000 b/d; 2020
- crude oil refinery—new diesel-intensive 300 000 b/d; 2020
- LNG regassification plant; 2008
- new biodiesel refinery; 2007
- new bioethanol refinery; 2008
- new small biodiesel refinery; 2007
- Sasol CTL—new; 2014

A range of other factors is 'constrained' in energy modelling. MARKAL itself solves for the least-cost solution, in the sense that its objective function is least cost-minimisation. However, the objective function is subject to a number of built-in constraints, for example, that energy supply must meet demand, and that an adequate reserve margin must be maintained. In addition, the user can define additional constraints, so-called Adratios. The most commonly used of these are RAT_ACTs, which define the relationship of an activity to other specified parameters. For example, if the energy demand for lighting in residential households could be met by incandescents, CFLs, candles and paraffin lights, the relevant RAT_ACT was defined to match penetration rates—the share of demand met by different technologies and hence from different energy sources. Observed patterns of fuel use (in this example for different household types) were used as a starting point. These ratios are kept fixed if there is no reason to expect that they will change. To allow fuel-switching in policy cases, RAT_ACTs are defined with upper and lower bounds, so that the shares are able to change over time.

Availability of water

Water constraints on new coal-to-liquid plants

At the time of the LTMS process (2006–07), Sasol had two plants receiving water from the Integrated Vaal River System. The Sasol Secunda Complex's primary source of water was Grootdraai Dam, which will be supported through the Vaal River Eastern Sub-system Augmentation Project in 2008. The Sasol Sasolburg Complex was supplied from the Vaal Dam, which was supported from the Thukela-Vaal Transfer Scheme, as well as the Lesotho Highlands Water Project. The water requirements for the two complexes are presented in the following table for the indicated years of the DWAF planning period (DWAF 2006).

Table 2.16: Sasol's water requirements

	Water requirements (million m^3 / annum)					
	2006	*2010*	*2015*	*2020*	*2025*	*2030*
Sasol Secunda Complex	92.0	91.3	107.8	112.1	117.2	123.1
Sasol Sasolburg Complex	26.4	28.9	32.3	35.5	38.9	42.7
Total	118.5	120.2	140.1	147.6	156.1	165.8

Source: (DWAF 2006)

This projection by DWAF did not include any new plants from Sasol. According to Sasol, the water requirement per new coal-to-liquid (CTL) of 80 000 bbl / d was approximately 40 million m^3 (Fraser 2007). The allocation of 3 000 million m^3 of water in the Vaal water system was fully allocated in 2007.

Under normal economic and population growth scenarios, the next augmentation to the Vaal water system from the Lesotho Highlands Transfer scheme was planned for around 2020. This would be followed by a transfer scheme from the Thukela in 2035. It was envisaged that augmentation from the Umzimvubu would only be required in 2050. This would be a very costly scheme—estimated at twice the cost of the other two (Van Rooyen 2007).

The system can accommodate two new CTL plants by 2020 by implementing stringent demand-side management in the Vaal system. A major problem with this, however, was that it would bring the system too close to its limits, leaving very little reserve margin. Given that a 12- to 15-year period from conception to commissioning was required, it was already considered unlikely that one of the augmentation schemes would be built before 2020 in time for additional Sasol plants (Van Rooyen 2007).

In order to accommodate the additional three CTLs after 2020, the Thukela and Umzimvubu augmentations would need to be brought forward. This would increase the financial burden to DWAF in terms of their capital costs forecast to the order of tens of billions of rands. A letter from Sasol concluded that 'no single factor will prevent the implementation of CTL facilities as described in the current working document and technical report for SBT4, although the costs of securing a reliable supply may be prohibitive under current economic considerations' (Fraser 2007)

Table 2.17: The present value costs and capacity

Scheme	*Capacity*	*Estimated cost*
Lesotho Highlands	~460 million m^3 (DWAF 2006)	Possibly same magnitude as Thukela
Thukela (KZN)	450 million m^3 (DWAF 2001a)	R5 billion (1998) (DWAF 2001a)
Umzimvubu (E.Cape)	630–1 260 million m^3 (A portion of this would be needed for agriculture in Transkei.) (Van Rooyen 2007)	R17–32 billion (2006) (Rademeyer 2007)

Other options to bring new water into the Vaal system could include:

- desalination from Richard's Bay, pumped up to the Vaal River;
- reallocation of water use; and
- use of return flows in the Vaal system, already taking place.

DWAF had completed the first stage reconciliation strategy for the Vaal River system and during the time of the LTMS process were working on the second phase study which would incorporate updated water requirements from the bulk users, Eskom and Sasol.

Water for coal-fired power stations

In 2007 Eskom operated 12 coal-fired electrical power stations, which received water from the Integrated Vaal River System. Some of these stations have been decommissioned but are to be taken out of mothballs to increase the supply in response to the growing demand for electrical power to fuel the South African economy. There are also plans to develop three new power stations, envisaged to receive water from the Vaal River System. Two are scheduled to receive water from the Vaal Dam, and a third plant is planned to be located close to the existing Kendal Power Station, receiving water from the Eastern Vaal River Sub-system (a component of the Integrated Vaal River System). Table 2.18 provides a summary of the water requirements and lists all the power stations and their primary water source, as well as the projection of water requirements for the indicated years of the DWAF planning period (DWAF 2006).

The DWAF projections do not include any new plants envisaged under the LTMS. Additional plants will have a less significant impact if they are dry-cooled—that is, they would add less than 4 million m^3 per annum per new dry-cooled station to the total of about 400 million m^3.

Table 2.18: Eskom's water requirements

Power station	*Primary water source*	*Water requirements (million m^3 / annum)*					
		2006	*2010*	*2015*	*2020*	*2025*	*2030*
Hendrina	Komati sub-system	31.0	32.4	33.0	32.7	32.7	32.7
Arnot		29.4	33.4	36.1	36.5	36.6	36.6
Duvha		50.8	50.4	51.6	52.2	52.2	52.2
Komati		2.6	5.6	9.9	8.3	8.4	8.4
Kriel	Usutu sub-system	38.8	40.7	43.5	43.2	43.5	43.5
Matla		51.5	53.6	51.6	54.3	54.3	54.3
Kendal		3.2	3.3	3.4	3.4	3.4	3.4
Camden		5.5	19.2	23.2	23.2	23.2	23.2
New coal-fired 1		0.0	0.6	2.9	3.7	3.7	3.7
Majuba	Zaaihoek sub-system	19.2	25.6	25.6	24.1	24.1	24.1
Tutuka	Grootdraai sub-system	34.5	46.2	44.3	48.8	48.8	48.8
Grootvlei	Vaal Dam	0.8	6.1	10.4	10.1	10.1	10.1
Lethabo		45.5	46.6	49.4	50.1	50.1	50.1
New coal-fired 2		0.0	0.0	0.6	3.0	3.0	3.0
New coal-fired 3		0.0	0.0	0.0	2.6	3.0	3.0
Total		312.9	361.7	387.5	396.3	397.2	397.2

Source: (DWAF 2006)

Use the Market reduces emissions by 17 434 Mt CO_2-eq between 2003 and 2050. The scale of relative emission reductions is twice that of any other wedges shown at an average of 363 Mt CO_2-eq per year (see Chapter 5, Figure 5.1) and larger than the other two strategic options. Emissions in 2050 are 620 Mt CO_2-eq.

Chapter Three

The Gap: Where emissions are going and need to go

The LTMS process focused on just two scenarios. Growth without Constraints (GWC) is the scenario in which the economy and emissions grow as if there were no carbon constraint. Pushing the envelope on the other side is a scenario showing the reductions that science indicates would be required (RBS) to avoid the worst impacts, acting together with the other scenarios. The two scenarios, GWC and RBS, illustrate where emissions might be going and where they should be going, if South Africa took the science seriously. The gap between the two scenarios framed the strategic options that were modelled.

Growth without Constraints (GWC)

What would the economy and greenhouse gas emissions look like if by 2050 (and beyond) South Africa were to develop without any consideration of greenhouse gas emission? What would be the scenario if there were no climate impacts highly damaging to the economy, if there was no significant oil constraint, if the country made its choices to energise our economy purely on least-cost grounds and without internalising external costs? This scenario is called Growth without Constraints (GWC) in the long term mitigation scenario process. All other scenarios and strategic options are assessed against it—it is the modelling reference case.

GWC is the 'no-mitigation' scenario, in which there is growth without constraints. It involves no change from current trends, not even implementing existing policy.

Figure 3.1 shows that emissions under GWC increase dramatically, increasing more than four-fold by 2050. Most of the GHG emissions continue to be associated with energy supply and use, with non-energy emissions (industrial processes, waste, agriculture and LULUCF—land use, land use change and forestry) contributing roughly a fifth. GDP growth drives much of this increase, with more detailed reasons elaborated in the text below.

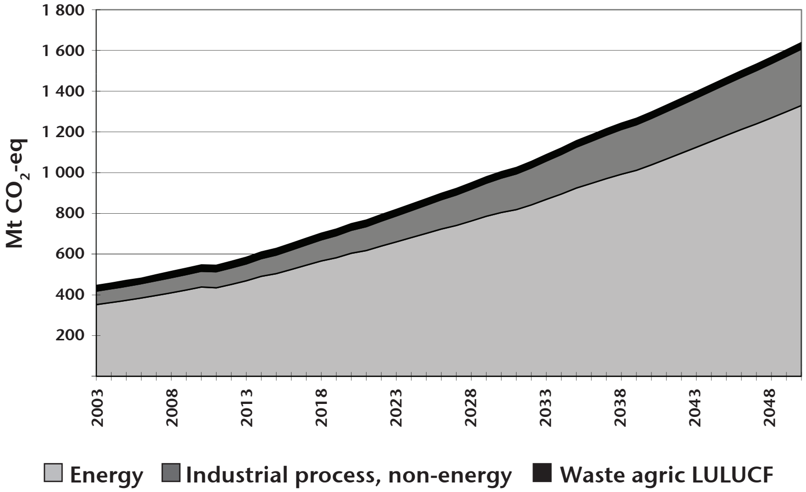

Figure 3.1: Energy and non-energy emissions under Growth without Constraints, Mt CO_2-eq

Assumptions about economic growth that underpin the GWC scenario are consistent with the growth targets of the Accelerated and Shared Growth Initiative for SA (AsgiSA), ranging between 3% and 6% GDP growth per year. These and other assumptions were fed into the model, which selected the least-cost sources of energy to fuel the economy over the period 2003 to 2050. Current trends in land use, agriculture and waste sectors were assumed to continue. Overall fuel consumption grows more than five-fold, mainly in the industry and transport sectors. There is no incentive for (and therefore little uptake of) energy efficiency, despite the potential net savings over time. No significant changes in human behaviour are assumed in the GWC scenario.

In the 'Growth without Constraints' scenario, energy demand grows mainly in the industry and transport sectors. Total fuel consumption across all sectors increases more than five-fold, from 2365 PJ in 2003 to 11 915 PJ in 2050. Figure 3.2 shows that the growth in commercial, residential and agricultural fuel use are relatively small in comparison. The predominant fuels differ by sectors. About half of industrial fuel use comes from coal, with another third from electricity. Industrial process emissions grow particularly in synfuels and sectors such as iron and steel, cement and ferro-alloys. In 2050, the commercial sector uses electricity for 65% of its energy needs, with another fifth from coal. Fuel use in transport is dominated by petrol (55% in 2003, but 46% by 2050), diesel (31%; 30%) and jet fuel (12% increasing to 18%). The residential sector is well known for its multiple fuel use, yet the electrification programme resulted in 63% of household fuel use being in the form of electricity in 2003. This increases to 88% by 2050. Biomass (mostly fuelwood), paraffin and coal continue to be used, with solar energy not making a major contribution in this scenario.

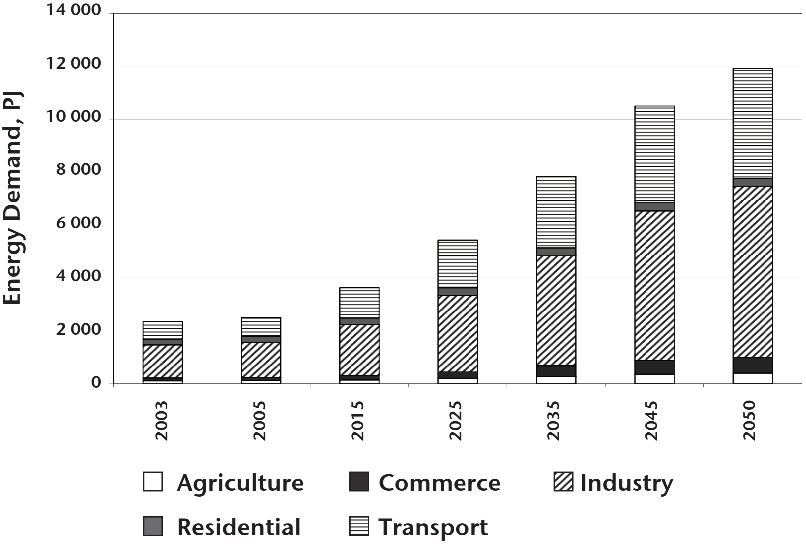

Figure 3.2: Fuel use by sector, all fuels

In Growth without Constraints, electricity continues to be generated overwhelmingly from coal and to a lesser extent nuclear power. As existing coal stations come to the end of their life-time, they are replaced with new coal stations. New pulverised fuel coal plants are all supercritical with a higher efficiency of 38% rising to 40% over time—no more sub-critical PF coal plants (34.5% efficiency) are built (23 GW, or 7 new plants, by 2050). Some integrated gasification combined cycle (IGCC) plants are built (68 GW, or 21 new plants, by 2050). IGCC becomes attractive as it is only slightly more expensive but significantly more efficient than super-critical coal technology. Since no carbon constraints are imposed, no electricity plants have carbon capture and storage (CCS). A total of nine new conventional nuclear plants are built, mostly between 2023 and 2040, adding 15 GW of new capacity. Twelve modules of PBMR (Pebble Bed Modular Reactors) are built for domestic use. Very few renewables enter the electricity mix in the

GWC scenario. No electricity is generated from solar, thermal or wind, with the only significant addition being 70 MW of landfill gas.

Figure 3.3 shows new super-critical coal starting to come into the mix from 2016, with IGCC from 2020, together with some combined cycle gas turbines and PWR nuclear. The share of coal-fired electricity-generating capacity stays over 75% for the period. The share of coal and nuclear continues close to 90% until around 2050. CCGT provides 3% capacity during the period.

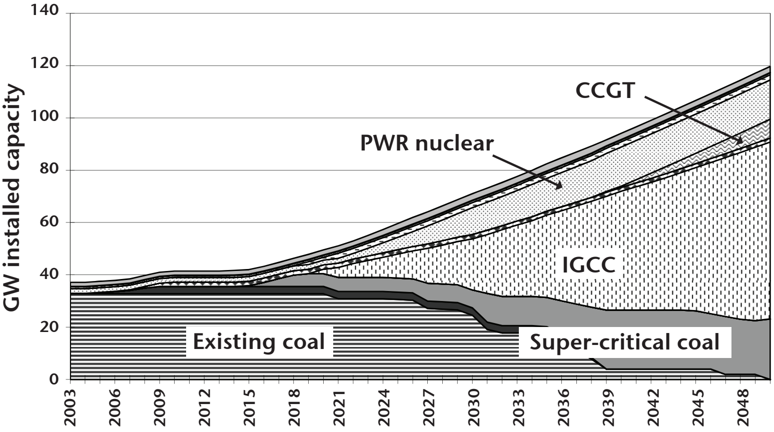

Figure 3.3: Electricity expansion plan in the GWC case, GW installed capacity, 2003–2050

Renewables remain limited to a small share of capacity, and do not enter the generation mix in a significant way in the GWC scenario. Renewable energy technologies for electricity generation contribute less than 1% of installed capacity, declining from 2.18% of installed capacity in 2003 to 0.74% in 2050 (see also Table 3.1), comprising only existing hydro and biomass (mainly bagasse) capacity, and a small amount of added landfill gas capacity. Contribution of renewable sources to electricity sent out is around half this amount, due to lower availability factors.

Electricity production continues to be mainly from coal-fired power stations, which can be run 88% of the time. The gas-fired power stations are suitable for peak generation, and thus do not run as much. Renewable energy technologies will run when the resource is available and thus have smaller shares of electricity generated. However, some designs improve availability factors, such as the use of molten salt in the solar power tower.

Table 3.1: Projected electricity-generating capacity by type of power plant

	2003	*2005*	*2015*	*2025*	*2035*	*2045*	*2050*
Existing coal	32.8	32.8	32.8	30.6	17.8	4.0	0.0
Mothballed coal	0	0.38	2.79	2.79	2.41	0	0
Supercritical coal	0	0	0.31	5.38	11.17	22.26	23.16
FBC	0	0	0	0	0	0	0
IGCC	0.0	0.0	0.0	9.2	31.5	54.8	67.6
OCGT liquid fuels	0.17	0.17	1.69	1.69	1.52	1.52	1.52
OCGT nat gas	0	0	0	0	0	0	0
CCGT	0	0	0	0	0	3.96	7.21
PWR nuclear	1.8	1.8	1.8	4.75	12.49	15	15
PBMR	0	0	0	1.98	1.98	1.98	1.98
Hydro	0.73	0.73	0.73	0.73	0.73	0.73	0.73
Landfill gas	0	0	0.07	0.07	0.07	0.07	0.07
Solar trough	0	0	0	0	0	0	0
Solar tower	0	0	0	0	0	0	0
Solar PV	0	0	0	0	0	0	0
Wind	0	0	0	0	0	0	0
Biomass	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Pumped storage[11]	1.58	1.58	1.77	2.38	2.73	2.33	2.33
Total	37	38	42	60	82	107	120

The capacity to produce petroleum products from refineries is dominated by crude oil and synfuel refineries in GWC. Five new crude refineries are built within the period as well as five new coal-to-liquid plants, each with half the capacity of Secunda are built in GWC.

All new crude refineries are assumed to have a capacity of 300 000 bbl / day. Sasol have indicated that all new coal-to-liquid plants would be low-temperature Fischer-Tropsch, with a product profile of 70% diesel, 25% naphtha (used for petrol) and 5% LPG. The five new oil refineries add 1.5 million barrels per day by 2050. In the GWC scenario, coal-to-liquid plants are built without carbon capture and storage (CCS).The costs of

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[11] Pumped storage does not generate electricity from a primary energy source. Rather, electricity is used to pump water uphill and run it downhill again at a time needed. There is a net loss of energy, not a gain. However, it is common practice to include these stations, since they are important means of storage and the meeting of peak demand.

bringing forward water supply options are a potential constraint, with the costs of securing a reliable supply potentially prohibitive under current economic conditions (see Chapter 2, page 56, **Availability of water**).

Although both sources of liquid fuels expand considerably, the share produced by crude oil refineries begins at around 69% (fraction of total energy) in the base year, declines only slightly to a low of 67% in 2020, rising again to 76% by 2050. After that, increasing demand is met mainly from new crude refineries and imports. Five new 300 000 bbl / day crude refineries are commissioned between 2011 and 2047.

Given such constraints, it is assumed that a new coal-to-liquid plant, with a capacity of 80 000 bbl / d (half of Secunda) could be built no faster than one every six years. Five new coal-to-liquid plants of a capacity of 80 000 bbl / d are commissioned between 2014 and 2038. Synfuel production begins at around 31% of the total domestic fuel production and declining to 21% in 2050. High net exports in 2003 (27% of production) decline to 1% by 2050. Biofuels play an insignificant role, rising from 0.4% of domestic fuels supply in 2011 to just under 2% in 2050.

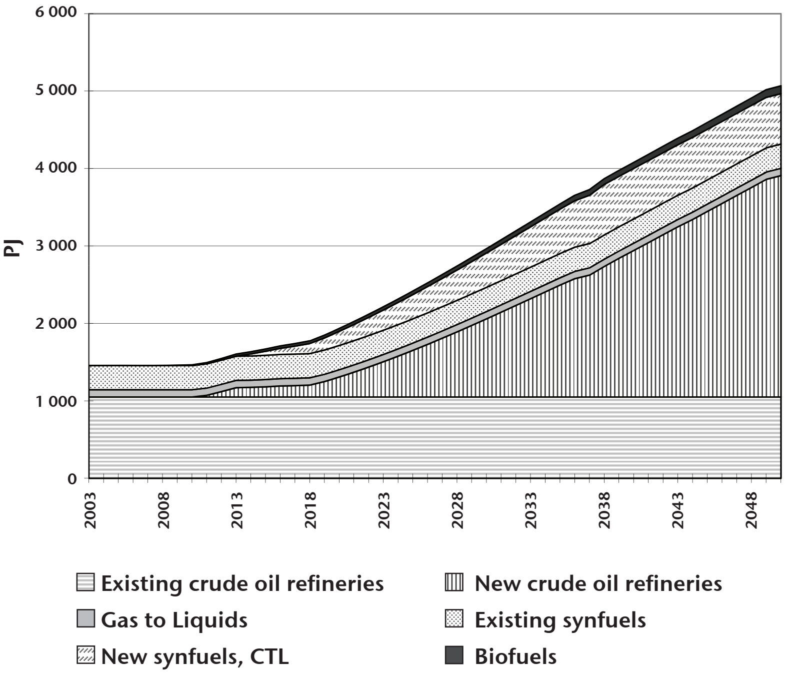

Figure 3.4: Growth of refinery capacity in the GWC case, 2003–2050

On current energy trends, greenhouse gas emissions will rise dramatically. Without constraints, growth leads to an almost four-fold increase in greenhouse gas (GHG) emissions—from 446 million tons of CO_2—equivalent (Mt CO_2-eq)[12] in 2003 to 1 640 Mt CO_2—eq by 2050. Energy-related emissions (CO_2, CH_4 and N_20) increase just under four times from the base year to 2050. Together with increases from synfuels, this drives a similar scale increase in GHGs overall, including non-energy emissions. Figure 3.5 summarises the emissions and respective shares of each major sector.

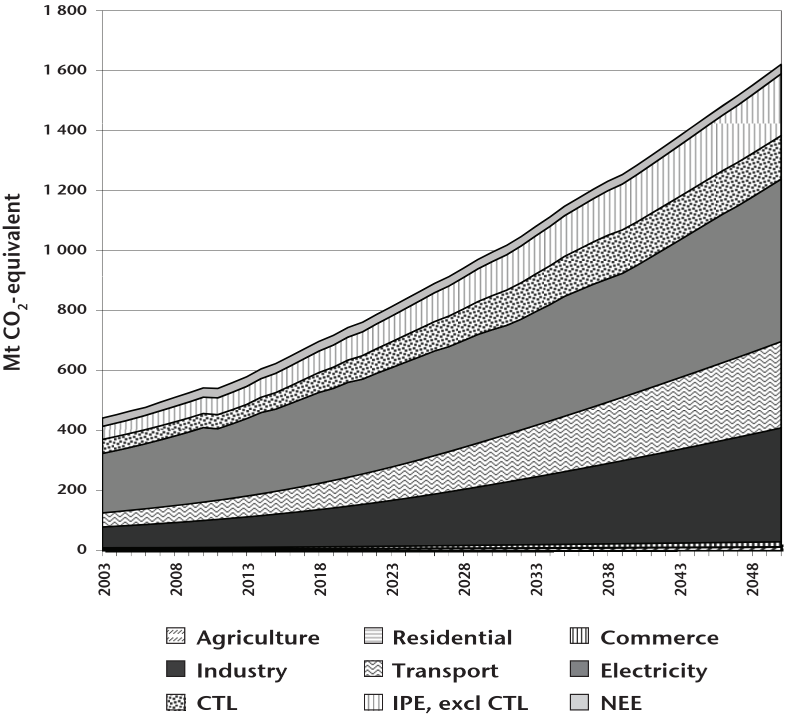

Figure 3.5: Projections of GHG emissions by sector in the GWC case, 2003–2050 (Some elements occur in numbers too small to be visible)
CTL is coal-to-liquids; IPE are industrial process emissions, not including CTL; NEE are non-energy emissions not already counted in the previous two. The emissions from commercial, residential and agricultural energy use are too small to see on this scale.

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[12] 'Megatons' are millions of tons, abbreviated Mt. Emission reductions from the major GHGs are converted to CO_2-equivalents by Global Warming Potentials, 21 per ton of methane, 310 per ton of nitrous oxide. Units of million tons are preferred; inventories tend to report in Gg. 1 Mt = 1 000 Gg.

Emissions continue to be dominated by energy sources. Electricity generation accounts for 45% of greenhouse gas emissions in 2003, declining to 33% in 2050. The declining share of electricity is due to emissions growth from liquid fuels, with five new coal-to-liquid plants. Industrial process emissions (non-energy) increase more than four times, with the largest share in this category coming from synfuels. Emissions in the other non-energy sectors—notably waste, agriculture and forestry—increase much less rapidly than for the energy sector.

The LTMS process considers another trajectory, Current Development Plans (CDP), which assumes that government policy *is* implemented. Particularly, policies on energy efficiency and renewable energy are assumed to be extended until 2050. CDP is shown to represent a significant effort in reducing emissions measured in millions of tons of CO_2 avoided compared to Growth without Constraints. Nonetheless, in CDP overall GHG emission still rise dramatically. The emissions trajectory is not radically different from the Growth without Constraints scenario—it still continues climbing. Emissions reach a level above 1500 Mt per year in 2050. More detailed analysis of CDP is included in the information on the CD-Rom, since most of the LTMS analysis focused on GWC and RBS.

The Growth without Constraints scenario presents an economy and society based very much on the patterns and dynamics that dominate South Africa today. Mining has declined and the composition of GDP has moved even further into tertiary sectors. The scenario assumes that all resource constraints (e.g. local water availability) have been overcome. It further assumes that industrial policy continues with its current, energy-intensive focus. No negative feedbacks of a changing climate are considered in this scenario. In the absence of constraints, the economy by 2050 is considered to be performing well, and by all accounts South Africa is seen as a successful country having achieved its goals. Its emissions, however, have quadrupled.

In plain language, if our economy grows without constraints over the next few decades, GHG emissions will continue to escalate, multiplying more than four-fold by mid-century. Even though our absolute emissions are a small share, the consequences lie in political dynamics. If the other countries (and more specifically the larger developing ones and the US) do the same, the implications are that global emissions will increase dramatically—and dangerous, if not catastrophic, climate change will very likely be upon us. The predicted impacts of climate change will be at the higher end of the projections, rather than the more cautious estimates. This would have a very serious impact on South Africa, in turn.

Required by Science (RBS)

The second scenario, Required by Science, is different from GWC and from the strategic options modelled in the LTMS process. It is the only scenario or option driven by a climate target. Required by Science (RBS) asks what would happen if South Africa reduced emissions by the same percentage that is needed globally, that is, -30% to -40% from 2003 levels by 2050.

In other words, if South Africa had all the resources and technology at its disposal to contribute to the global mitigation effort that is required to stabilise the climate, what could it achieve by 2050?

The assumption underpinning the RBS scenario is that South Africa would join the world community in taking action to stabilise GHG concentrations, negotiating a target as its fair contribution to this shared vision.

The IPCC's Second Assessment report had indicated the need for a 60-80% reduction in order to achieve stabilisation of concentrations for GHGs in the atmosphere, which is the objective of the UNFCCC. The scenario assumes that South Africa implements mitigation to the extent required by science *for global emission reductions*, not adjusted for differentiation between Annex I and non-Annex I.

Subsequent to the SBT agreement, the IPCC's Fourth Assessment Report (AR4) framed the challenge in different terms:

> For any given stabilisation pathway, a higher climate sensitivity raises the probability of exceeding temperature thresholds for key vulnerabilities *(high agreement, much evidence)*. For example, policymakers may want to use the highest values of climate sensitivity (i.e. 4.5°C) within the 'likely' range of 2–4.5°C set out by Working Group I (Ch 10) to guide decisions, which would mean that achieving a target of 2°C (above the pre-industrial level), at equilibrium, is already outside the range of scenarios considered in this chapter, whilst a target of 3°C (above the pre-industrial level) would imply stringent mitigation scenarios with emissions peaking within 10 years. Using the 'best estimate' assumption of climate sensitivity, the most stringent scenarios (stabilising at 435–490 ppmv CO_2-eq) could limit global mean temperature increases to 2–2.4°C above the pre-industrial level, at equilibrium, requiring emissions to peak within 15 years and to be around 50% of current levels by 2050. Scenarios stabilising at 535–590 ppmv CO_2-eq could limit the increase to 2.8-3.2°C above the pre-industrial level and those at 590–710 CO_2-eq to 3.2–4°C, requiring emissions to peak within the next 25 and 55 years respectively. (IPCC 2007a: chapter 3)

The AR4 spells out the trade-off between mitigation and climate impacts more clearly. Emission reductions relate to atmospheric concentrations and ultimately temperature increase considered tolerable and to climate sensitivity. If climate change impacts over 2°C are not considered tolerable, then a global target to reduce emissions needs to be at least 50% below 1990 levels by 2050. Indeed, halving global emissions by mid-century has only about a half:half chance of keeping temperatures below 2°C (Meinshausen 2005; Rogelj et al. 2009).

Based on this information, the LTMS Scenario Building Team agreed to consider reductions of 30–40% of the base year levels by 2050. This is the scenario of actions 'required by science' (RBS). The burden taken up by South Africa is not exact, but is seen rather as a target band of reductions between 30% and 40% from 2003 levels by 2050.

A burden-sharing discount is assumed; that is, that SA bears less than its proportional share of the global burden of reduction because it is a developing country. The lower end of the target (-40%) can be thought of as a global or collective bottom line. The upper end of the target range suggests some differentiation in responsibility, depending on countries' different capabilities and different national circumstances.

It is assumed in this scenario that South Africa does not have to take the same mitigation actions as the developed countries but, along with other major emitters in the developing world, it takes responsibility for quantifiable mitigation action commensurate with its level of development and national circumstances.

The degree of the burden-sharing discount could be based on a number of factors, including:

- South Africa's status as a developing country and our imperative to reduce poverty
- The coal-based nature of South Africa's energy economy and the degree of effort and cost to make the changes required
- The extent to which the technological and financial resource transfers agreed in the Convention are realised.

The target range can be made even wider, although this is not explored in the RBS scenario.

The RBS scenario has four key points—the starting point, the two end points (with the percentage reductions stated) and the peak (both its level and timing). The RBS reductions in 2050 are roughly half the IPCC SAR reductions of -60% to -80% from 1990 levels in half the time; that is, in 2050 instead of 2100. Later assessments have indicated even greater reductions, but ultimately the reductions required depend on the level of stabilisation of atmospheric GHG concentrations desired. In this scenario, only the emissions trajectories are sketched.

Initial analysis shows that RBS cannot be achieved within a least-cost minimisation framework and the 'ambitious but realistic' limits on resources, technologies, and policies implied in that modelling context. The RBS climate target cannot be met using only known technologies, policies and measures with well-understood parameters, including cost. Put another way, in a carbon-constrained world it will not be feasible to continue with growth as usual.

To indicate the level of emission reductions that are Required by Science, it is assumed that emissions will continue to increase only for a short while, peaking by 2020 at 473 Mt CO_2-eq (already slightly lower than GWC), before declining to 65% of base year levels—that is, -35% means that emissions in 2050 are 290 Mt CO_2-eq. The highest (lowest) part of the RBS band peaks at 483 (463) Mt in 2026 (2016), before declining to -30% (-40%) or 314 (268) Mt in 2050. In other words, the later the peak, the higher the emissions level at which it peaks and the higher the emissions at the end.

The Scenario Building Team suggested that the RBS scenario show a range. The lower line, reducing to -40% by 2050, shows a global or collective bottom line, while the upper line at -30% indicates that South Africa's contribution might be lower, as developing countries have less responsibility than those with greater historical emissions. Compared to the gap between GWC and the whole RBS cloud, however, the differences within the RBS cloud are within a relatively narrow range.

Table 3.2: Parameters used to define the RBS cloud

	Beginning	*Peak value*	*Peak year*	*End value*	*% of start*
Low cloud	446	463	2016	268	60%
Median	446	473	2020	290	65%
High cloud	448	483	2026	314	70%

The RBS 'cloud' in Figure 3.6 is constructed on a storyline that represents emissions peaking soon and then declining to specified levels. In the first few years emissions continue to grow, but the rate of growth is already lower than in GWC. For the bottom line of the RBS cloud, the peak is earliest (2016); for the top line it is later, by 2026. The lines do not converge by 2050. The earlier peak (bottom line) reduces emissions by 40% below 2003 levels by 2050, while the top line gets to 30% reductions. The later the peak, the higher the emissions level at which it peaks (463, 473 and 483 Mt CO_2-eq respectively). This would to some extent reflect an adjustment to national circumstances, where countries more reliant on fossil fuels are required to do less than those with large renewable resources. Another example would be that some countries need a lot of energy to heat or cool space, while others have a moderate climate. The same level of comfort has different emissions implications. The middle line peaks by 2020 and reduces emissions by 35% by 2050.

While the RBS scenario was not analysed through the same modelling as GWC and the strategic options, several important statements could be made about RBS as a scenario. It assumes that climate security is guaranteed through joint international action. Developed countries reduce emissions by -80% to -95% from 1990 levels by 2050, enabling South Africa to limit its emissions to between 30% to 40% below 2003 levels. South Africa suffers fewer dramatic climate change impacts, and experiences reduced costs for adaptation and lower direct damage costs.

The Required by Science scenario sees a South Africa in 2050 vastly different from the one we know today. New technologies dominate the electricity generation and transport sectors, and the renewable and nuclear technologies encountered in the Growth without Constraints scenario are taken up much earlier, and at a much larger scale. It is assumed that large-scale investment in new technologies across the globe will have substantially reduced the unit costs of technologies, for example renewables. New technologies, notably hydrogen-based transport, will by then be the norm, with hydrogen being manufactured through non-carbon means. Although the largest emissions reductions are achieved in the energy and fuel sectors, a good proportion of emissions reduction come about through widespread changes in human behaviour patterns that underpin GHG emission. Much of this is achieved through awareness, as most citizens will be acutely concerned about emissions and adopting low emission lifestyles. The changes required for RBS are picked up again in considering options not modelled (see Chapter 6, page 163, **Reach for the Goal**).

To a large degree, the Required by Science scenario imagines a post-carbon world very different from ours, one that is therefore difficult to describe in detail. What we do know, however, is that achieving this emissions target range will be an immense task.

The gap between Growth without Constraints and Required by Science

The emissions projections for GWC and RBS are shown in Figure 3.6, showing the space within which South Africa's solutions to climate mitigation need to be found.

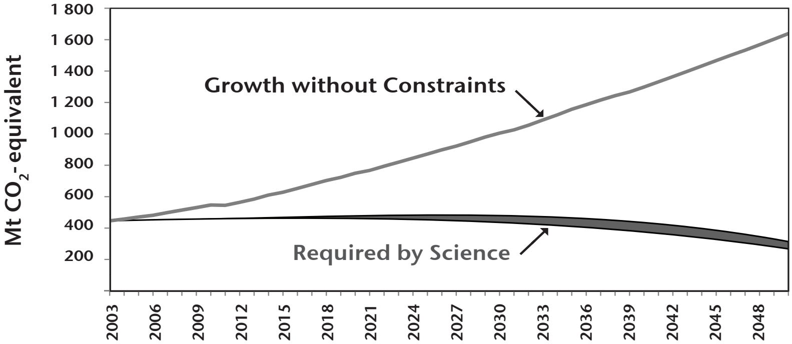

Figure 3.6: Emission reductions Required by Science compared to GWC

As can be seen, there is a large gap between the emissions trajectories of the Growth without Constraints scenario and the Required by Science scenario. Growth without Constraints emissions grow exponentially, while Required by Science peaks quite early, in 2020, at around 470 Mt CO_2-eq, and then declines. The gap in 2050 represents some 1 300 Mt per year of mitigation effort—the gap itself is three times larger than South Africa's total emissions in 2003.

By 2050 the Growth without Constraints and the Required by Science scenarios look dramatically different from each other, both in terms of the development path followed and certainly in their respective emission trajectories shown in Figure 3.6.

The huge gap between emissions in the GWC and RBS scenarios was a shock to the LTMS Scenario Building Team. A significant challenge had been expected, but reductions at three times the volume of base year emissions posed a stark challenge. The shock of this evidence-based approach spurred the SBT to frame RBS as an effective goal. What had earlier in the process been contemplated as scenarios were now called 'strategic options'. The goal of strategic options is to get from GWC emission to RBS. To build up credible strategic options, a wide range of mitigation actions were brainstormed, modelled and combined.

Chapter Four

Taking action on mitigation

The LTMS process explored a wide range of mitigation actions—in the areas of energy supply, energy use and non-energy emissions. The results are reported for each individual wedge, with overviews summarising the key results in tabular and graphical form.[13]

Mitigation actions in the energy sector

Energy efficiency in the commercial sector

In the commercial sector, a number of energy-efficient technologies are available to replace older demand technologies or reduce their energy consumption. These technologies include energy-efficient HVAC systems, heat pumps, variable-speed drives, efficient motors and efficient boilers. In the mitigation policy case, these technologies are introduced in 2008; that is, in the first year that government is expecting to implement awareness campaigns under the energy strategy. The exception is efficient lighting options such as CFLs which were introduced prior to 2008. Attempts to improve lighting efficiency through the use of CFLs and electronic ballasts have already begun through demand-side management campaigns.

There is large scope to improve the energy efficiency of commercial buildings in South Africa. For example, the Nedbank building in Cape Town has managed to achieve a reduction in energy intensity of 65% below that of other similar buildings through design, through a combination of better design of the building and more energy-efficient materials and appliances.

The standards, retrofits and other management actions implemented to improve the energy efficiency of the commercial sector impact on either the useful energy intensity of demand or the energy efficiency of the technology meeting the demand. Building thermal design or design measures that reduce lighting demand will have an impact on energy intensity and will

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[13] See Chapter 5, Table 5.1: Summary table showing mitigation cost, total emission reductions and total mitigation costs in relation to GDP and the energy system (page 144) and Figure 5.1: Individual LTMS mitigation options or wedges (page 151). Additional information in tables and figures for individual wedges is included on the CD-Rom accompanying this book.

reduce the useful energy demand to be met by HVAC systems, heating systems and lighting. These improvements to useful energy intensity by lighting and thermal design standards are restricted to new buildings in the scenario. Retrofits to the lighting systems or HVAC systems in existing buildings are included as an improvement in energy efficiency.

New technologies are given an investment bound which restricts the investment in new capacity of the technology each year. This is done so that their use is gradually increased during the planning period. In this way a more realistic policy impact is modelled.

Assumptions are made around the payback period for energy efficiency measures and the marginal cost of the electricity saved. From these assumptions, we calculate an investment cost for the efficiency measure.

Another important aspect of commercial efficiency is the thermal performance of buildings. Assumptions can be made about the potential improvement in efficiency of new buildings should building standards be introduced. Certain measures can also be applied to older buildings as retrofits.

HVAC systems

HVAC retrofits to more efficient HVAC systems and the improvement of the energy efficiency of HVAC systems are allowed in both existing and new buildings. The savings are assumed to result from audits and other awareness campaigns. The efficiency of HVAC systems can be improved through the use of variable speed drives (VSDs) on fans, retrofitting HVAC systems and using alternative HVAC systems such as heat pumps or central air-conditioning units that have a higher coefficient of performance (COP).

Variable speed drives are assumed to improve the efficiency of HVAC systems by 15% and this efficiency improvement is applicable to 12.5% of building floor space.

HVAC retrofits to HVAC systems in old buildings are allowed in one-third of all buildings and can improve energy efficiency by an average of 35%. Generally these improvements are easy to implement and are assumed in the model to have a payback period of five years.

Efficient HVAC systems in new buildings are allowed in one-third of buildings in 2015, and the efficiency of the system can improve by an average 42.5%. A payback period of five years is assumed for these measures.

Heat pumps and central air conditioners meet a greater portion of demand after 2008. The portion of demand they can meet is increased 5%

between 2008 and 2015 and a further 6% by 2030. This assumes that all new buildings will have the option of using either a heat pump or central air conditioner to meet their cooling needs.

Thermal design

Building standards aimed at improving the thermal design of buildings could reduce the useful energy demand for cooling by an average 40%. The standards and thus improvement in useful energy demand apply to new buildings only.

It is assumed that the 40% savings in demand for cooling can be achieved in 50% of new buildings each year and a further 30% savings can be achieved in 40% of buildings. These savings are introduced into new buildings from 2008 onwards.

Efficient lighting

Retrofits and a move towards CFLs improve the energy efficiency of lighting in existing buildings. Standards reduce the useful energy demand for lighting in new buildings. Eskom DSM campaigns targeting lighting have been very successful and are achieving significant savings. These campaigns include the subsidy of the sale of electronic ballasts which have effectively eliminated the sale of magnetic ballasts. When electronic ballasts replace magnetic ballasts there is a saving of 20%.

Lighting demand in existing buildings is assumed to be improved in two ways. Either magnetic ballasts are replaced with electronic ballasts, achieving a savings of 20%, or the entire lighting system will be retrofitted, achieving a saving of 40%. Again this is a conservative saving. Retrofitted commercial buildings, such as Plein Street in Cape Town, recorded savings as high as 60%.

In existing buildings, savings of 20% through the replacing of magnetic with electronic ballasts are allowed in 50% of buildings, a further 40% saving through the complete retrofit is allowed in 20% of buildings by 2015. The assumed payback period for the lighting retrofit is four years, and ballasts are replaced with electronic ballasts as they fail at no additional cost.

CFLs replace 3.3% of demand for incandescent lighting in 2015 and 6% of demand for incandescent lighting by 2030.

In new buildings, improved design would, in the modelled mitigate case, reduce demand by 60% in 40% of buildings and 30% in a further 40% of buildings.

Water heating

Water heating efficiency is improved through the increased use of solar water heaters and heat pumps to meet demand. Both technologies can meet up to 10% of demand in new buildings in 2015 and 20% of demand in 2030.

Other appliances

The energy required by new electrical appliances or equipment, such as computers and fridges, reduces in the model over time. These improvements in energy efficiency rely on design improvements to technologies. Other savings are the result of behaviour changes and rely on successful awareness campaigns or training. Assumed improvements of 25% of appliance demand can increase 15% in efficiency, and a further 25% can achieve a 30% increase in efficiency. These measures have a one-year payback.

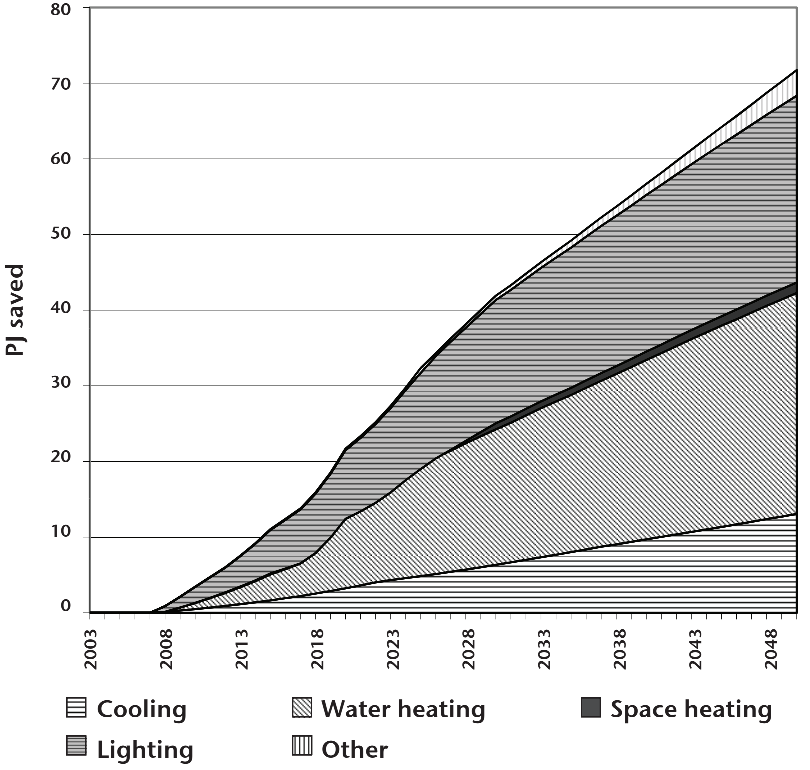

Figure 4.1: Fuel use comparison in the commercial sector

Results for commercial energy efficiency

The commercial energy efficiency interventions result in less electricity, liquid fuels and solid fuels being used overall, but more gaseous fuel and renewables. More specifically, there are substantial reductions in coal for space heating and LPG for water heating. More efficient lighting—fluorescent and CFLs—replaces incandescents. Consumption of non-renewable fuels in both cases is approximately 1 000 PJ lower than in GWC. The main savings are in water heating, followed by lighting and HVAC.

The change in fuel-use patterns in Figure 4.1 reduces emissions. Commercial energy efficiency can reduce an average of 8 Mt CO_2-eq per year, adding up to 381 Mt over the period. At a 10% discount rate, the mitigation costs are -R203 / tCO_2-eq. Like other energy efficiency options, the commercial one is a 'net negative cost option'—that is, the upfront costs of improving efficiency are more than offset by the energy savings over time.

Energy efficiency in the industrial sector

The industrial sector promises great opportunities for improving energy efficiency. Improvements are likely through improved lighting efficiency, compressed air efficiency, motor efficiency, thermal efficiency, steam system efficiency and HVAC efficiency. These are standard measures and are all easily implemented.

For each end-use demand in industry, such as boiler fuels, compressed air, etc., an assumption is made about how much energy can be saved through efficiency measures. These assumptions are based on currently available technology and studies on industrial efficiency potential (Howells et al. 2003).

Efficiency measures in the industrial sector are introduced in the model in 2008 and continue to improve until 2030. They are driven by awareness campaigns, auditing of industrial facilities, and the implementation of standards within the sector.

Savings for all processes reliant on electrical energy are presented in Table 4.1. In all cases, the savings suggested are the average savings that could be achieved across all types of industry in the industrial subsectors.

Thermal savings

These savings are realised through savings in the steam system as well as improved efficiency in other areas. Savings in the steam system can be achieved through steam trap maintenance, improved boiler efficiency, isolating steam from unused lines, repairing steam leaks, optimising condensate return, minimising vented steam and a number of other measures. The focus here is on improving the efficiency of the steam system and boiler and not on improving the efficiency of the end-use process. It is estimated that a 20% improvement in steam system efficiency could be achieved and that the average payback period is 1.4 years.

Compressed air savings

Compressed air savings can be realised at the compressors as well as the ducting system. Fixing leaks in compressed air pipes, closing pipes that are not needed and reducing elbows all result in savings that can be achieved in the piping system with minimal capital expense. Sequencing compressors to meet demand so that they run at full load or using more compressors of smaller size, as well as using cool intake air and waste heat recovery, are all ways in which savings can be made at the compressors at a low cost. Typically, these savings have a payback period of less than a year. The payback period is estimated at 11 months with a saving of 20%.

Efficient lighting

Lighting efficiency can be improved by switching to more efficient lamps and fixtures; this includes replacing magnetic ballasts with electronic ballasts and improved lighting design. Experience through DSM lighting programmes in South Africa has shown that between 30% and 60% savings in lighting in factories is achievable. Additional savings can be achieved by making use of daylight through sky lighting, or using sensors to switch lights off in areas where they are not needed continuously. It is estimated that an average 40% savings could be achieved and that the average payback period is 3.6 years.

Efficient motors

Motor savings can be achieved through the correct sizing of motors and the use of high-efficiency motors. A payback period of six years is estimated for these measures along with a saving of 5%.

Variable-speed drives

Variable-speed drives, also called variable-frequency drives, achieve savings by regulating the speed of the motor. Variable-speed drives can achieve savings of between 5% and 10% depending on the application. The largest savings are generally realised for fans and pumps where the input power varies with the cube of the pump or fan speed. The assumed payback period for variable-speed drives is seven years.

Industrial measures are assumed to have a penetration rate of between 2% and 7% each year; that is, 2% to 7% of demand is assumed to improve in efficiency each year. This penetration rate in the model is based on an anticipated success of audits and awareness campaigns, but significant effort on the part of government would be needed if this take-up rate is to be achieved in reality (Howells et al. 2003).

Results for industrial energy efficiency

Industrial energy showed the largest cumulative reduction in emissions among the LTMS wedges of energy efficiency.

Table 4.1: Overall efficiency improvements, distinguishing technological efficiency and systems savings

	2008	*2015*	*2030*	*2050*
Boilers and steam systems	0%	10, 10%	16, 16%	20, 20%
Compressed air	0%	7.5, 7.5%	16,16%	20, 20%
Process heat	0%	3,-%	4, -%	5, -%
HVAC	0%	12, -%	18, -%	25, -%
HVAC with waste heat	0%	0%	10%	30%
Lighting	0%	30,10%	70,10%	75,10%
Other motive	0%	9%	11%	15%
Pumping, fans (process flow)	0%	10%	25%	40%
Process cooling	0%	5%	7%	10%

Table 4.1 emerged from the discussions at a small meeting on industrial energy efficiency.[14] It shows the revised estimates of overall efficiency improvements achievable in the near term (2008) and three future years, 2015, 2030 and 2050. Technical efficiency gains may be limited when

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[14] The LTMS process included a meeting with industry stakeholders on this particular issue (21 June 2007, chaired by Ian Langridge, Energy Efficiency Technical Committee).

considering technology in a narrow sense, but further savings are possible when taking the broader system into account. The percentages are additive to give overall savings.

The industrial energy efficiency wedge was not doubled, compared to initial analysis. The revised analysis, based on the adjusted energy savings considered possible at various periods, yielded emission reductions of 4 805 Mt CO_2-eq over the period. Industrial energy efficiency is also a net negative cost mitigation action, at -34 / tCO_2-eq. The range of interventions in industrial efficiency covers a range of more energy-intensive activities, leading to larger total reductions.

Energy efficiency in transport

Increased efficiency in the transport sector results from several options: a shift for passenger transport from private to public modes; greater use of electric vehicles; requirements to increase the share of biofuels as well as subsidies for biofuels; more efficient light vehicles; hybrid vehicles and limiting vehicle size or the use of sport utility vehicles (SUVs).

The overall target for final energy demand reduction in the transport sector by 2015 considered in the LTMS process is 9%. In order to reach this goal a number of stringent policies or measures need to be introduced. Two important differences in modelling the transport sector differentiate it from others in this study:

- In the transport sector, the model is tightly constrained, and does not optimise in the way that it does in the rest of the energy system. The rationale for this is that consumers apply a range of other criteria to purchasing transport services in addition to purely economic considerations.
- The basic units in the transport section are passenger-kilometres.[15] The advantage of this approach is that modal shifts can be modelled far more easily. Thus, in the case of vehicle efficiency, improvements in engine efficiency are not modelled directly. Instead, the efficiency improvement is in the amount of energy required per passenger-kilometre; however, since the number of passengers in vehicles remains the same, this approach approximates vehicle efficiency improvement.

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[15] This is a measure of transport services, thus one passenger-kilometre = transport required to move one passenger one km.

More efficient vehicles and increased use of diesel

In the GWC scenario, all new private passenger vehicles and light commercial vehicles increased in efficiency by 0.4% per annum. In the policy scenario, this efficiency improvement is increased to 0.9% per annum.

Vehicle efficiency increases 0.5% in GWC, whereas as in CDP, it increases by 0.4% between 2003 and 2007, and 0.9% thereafter. Vehicle efficiency improves by 1.2% per year, based on savings which have been achieved in the United Kingdom (An & Sauer 2004), saving a significant amount of petrol. There is a significant reduction in domestic fuel requirements (17%), significantly less refinery capacity is built domestically, and imports increase significantly to balance the domestic product profile. In addition to this, vehicle occupancy is assumed to increase from 2.1 passengers per vehicle-km to 2.2 passengers per vehicle-km.

The taxi recapitalisation plan is also included in this scenario. In the base case the LTMS research teams assumed a moderate increase in the number of diesel taxis introduced to the taxi fleet, and a significant impact is only made after 2015. The diesel taxis that form part of the programme are larger Midi bus vehicles that seat 19 to 35 passengers compared with the mini buses that seat 18 passengers or less and are designed for longer distances. In the policy case, the target is introduced sooner so that, by 2015, 4.7% of taxis are diesel. This is increased further to 7.4% by 2030.

The number of private diesel cars also increases in comparison to the base case where an increase is only noticed after 2015. It increases further to 15% in 2030. The number of diesel passenger vehicles has increased dramatically over the past few years. While the base case demonstrates this with an increase from 2.8% in 2001 to 5% in 2030 of private passenger-kilometres, this efficient transport scenario allows the model greater penetration of diesel vehicles. In this scenario, diesel cars made up 15% to 30% of private passenger-kilometres by 2030.

The two most important factors in reducing costs are first that more efficient vehicles save 14% of petrol consumption over the period (saving 25% in 2050), and save 12% of diesel (22% in 2050). Second, the construction of new crude refineries is delayed and avoided (only three new refineries are built as opposed to five), reducing system costs.

Greater vehicle efficiency is a negative-cost mitigation option. The wedge results in an annual average emission reduction relative to the reference case of 16 Mt CO_2-eq per year. Between 2003 and 2050, some 758 Mt CO_2-eq can be avoided at a cost of -R269 / tCO_2. Both the cost-effectiveness and the scale of the reductions suggest that there is significant mitigation potential in proactively promoting a greater increase in the efficiency of South Africa's vehicle fleet.

Hybrid vehicles

Hybrid vehicles are included as an option for improved vehicle efficiency. These vehicles can make up 2% of passenger km by 2030. SUV use decreased compared to the base case where it is assumed to increase up to 2%. In the modelling case implementing the mitigation action, the use of SUVs is capped at 1% of private passenger-kilometres.

With 40% of cars being hybrids by 2030 (starting from zero in 2003), costs increase with the price of vehicles being more than double that of regular petrol cars. The increased use of hybrids displaces only petrol-driven private passenger vehicles. The efficiency of hybrids is more than double in passenger-kilometres per fuel use. Introducing hybrids results in substantial emissions savings over the period of 381 Mt CO_2-eq, but at a high cost of R1 987 / tCO_2 at a 10% discount rate. This is a significant cost for reductions that average only 8 Mt CO_2-eq per year.

Electric vehicles

Purchase prices are higher at R176 000 for an electric vehicle, compared to R100 000 for petrol and R115 000 for diesel cars, although these prices are expected to decline with technology learning. The 'well-to-wheels' implications for GHG emissions depend, of course, where the electricity comes from. If electricity is generated in a coal-dominated grid—as is the case for both the US and SA—the emission reductions will be less than for a vehicle which uses a lot of lower or zero-carbon fuels for electricity generation. A recent study on electric vehicles in the US by EPRI and NRDC has shown that emission reductions are possible even in coal-dominated grids (EPRI & NRDC 2007). The analysis shown here assumes that electric vehicles make up 60% of the private passenger car market, which displaces only about a quarter of petrol use in the transport sector (the remainder is used by petrol minibus taxis, light commercial vehicles, and the remaining private passenger vehicles). If a GWC-type grid is assumed, the take-up of electric vehicles results in a mitigation of 450 Mt CO_2-eq over the period, even on a coal-dominated grid, at a relatively high cost of R607 per ton. As vehicle costs decrease, this will become a more affordable mitigation option. In addition to CO_2 mitigation, electric vehicles also have other co-benefits, such as the lowering of local air pollution in urban areas.

If a grid dominated by nuclear and renewable forms of energy is assumed, the CO_2 savings are somewhat higher, at 6 255 Mt CO_2-eq over the period, at a mitigation cost of R102 / tCO_2-eq. However, these costs and savings include those of the transformed electricity grid. Thus, if one subtracts the effects of the change in the grid, the net savings for electric vehicles are 666 Mt CO_2-eq.

Modal shift in passenger and freight transport

Another mitigation action modelled as an LTMS wedge is an increased use of public transport. In the GWC case, public transport is 51.2% of demand, while in the modelled action public transport is assumed to grow by 25% above this. A modal shift in passenger transport means that more passenger-kilometres are produced by the same energy use. The emission reduction is mostly due to reduced use of diesel and petrol (although electricity use increases at the same time). The costs for this wedge *include* infrastructure costs. The scale of investment required in public transport systems would at least reduce and maybe outweigh the cost savings from more efficient transport. Even with infrastructure costs taken into account, the costs are still net negative, at -R1 131 t / CO_2-eq. Total emissions of 469 Mt CO_2-eq are saved over the period.

The use of rail for freight is also increased. The GWC scenario assumes that 28.3% of tonne-km is transported by rail in 2015 and 32.3% in 2030. In this scenario, the use of rail for freight is projected to increase to 44.6% in 2015 and 45.15% in 2030.

Biofuels and subsidies

For this mitigation action, the biofuels blends are increased and the effects on cost and emission reduction analysed. The blend fractions are increased to 8% ethanol with petrol and 2% biodiesel with diesel in 2013. Thereafter the percentage of ethanol in petrol is taken up to an assumed maximum of 20% and biodiesel to a maximum of 5% in 2030. A rate of 20% ethanol is the maximum fuel blend for petrol cars before major modifications are required and the volume of ethanol required to achieve this blend could be produced in South Africa without impacting on food supply, based on agricultural trends and land availabilities.

However, if we also produce biofuels for sale to other foreign countries, this may no longer be true.

Bioethanol is produced locally from maize in the scenario, whereas biodiesel is produced from imported sunflower seeds, or other imported feedstock. The cost of feedstock as well as plant capacity is included in the scenario. Biofuels form part of a more general renewable energy option, but are reported separately. In addition, as an economic instrument, a subsidy for biofuels has also been modelled. The biofuels wedge resulted in total emission reductions of 154 Mt CO_2-eq over the whole period. Average reductions of 3 Mt CO_2-eq per year come at a relatively high mitigation cost of R524 / tCO_2-eq. The moderate scale of reductions reflects the limits on the potential of biofuel in SA, which needs to take into account issues of food security, availability of arable land and water, and potential impacts on biodiversity.

A subsidy was applied to biofuels of R1.66 per litre, which resulted in biofuels comprising 9% of the domestic fuel by 2050, and mitigation of 573 Mt CO_2-eq over the period, at a cost of R697 / ton. Biofuels displace one crude refinery, and thus significantly lower oil imports.

Limits on vehicle size

Limiting the share of larger, more expensive SUVs requires a shift to smaller vehicles. Not only is the capital cost of smaller vehicles about a third of SUVs but they deliver more passenger-kilometres per litre of fuel.

A limit on vehicle size is implemented in the model that only 1% of private passenger-kilometres can come from SUVs, most coming from smaller-engine vehicles. Emission reductions are 18 Mt of CO_2-eq over the period, at a cost of –R4 404 per ton (see Table 5.1, page 144). The highly reduced costs are realistic, as they reflect a move to vehicles that have a lower capital cost and lower running costs.

Energy efficiency in the residential sector

In the residential sector, savings are achieved by allowing households to switch to more efficient appliances and fuels. The target for final energy demand reduction by 2015 in the residential sector is 10%. In order to reach this target, fairly significant changes need to take place in the early part of the time period. The following measures are the most important taken in the residential case to achieve the savings.

Basa Njengo Magogo

The 'Basa Njengo Magogo' is a coal brazier with an improved method of use, which shows an increase in efficiency of 37.5%. This method of cooking is simple and requires no additional or alternative appliance, and is part of a Department of Minerals and Energy programme to reduce local air pollutants in low-income areas. The combustion of fuel is more efficient in the Basa Njengo Magogo method of cooking because the fire is lit from the top of the brazier and burns slowly down, whereas in the traditional method of cooking the fire is lit at the bottom of the stove. Its major advantages include reduced particulate emission, ease of ignition and reduction of coal required by 17%. This coal saving equates to 1kg per use and, at a cost of approximately R1 per kilogram of coal, this translates to a saving of R30 per month (Le Roux et al. 2005).

In the base case (or Growth without Constraint), the Basa Njengo Magogo method is used in up to 3% of households in 2015 and 7% in 2030. In the GWC case, up to 20% of urban low-income electrified and non-electrified households shift to the Basa Njengo Magogo method by 2015 and 40% by 2030 for space heating and cooking. These upper rates are based on assumptions about the effectiveness of government programmes to reach households and convince them to shift to the new method.

Solar water heaters

Solar water heaters (SWHs) are gaining popularity in cities such as Cape Town, which are considering policies to make solar water heaters on new homes a by-law. In the residential reference case, a high rate of solar water heater use is assumed, as shown in Table 4.2. A much lower rate is assumed for old houses.

Table 4.2: Assumed rates of adoption of solar water heaters by household type (a much lower rate is assumed for old houses)

	2008	*2015*	*2030*	*2050*
New houses				
Rural rich electrified	1%	25%	60%	65%
Rural poor electrified	1%	25%	60%	65%
Rural poor unelectrified	1%	5%	10%	20%
Urban rich electrified	1%	50%	75%	75%

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	2008	*2015*	*2030*	*2050*
Urban poor electrified	1%	55%	80%	80%
Urban poor unelectrified	1%	7%	15%	20%
Old houses				
Rural rich electrified	1%	8%	10%	15%
Rural poor electrified	0%	2%	5%	7%
Rural poor unelectrified	0%	0.5%	2%	4%
Urban rich electrified	1%	5%	10%	20%
Urban poor electrified	1%	2%	6%	10%
Urban poor unelectrified	0%	0%	0%	0%

Geyser blankets

Geyser blankets are another efficient form of water-heating technology used in this scenario. The scenario depicts a high uptake (approximately 65%) of electric geysers insulated with a geyser blanket (or similarly effective insulation) by 2015 (Howells et al. 2003). Geyser blankets achieve a 14.3% improvement in efficiency.

Thermal efficiency of houses

Thermal performance of buildings can be improved through addition of insulation, ceilings and general thermal efficiency building standards. In many low-income households, ceilings are omitted as a cost-saving mechanism. However, they greatly affect the thermal comfort and space heating requirements of the building. In this scenario there is a high level of thermal efficiency in new buildings and a lower one for old buildings where limited retrofit is possible and more costly. In new houses, it is likely that all new houses will have improved insulation. Of those, 50% will have significant winter heating requirement and the improved insulation will result in a 30% reduction in space heating requirements (Howells et al. 2003).

Ethanol gel

Ethanol gel fuel is a new substitute for paraffin used in low-income houses for cooking and lighting. Its advantages are mainly safety (if knocked over, gel fuel stoves will not cause widespread fires as paraffin stoves do) and reduced particulate emissions. The efficiency of these stoves is under investigation and, while the calorific value of ethanol gel was thought to be similar to paraffin (23 MJ/kg for gel versus 25 MJ/kg for paraffin), recent studies have shown that the energy intensity of ethanol gel fuel is closer to 16 MJ/kg (Lloyd & Visagie 2007). Another drawback is that, during tests, a large amount of water vapour collects at the bottom of the pot during cooking. This reduces the efficiency of the stove and lengthens the time required for cooking. The cost of the gel fuel could also prove prohibitive since five litres of gel fuel costs approximately R160 whereas the same amount of paraffin costs R50 (Makgetla 2006). Nevertheless, users of the gel fuel stoves have commented that the clean-burning fuel is more pleasant to use and easier to store and transfer than paraffin. And, while costs are high, they claim that an amount of gel fuel that could last up to a month would only last a week if it were paraffin (Makgetla 2006). It is interesting to note that the efficiencies of gel fuel stoves and paraffin stoves are not very different (0.41 versus 0.4), yet the calorific value of the fuels and resultant energy costs are very different.

Gel fuel stoves could prove to be very unfavourable in a least-cost optimising scenario. In the GWC case there is little to no uptake of gel fuel into the residential fuel mix. However, in the base case, the bounds on the use of gel fuel are opened up, and the model is free to choose the least-cost option to meet demand.

Lighting

Lighting in the residential sector is another area in which significant savings are possible. Eskom has already initiated a massive roll-out of CFLs in the Western Cape to aid with the recent power shortages. In the GWC or base case, a very low usage of CFLs is depicted: 5.3% in urban areas and 1.9% in rural areas. In the base case this is increased dramatically to 40% by 2015 in urban areas and up to 35% in rural areas. The upper rate of usage continues to increase to 60% and 50% by 2030 in urban and rural areas respectively. These rates remain constant to 2050.

For other water heating, cooking and space heating technologies, the upper and lower bounds are widened in the reference case, so as to give the model the freedom to choose most efficient fuel and technologies to meet demand.

Results: Residential sector

Residential mitigation actions save a moderate amount of CO_2 over the period—430 Mt CO_2-eq. These come at a cost of -R198 / tCO_2-eq. Most energy savings derive from water heating, with a smaller saving from lighting.

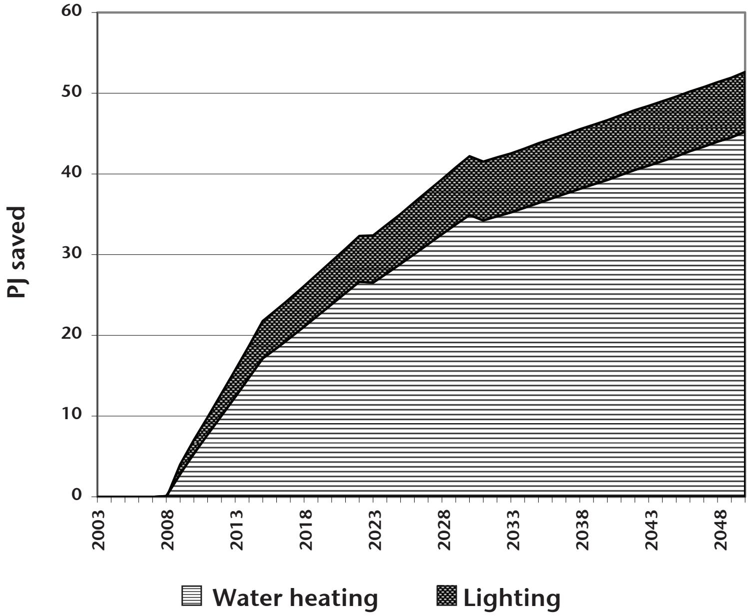

Figure 4.2: Savings through energy-efficiency measures in the residential sector

Residential energy efficiency (including SWH) is a good, negative-cost mitigation option. While individual interventions are small, across a large number of households they add up to avoided emissions of more than 400 Mt CO_2-eq over time. In addition, there are clear socio-economic benefits—increased service of hot water, warmer houses, and lower fuel bills. These factors make this option an important candidate for a portfolio of mitigation actions.

Renewable electricity

The LTMS model parameters specify that 15% of electricity sent out in 2020 must come from renewable sources, and 27% by 2030 (around 443 PJ). Included in the renewable options to meet demand are hydro, wind, solar, biomass and landfill gas technologies. Imported hydro is restricted in this scenario to 15% of supply. These parameters define the first of two renewable energy wedges in LTMS, the second with more extensive take-up.

In the initial renewable electricity wedge, 15% of electricity dispatched must come from domestic renewable resources by 2020, from South

African hydro, wind, solar thermal, landfill gas, photovoltaics, bagasse/pulp and paper. This is extrapolated to 27% by 2030, at which level it remains thereafter. Each of these technologies has an upper limit of capacity that can be built over the period.

The initial renewable energy scenario sees the introduction of solar power towers, solar parabolic trough and wind turbines. The extent to which each is introduced can be seen in Figure 4.3. The solar power tower comes into the mix from 2014 and reaches its limit of 30 GW in 2045. The electricity generation of the solar parabolic trough starts off much smaller, but reaches 16 GW by 2050. Wind comes in gradually, mostly at 25% availability, reaching a peak of 15 GW installed capacity in 2030, but declining to 7 GW by 2050.

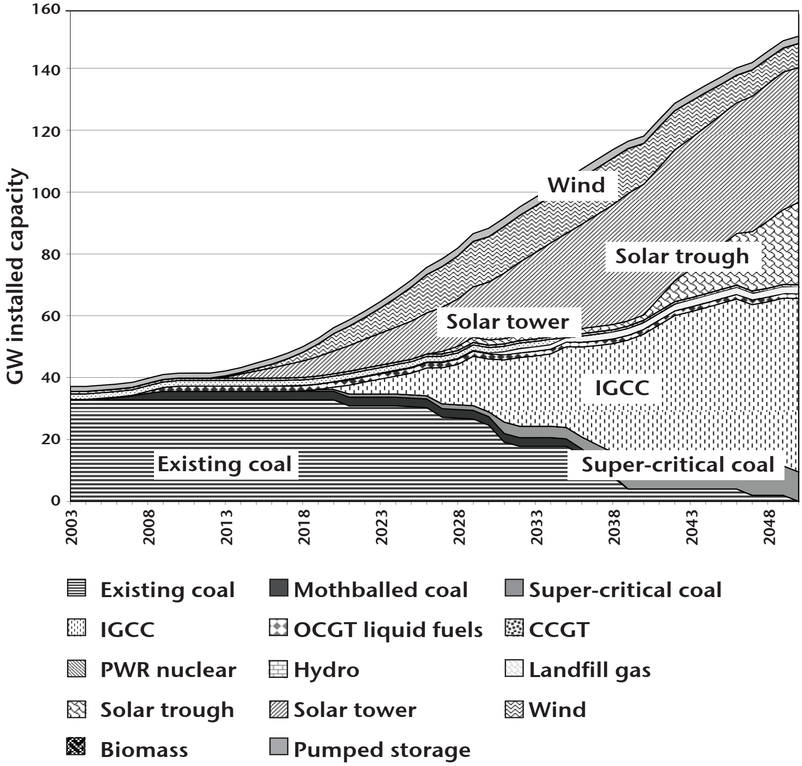

Figure 4.3: Electricity-generating capacity from renewable energy, with learning (Some elements occur in numbers too small to be visible)

Figure 4.3 shows installed capacity (GW), not electricity generated (kWh). Since renewable energy technologies generally have lower availability factors (with the exception of the solar tower at 60%), more capacity needs to be built for the same electricity output than for a high-availability plant; thus the size of the grid in this case is 140 GW, 20 GW larger than in GWC.

The emission reductions for a 27% renewable electricity wedge add up to 2 010 Mt CO_2 over the period. The mitigation cost is R52 / ton CO_2-eq at a 10% discount rate, reducing emission on average by 42 Mt CO_2-eq per year.

If technology learning is assumed for both GWC and the renewable case, the mitigation costs decline significantly, becoming negative at –R143 / tCO_2-eq. The total emission reductions are also increased to 2 757 Mt CO_2-eq over the period. Emission reductions increase with learning, even when compared to the base case with learning. Annual emission reductions are 15 Mt CO_2-eq higher if technology learning is assumed. The conclusion is that, if SA found itself in a world in which new technologies got cheaper due to investment globally, emission reductions would be more cost-effective, and still deliver significant reductions.

In another—extended—wedge, electricity generation from renewable energy sources is extended to 50% by 2050. Total emission reductions increase to 3 285 Mt CO_2-eq, but at a higher mitigation cost of R92 / tCO_2-eq. The wedge is implemented in other respects as for the 27% case.

When taking learning into consideration, mitigation costs are R3 / tCO_2-eq, with annual emissions reductions of 83 Mt CO_2-eq. A total of 3 990 Mt is mitigated over the period. For the mitigation costs of renewable energy technologies, assumptions about learning are clearly important.

Nuclear power

In this scenario, the contribution of nuclear technologies to the supply of electricity is increased, in the form of the pebble bed modular reactor (PBMR) and new pressurised water reactors (PWRs) similar to the ones in operation at Koeberg. Starting in 2015, nuclear energy supplies 27% of electricity demand by 2030 in this scenario.

For the initial wedge, either the PBMR, or new PWR nuclear plants must provide 27% of electricity generated by 2030. No new nuclear capacity can be commissioned before 2013, when the first PBMR can be commissioned, with the PWR in 2015. The upper limits on capacity are relaxed in the mitigation case (100 GW PWR max; 50 GW PBMR).

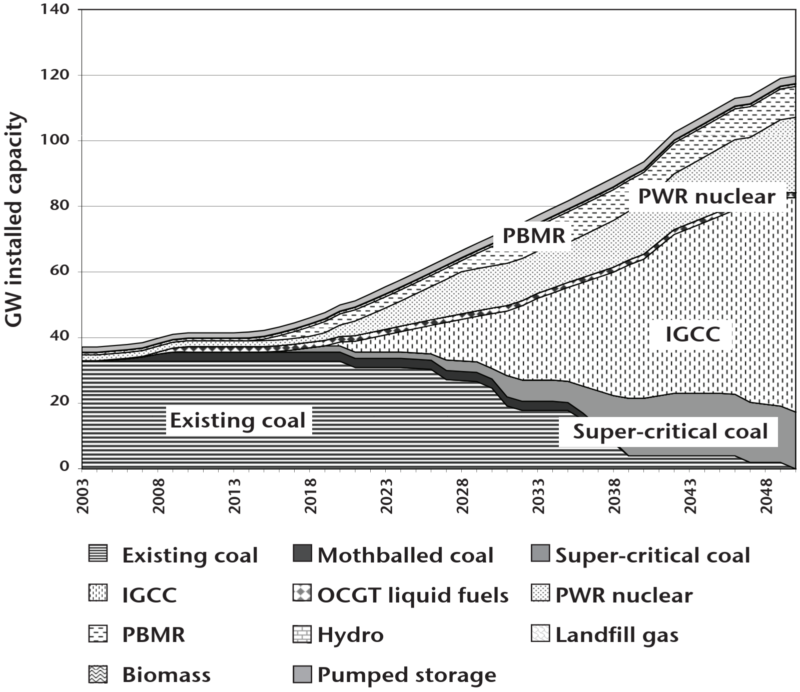

Figure 4.4: Electricity-generating capacity for nuclear mitigation (Some elements occur in numbers too small to be visible)

The PBMR reaches more than 1% of installed capacity in 2015 and 8% by 2050, a capacity of 9 GW. PWR plants see Koeberg coming to the end of its life by 2035, but total PWR capacity reaches 15% of total installed capacity in 2025, increasing to 19% by the end of the period, nuclear totalling 23 GW of capacity in 2050.

The total emission reductions from building nuclear power are 1 660 Mt CO_2-equivalent over the 48 years. The cost of saving is R18 per tCO_2-eq at 10% discount rate. Mitigation costs are lower than for renewables. This result is probably due to two factors—the higher availability factor of nuclear plants, and the relative costs (without technology learning). The annual emission reductions average 35 Mt CO_2-eq.

The nuclear mitigation action was modelled in extended form, reaching 50% of electricity generated in 2050. As can be seen in Figure 4.5, most of the increase in nuclear capacity comes from the PWR.

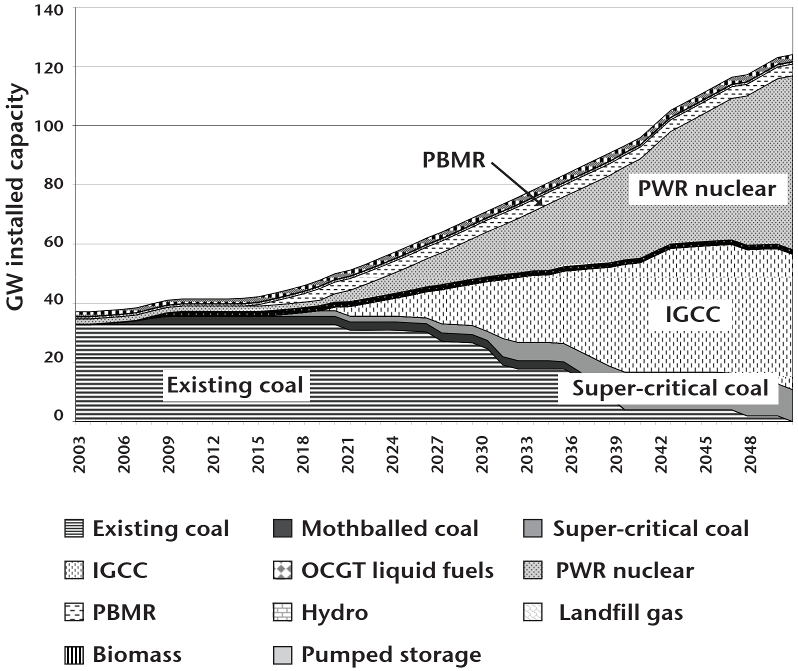

Figure 4.5: Electricity-generating capacity for nuclear mitigation, extended (Some elements occur in numbers too small to be visible)

The extended wedge shows substantial emission reductions of 72 Mt CO_2-eq per year on average, totalling 3 467 Mt CO_2-eq from 2003 to 2050. This is a significant increase over nuclear at 27%, which saved less than 2000 Mt, at a slightly higher mitigation cost—from R18 to R20 / tCO_2-eq. The annual reductions are 72 Mt CO_2-eq, a large wedge in the South African context. Total emission reductions are 3 467 Mt CO_2-eq over the period.

Combinations of renewable and nuclear power

To investigate the effect of renewables and nuclear combined, the wedges combine the nuclear and renewable mitigation options at 50% each. The resulting grid is dominated by PWR nuclear and the solar tower and trough technologies. The total capacity of the grid is 180 GW by 2050, requiring significantly more installed capacity than in other wedges (generally 120 to 140 GW).

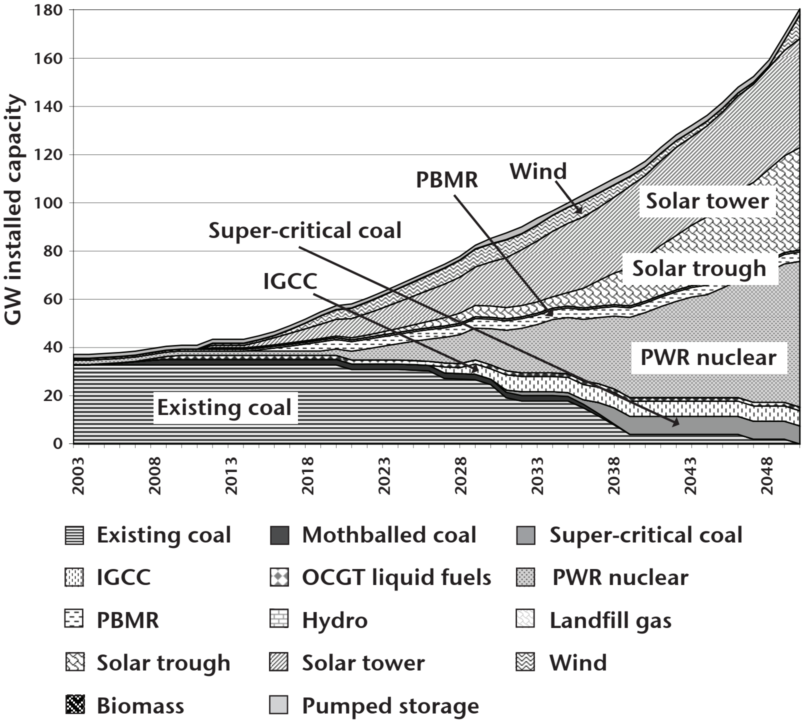

Figure 4.6: Electricity-generating capacity for nuclear and renewables mitigation (Some elements occur in numbers too small to be visible)

Renewable electricity and nuclear power each to 50%

This would need a commitment to make South Africa's electricity generation zero-carbon by 2050. With complete decarbonisation of the electricity sector, 8 297 Mt CO_2-eq can be avoided, 173 Mt on average each year. By the end of the period, emission reductions reach 560 Mt, reducing the gap to RBS to 59%. However, emissions still increase in absolute terms due to increases in other sectors of the economy. Mitigation costs are R52 / tCO_2-eq at a 10% discount rate. This combination of extended wedges stays below 1% of GDP.

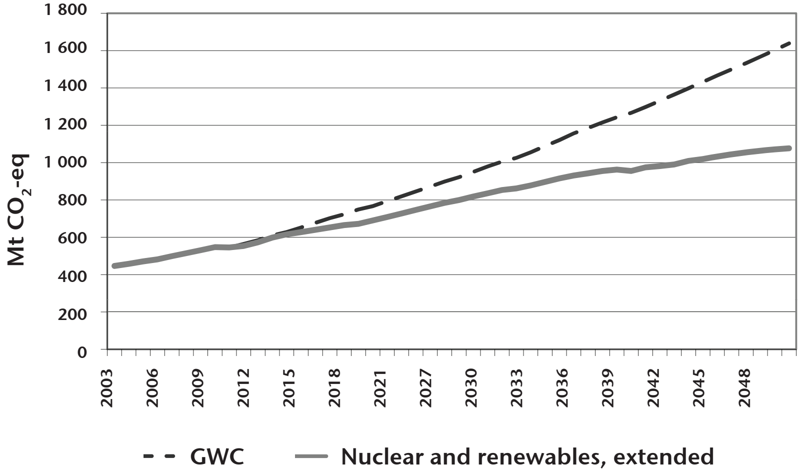

Figure 4.7: Emissions from 50% renewables and nuclear power each, compared to total emissions in GWC

In other words, even very aggressive mitigation in the electricity sector on its own will not prevent growth in absolute emissions. Mitigation action is needed in several sectors to get anywhere near what is Required by Science—there is no 'magic bullet'. A portfolio of technologies will be needed, as suggested in the IPCC's Fourth Assessment Report. (IPCC 2007a).

Variants: 80% nuclear and renewables

Two variants of the extended renewable and nuclear wedges were run, exploring a full range of scenarios despite different views in the LTMS Scenario Building Team on the feasibility of very high uptake of renewables. Both were extended so that 80% of electricity would have to be generated from nuclear and renewable sources respectively in 2050. The remaining 20% could come from any source.

The cumulative emission reductions (2003–2050) were 5 095 Mt CO_2-eq for the 80% nuclear and 4 780 Mt for 80% renewable variant. The cost-effectiveness of mitigation in these two cases, at a 10% discount rate, is R12 / tCO_2-eq for 80% nuclear and R65 for 80% renewables. The mitigation costs relative to economy (GDP) and the total energy system costs are reported. The total mitigation costs for 80% renewables would amount to 0.7% of GDP; or raise energy system costs by 3.1%. Similarly, nuclear would impose costs equivalent on average over the period 2003 to 2050 of 0.15% of GDP, or 0.7% more in energy system costs.

The energy modelling team expressed low confidence in the results (Hughes et al. 2007), the fundamental reason being that the energy system is stretched beyond limits normally considered in modelling. Assumptions that hold at lower penetration rates no longer apply at these levels. More specifically the following aspects apply:

For renewables: This case uses the same assumptions for the availability of renewable plants as the base case. It is important to note that we have six time-slices in the MARKAL energy model. These time-slices each contain a demand for a summer day and summer night, winter day and winter night and intermediate day and intermediate night. The time-slice fraction allocated to day within the model is 0.62, and night 0.38. In order to simulate a load profile, the demand for electricity by the sectors differs in each time-slice. For instance, in the commercial sector, demand during the winter day is assumed to be 71% of the daily demand in the season, and the seasonal winter demand is assumed to be 32% of the total demand in the year. With these limited parameters it is possible to simulate a very rough load profile.

The renewable options are modelled using an annual plant availability. The option does exist in MARKAL to use a time-slice availability, but this is largely unknown in the South African context for both wind and solar thermal electricity technologies, which make the largest contributors towards renewable energy generation. In the cases where renewable generation contributes to the total electricity generated to a lesser extent, the load profile and availability simplifications can be acceptable; however, where renewables are included at 80%, both the roughness of load profile and the lack of time-specific generation data, which could include increased costs for plants that may require large amounts of storage, make the results very inaccurate.

For nuclear power: The analysis assumes no constraints on the delivery of plants, or parts of the system that would have to be imported. At lower levels of penetration, this might be a plausible assumption. But if South Africa orders large numbers of nuclear plants (at the same time as other countries might do this), this constraint becomes significant.

South Africa currently imports its nuclear fuel in processed form. Similar arguments might apply to the fuel, or alternatively, a full nuclear fuel cycle might be developed domestically. The costs of developing a nuclear fuel cycle are not included in the modelling, which would need to be added to the costs assumed.

Given large amounts of nuclear power, the stand-by capacity for cooling may be larger. This has not been modelled. Again, this is a simplification that modellers find acceptable at lower penetration rates, but that becomes a significant issue at higher levels.

Cleaner coal—IGCC

The cleaner coal mitigation action comprises an increase in IGCC, with a much more optimistic penetration rate for the technology. In 2018, super-critical coal constitutes more than 9% of installed capacity. It reaches 10GW of installed capacity by 2050. IGCC is 16% of the mix mid-way through (2025) and 67% by 2050. There is no extended cleaner coal wedge, since super-critical coal plants are in GWC by definition—no more sub-critical plants are to be built, as can be seen in Figure 4.8, with some CCGT and PWR nuclear coming in. Cleaner coal is sometimes understood to include CCS from electricity generation as well (see wedge in Figure 4.9.)

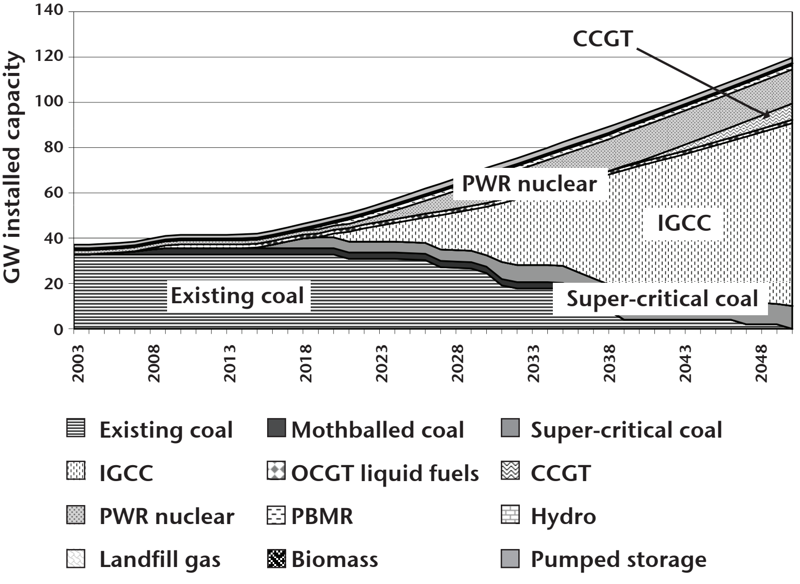

Figure 4.8: Electricity-generating capacity for cleaner coal (Some elements occur in numbers too small to be visible)

As with renewable energy technologies, learning for cleaner coal technologies is a function of global installed capacity. For cleaner coal technologies, data were available for super-critical coal (4%), which is included in GWC and therefore no different in the mitigation case. The cleaner coal wedge in the LTMS analysis is relatively small, with annual average reductions of 3 Mt CO_2-eq. Over the period, the reductions add up to 167 Mt CO_2-eq, at a cost of –R5 / tCO_2-eq, due to the increased efficiency of IGCC technology.

Cleaner coal—limited CCS from electricity generation

Carbon capture and storage (CCS) is different from other mitigation options in that it actively captures the emissions and stores carbon dioxide (CO_2). Using CCS will in general necessitate the addressing of a range of concerns about its impacts on local sustainable development and an appropriate regulatory framework would need to be developed. Power plants with CCS use more fuel than those without and do not capture all of the CO_2 emitted (roughly 86%) (IPCC 2005a).

Carbon capture and storage (CCS) on electricity generation is limited to 2 Mt per year, adjusted downward from the previous 20 Mt modelled for SBT4. The SBT subsequently suggested a lower limit, given the scale of existing and planned CCS facilities. Costs for the higher figure are also reported.

It is important to understand that the amount of carbon dioxide avoided by a power plant with CCS is *not* the same as the amount of CO_2 capture. The efficiency of a power station with CCS will be lower than that of a reference plant. As Figure 4.9 shows, some of the CO_2 captured and stored offsets the increase in total emissions. Second, there are some emissions from the plant with CCS (estimated at around 15%). Thus, while the CCS action stores say 2 Mt CO_2 per year, the net impact on emissions reduction is less. In addition, in this case the slightly higher capacity of coal-fired power displaces some renewables, hence the spike in emissions in 2048.

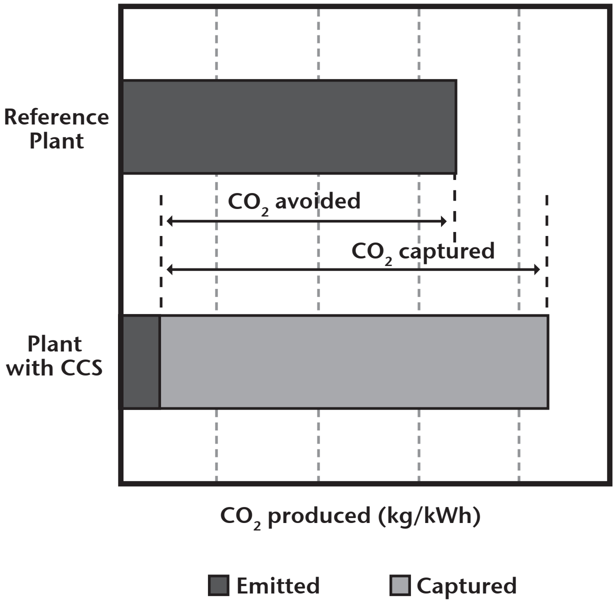

Figure 4.9: CO_2 capture and storage from power plants

Source: (IPCC 2005a)

The nominal cost of carbon capture and storage reported by IPCC has wide ranges, but would be over \$50 / tCO_2-eq.[16] In addition, South African geological conditions are not favourable for carbon capture, and thus a limit of 20 Mt CO_2-eq per year was imposed on the model; in addition, in South African conditions, this is unproven technology. Storing higher amounts of CO_2 per year would require a technological breakthrough. The streams of CO_2 available for capture are large, although for power stations the costs of separating fairly dilute streams of CO_2 from other gases make it more expensive than carbon capture and storage from synfuels. CCS limited to 2 Mt saves an average of 6 Mt of CO_2-eq per year. The difference between this figure and the storage limit is due to slight shifts away from coal in the model due to the increased price of carbon capture-generated power. CCS limited to 20 Mt only saves an average of 9 Mt a year, due to the same kinds of systemic effects.

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[16] Most of this (\$45 / tCO_2-eq) would be for capture, with the rest for transport (\$4), geological storage (\$4) and monitoring and verification (\$0.2).

Mitigation actions in the non-energy sectors

Most of South Africa's greenhouse gas emissions come from energy supply and use, but about one-fifth are from non-energy sectors. The LTMS process considered non-energy mitigation options for industrial process emissions, agriculture, waste and land-use change and forestry (LUCF).

Several mitigation actions related to industrial process emissions were considered.

- **Synfuels**—two mitigation options were modelled
  - capture the methane (CH_4) emissions from the existing coal-to-liquid plants; and
  - capture and store some of the carbon dioxide from potential new coal-to-liquid plants (in the MARKAL model), up to a limit of 20 Mt CO_2 per year.
- **Coal mining**—reduce methane emissions
  - by 25% or
  - by 50%.
- **Aluminium**—reduce perfluorocarbons (PFCs) emissions from existing plants
  - Initial data were gathered for modelling mitigation in iron and steel and ferro-alloys, but no results are available in time for the LTMS process. Similarly, initially mitigation options for reduction of clinker content in cement were analysed, but no final results were generated. Future work needs to establish key parameters if these options were to be included.

The mitigation options for the agriculture, waste and LUCF sectors were analysed (Taviv et al. 2007):

- Reduction of enteric fermentation by using a smaller, more productive herd, and through a move from rangelands to feedlots with improved feed.
- Improvement of manure management by disposal as dry spread instead of lagoons (80% of manure from dairy and feedlot will be disposed of as dry spread).
- Aggressive adoption of no tillage practice (on 80% of lands).
- Less aggressive adoption of no tillage practice (40% for wheat and 20% for maize).

- Aggressive adoption of waste management (20% waste minimisation, 15% composting, 35% of landfill gas (LFG) capture and use and 20% of LFG flaring).
- Less aggressive adoption of waste management (5% waste minimisation, 10% composting, 25% of LFG capture and use and 10% of LFG flaring).

Existing CTL with methane destruction

This option involves destroying the methane emissions from the existing coal-to-liquid (CTL) plants at Secunda using thermal oxidisers. 3.738 Mt CO_2-eq are destroyed per year from 2011 onwards, which reduces total emissions by 0.35% in 2030 and by 0.22% in 2050. In total over the period 146 Mt CO_2-eq of emissions are avoided at a levelised cost of R8 per ton CO_2-eq.

Carbon capture and storage in CTL

The LTMS Scenario Building Team decided to limit carbon capture and storage options for coal-to-liquid facilities to 2 Mt per year in one scenario, reflecting current global capacity, but also asked for modelling if storage increased by an order of magnitude. Due to the nature and scale of the carbon dioxide emissions from the Rectisol units of the Secunda plant, two options have been considered: first, a 2 Mt option, and second, a 23 Mt option, which would store all of the concentrated carbon dioxide stream from Secunda. Significant economies of scale are realised in the second option. Capture costs are assumed to be negligible, because of the high concentration of CO_2.

The 2 Mt option saves 78 Mt of carbon dioxide emissions over the period at a high cost of R476 / ton of CO_2. The 23 Mt option is more cost-effective, at R105 per ton of CO_2, and saves a total of 851 tons of CO_2 emissions over the period.

Coal mine methane

Only one option for destroying methane emissions from coal mining was considered, assuming underground mining, using thermal oxidisers and reducing methane emissions from coal mines by 50%. A decline in coal production in some of the mitigation actions in the energy sector modelled above would result in a decline in CH_4 emissions, but costs for such an option were not estimated. Reduction begins in 2020. The costs are relatively high, at R346 per ton CO_2-eq, with a relatively modest saving of 61 tons CO_2-eq over the period.

Aluminium PFC destruction

The impact of perfluorocarbon (PFC) destruction was estimated only for aluminium plant existing in 2003 since it was assumed that, in plant built subsequently, PFC emissions would be negligible. Thus, the impact of this action is slight: 29 Mt CO_2-eq are mitigated during the total period, which reduces total emissions by 0.07% in 2030 and 0.04% in 2050. The costs, however, are negligible, at only R0.16 per ton CO_2-eq.

Mitigation in livestock management

Sector description

In South Africa ruminant livestock production is largely based on rangelands (75%). About 15% of the cattle are in feedlots and about 10% in dairy farming. All sheep and goats are free-range, and essentially all pigs are feedlot-based (but they are not ruminants, so the emissions from enteric fermentation are smaller). The equids (horses and donkeys, also not ruminants) are mostly free-range, but their relative numbers are small. Free-range livestock produce slightly more methane per animal from enteric fermentation (because the forage quality is often lower), but produce no methane from their manure. The number of livestock is mainly restricted by the carrying capacity of the range, which has been stable for several decades and is more likely to decline in future than rise. This sector is mainly relegated to marginal agricultural areas (with the exception of dairy and feedlot operations), characterised by inherent risks such as low and erratic rainfall patterns, as well as natural disasters, such as fire, droughts, floods and bush encroachment. Under these conditions the amount and quality of available grazing (fodder) is a major constraint influencing animal production.

Enteric fermentation in cattle and sheep produced an estimated 0.9 Mt CH_4 / year in 1990 in South Africa. This is the largest single source of methane in the South African inventory. The methane is a by-product of digestion, and represents a loss of energy to the animal, which could otherwise be used for mass gain. Therefore, reduction of emissions is in the interests of the livestock farmers as well as a climate benefit. Increasing the efficiency of production (meat, milk, wool and hides) per animal can decrease these emissions and also may improve the net margins in the livestock sector, which are low.

Emissions from wildlife species were included in the GHG emission inventory (Van der Merwe & Scholes 1998). However these emissions are excluded from this model because no mitigation option is being considered for wild herbivores. Because wildlife numbers will never reach the levels that were in the region before intense human settlement, their emissions will not be considered as an additional anthropogenic emission.

Data, assumptions and calculations of baseline and mitigated emissions for enteric fermentation

The model for the livestock sector developed and used for the SA Country Study on Climate Change (Scholes et al. 2000) has been used as a basis for this study.

It was updated using latest data from agricultural statistics and extending the calculation for 50 years. Most of the data on livestock population was extracted from Abstract of Agricultural Statistics, 2006 and from the UN Food and Agriculture Organisation (FAO 2006).

The enteric methane emissions of livestock are dependent on the type, age and weight of animal, the quality and quantity of food and the energy expenditure of the animal. The mitigation option investigated for this study focuses on a smaller herd, made more productive through a move from rangelands to feedlots with improved feed.

A reduction of enteric emissions of methane could be achieved if the herd composition were optimised for maximum production and the feed quality were improved. Moving some livestock to feedlots and improving the quality of their feed reduces their enteric fermentation emissions, but increases the emissions from manure handling (see next section). Therefore these two processes are modelled together.

In the mitigation scenario for enteric fermentation, the total number of cattle is being reduced, starting in 2006 from 13.8 million to 9.7 million by 5% a year so that by 2011 it will have been reduced by 30%. It is assumed that the herd productivity remains the same despite this reduction, because the herd sex, age and breed composition are optimised for maximum production. The culling of surplus bulls, oxen and over-mature cows would reduce the total national herd, which would also marginally increase the quality of forage available to the remaining animals. It would also have benefits to the rangeland in terms of less soil erosion and better biodiversity protection.

It was further assumed that from 2006 the 5% of free-range herd is moved to feedlot each year till 45% of the cattle is in feedlots. This is a trend that is widespread around the world as a result of the economics of livestock raising, and changing consumer preferences. According to the Department of Agriculture (DoA) (Classen 2007), with the promotion of emerging farmers this change will be harder to achieve. However, this assumption was accepted in this version to allow keeping the beef production at the same level, although the total number of cattle will eventually be reduced by 30%. Further mitigation is achieved by supplementing the feed intake of range-fed and feedlot animals with high-digestibility, high-protein forage containing the appropriate oil content. The improved diet will reduce the methane production per animal, while simultaneously increasing per-animal production. The latter effect partly offsets the increased cost of meat production incurred by the purchase and transport of feed.

Since animal protein consumption invariably rises as populations become better-off and more urbanised, but the growth of the range-fed beef and small-stock populations is limited, it was assumed that the shortfall will largely be made up by a rise in the number of pigs and chickens. This assumption is in line with international trends. The increase is estimated from the GDP growth, and the numbers will stabilise after 2010.

The cost of production was based on three groups of expenditure: cost of food, veterinary services and fixed costs. The new updated productivity rates were provided by the DoA (Classen 2007).

The updated income rates (to keep the baseline consistent these are assumed to be applicable after 2005) were provided by the DoA (Classen 2007) for some of the categories and for others an increase, using the CPIX index, was assumed.

The further details on data sources, assumptions used and the methodology for calculation of emissions are provided in the LTMS Technical Appendix (ERC 2007a) and the input report for waste, forestry and agriculture sectors (Taviv et al. 2007).

Modelling results for enteric fermentation

The final results of emissions show reductions of 6.5 Mt CO_2-eq per year for enteric fermentation, reducing baseline emissions of 18.1 Mt to

11.6 Mt CO_2-eq with the mitigation action. The period for determining Net Present Value (NPV) and annualised cost is 48 years (from 2003 to 2050). The historical data from 2003 to 2005 are included to ensure consistency with other models. This NPV is calculated separately for income and cost. The mitigation costs are calculated to be R47 / tCO_2-eq, being the cost-efficiency calculated as annualised mitigation less baseline cost divided by mitigated amount of CO_2eq. As for wedges in other sectors, the detailed tables and figures are contained in the CD-Rom accompanying this book.

These results are very sensitive to the assumptions about the cost of providing high-quality food, productivity and the percentage of cattle moved to feedlot. For example, if the productivity of free-range cattle is reduced from 55 to 40 kg / head / annum, the improvement in productivity as a consequence of moving cattle to feedlot will be larger. This will result in a slight negative cost associated with mitigation.

Furthermore, local research is needed to show how improvement of productivity in the dairy sector can potentially reduce CH_4 emissions. The latest research in India and Bangladesh shows that the change of feed in dairy cattle could have negative costs and concurrent mitigation (Sirohi, Michaelowa & Sirohi 2007). Results from this research could be used to obtain support for rural marginal communities through a CDM mechanism. A similar approach could also be suitable for South African marginal rural communities.

It is suggested that a future model should be based on the cost of mitigation action and not on the differences between cost and value (income) of production. This will reduce the number of parameters to be modelled and provide more accurate and more consistent results.

Manure management

Sector description

Since livestock production in South Africa is mainly range-based, emission from manure is not as significant as in countries where feedlots dominate (e.g. in the US, manure management accounts for 25% of US agricultural methane emissions). The term 'manure' is used here to include both dung and urine produced by livestock.

Animal manures, when they decompose in continuously anaerobic (waterlogged) conditions, generate both methane and nitrous oxide. The emission from this source in South Africa is currently relatively small, since most animals produce their wastes under semi-arid free-range conditions, where the dung is scattered and rapidly consumed by insects, or desiccated. However, there is a trend in South Africa towards increasing the use of feedlots (the reasons underlying this trend are discussed in the section on enteric fermentation, page 102).

In feedlots, the excreta can be handled in a number of ways, with differing impacts on greenhouse gas emissions:

- In some cases it is simply allowed to accumulate in situ, in which case the lower layers become anaerobic, and methane, nitrous oxide and ammonia are generated. The excess nitrogen leaches into the groundwater or rivers, where it causes a major pollution problem. The ammonia has an offensive odour and contributes to acid deposition and nitrogen saturation of ecosystems.
- In populated areas, or regions where the water supply is sensitive to nitrogenous leachates, there is usually a legal requirement that the wastes be sluiced into bottom-sealed lagoons. The wastes decompose anaerobically in the lagoons, releasing methane, but no ammonia.
- In a completely closed anaerobic digestion system, called a biogas digester, the methane can be trapped and used as a fossil fuel substitute, to power machinery or provide heat. The ammonium and nitrate end up in the effluent water, which is then typically used for irrigation, delivering a fertilisation benefit if properly managed.
- A fourth disposal option is to scrape the wastes periodically (typically daily) and compost them aerobically (which generates insignificant amounts of methane or nitrous oxide, if properly conducted). The ‘kraal manure’ produced is applied to gardens and fields as an organic fertiliser. This is a saleable product, with the additional benefit of raising soil carbon storage.
- The last, new and largely untested option, is to partly dry the wastes, and then use them as feedstock for a ‘biomass converter’ (essentially a controlled incineration), which has activated carbon and energy as its outputs.

Data, assumptions and calculations of baseline and mitigated emissions for manure management

The decomposition of manure under anaerobic conditions produces methane. These conditions occur most readily when large numbers of animals are managed in a confined area (e.g. dairy farms, beef feedlots, and swine and poultry farms), and where manure is disposed of in liquid-based systems (lagoons).

The main factors affecting methane emissions are the amount of manure produced and the portion of the manure that decomposes anaerobically. The former depends on the rate of waste production per animal and the number of animals, and the latter on how the manure is managed.

The data on livestock required to estimate the amount of methane produced during the storage and treatment of manure are the same data required for the calculation of enteric fermentation. The emissions associated with the burning of dung for fuel are excluded, since this is a very rare practice in South Africa, with significant negative health impacts.

The methodology for emission calculations and emission factors is as recommended by IPCC guidelines (IPCC 1996).

For the baseline, it is assumed that half of manure from dairy and swine farming is disposed of and composted aerobically as scrape and the other half in lagoons. For feedlots and poultry it is assumed that 80% of manure is disposed of as scrape and 20% is disposed of in lagoons.

To model mitigation, it was assumed that 10% of the dairy and feedlot wastes is anaerobically digested or consumed in a biomass converter. Some 10% is treated in open lagoons, and the remaining 80% is scraped and spread in dry form. The 50% of manure from management from swine and poultry farms is spread in dry form, 10% disposed of in lagoons and the rest processed in digesters.

While previous study (Scholes et al. 2000) suggests that about 40% of manure is processed in digesters or converters, more recent research shows that it is not such a favourable solution (GRACE 2004). The digesters can be installed only for large numbers of animals (a few hundreds), they are unreliable and inefficient and most importantly they do not solve the GHG problem. They emit ammonia in excess of air pollution standards, which adds nitrous oxide to the atmosphere and this is much worse than adding methane. Finally, they are extremely expensive and have a short lifespan (about ten years). The only limitation of dry spread is availability of farm land where the manure can be disposed of. If a large feedlot is located in a peri-urban area, an additional cost of transport will be required. Also, the environmental impacts of potential pollution from nitrogen and potassium from manure should be considered. According to GRACE 2004, the best solution is not to keep more animals than the land can accommodate.

Modelling results for livestock manure

The costs of dry spreading are assumed to be R1.20 / ton manure, lagoons R10 / ton and digesters and converters R30 / ton. These values are approximate and based on information from human sewage disposal facilities. This wedge avoids about 1 Mt per year, or 47 Mt CO_2-eq over the period, at a net saving of R19 per ton.

The results of the option of processing 40% of manure in digesters show that, although the level of mitigation is almost the same, this is very expensive and instead of the benefit achievable in the dry-spreading option, the mitigation cost is quite high. However, processing manure in digesters might have to be used to minimise the pollution of land and water from the dry spread of manure.

These results are sensitive to the assumptions about the cost of disposal. Therefore further investigation of the costs would be beneficial. The assumption made about the use of a different disposal system could also be refined.

To improve the accuracy of the model, poultry farming needs to be split into three groups: broiler, layer and breeder, and different lifecycle and manure management methods should be applied to each.

Reduced tillage agriculture

Sector description

The conversion of land from natural grassland, savanna or forest to cropland, through the process of tillage, causes carbon to be lost from the soil. The main reasons are:

- the amount of belowground carbon produced by crop plants is typically less than from the original grasslands, and
- the physical disturbance caused by the plough accelerates the decomposition of the soil carbon already present.

Even on existing agricultural land, reduced tillage can assist with mitigation. A range of farming techniques called *no-till, reduced-till, returned residue* or *conservation tillage* could be used to grow crops with less soil disruption and a greater return of crop residues to the soil, with a zero or small loss of crop yield, and small positive or negative effects on net margin. *No-till*, a practice in which crops are sown by cutting a narrow slot in the soil for the seed, and herbicides are used in place of tillage for weed control, causes the least amount of soil disturbance. *Reduced till* sets out to reduce the intensity of tillage and the number of times that a field is cultivated during a crop cycle, by using special equipment and the selective application of herbicides. *Conservation tillage* uses specialised equipment to return mulch to the soil, and often plants cover crops during the fallow period. These practices have been partially adopted in South Africa, because they have soil conservation and fertility benefits and economic benefits from shorter planting time and savings on diesel used. The reduction in soil erosion is an important issue in South Africa as it incurs a social cost of about 4% of agricultural GDP (Scholes et al. 2000).

There are two main barriers to the widespread adoption of these farming techniques: lack of access to information; and the high capital cost of the specialised equipment needed.

However, there are many co-benefits of these practices and some of them are particularly suitable for emerging farmers. The African Conservation Tillage Network[17] was founded in 1998 with the objective of promoting conservation agriculture. Unfortunately this network has been inactive since 2003. In Zimbabwe, about 75% of farmers practised some form of conservation tillage (Ashburner, Friederrich & Benites 2002). Animal-drawn knife-rollers are popular on small to medium farms in Brazil and have been introduced to Africa in 2002. So, it was proven that the barrier of high capital costs could be overcome with suitable support for emerging farmers.

Internationally, the trend over the past several decades has been towards reduced tillage practices that have shallower depths, less soil mixing, and retention of a larger proportion of crop residues on the surface. The data from 126 studies worldwide (Paustian et al. 2006) estimated that soil carbon stocks in surface soil layers (to 30 cm depth) increased by an average of 10% to 20% over a 20-year time period under no-till practices compared with intensive tillage practices.

Data, assumptions and calculations for tillage

The model for the agricultural sector developed and used for the SA Country Study on Climate Change (Scholes et al. 2000) has been used as a basis for the study of tillage.

The area under cultivation was updated using the latest data from the Abstract of Agricultural statistics, 2006 for the period 1970 to 2000

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[17] http://www.sagis.org.za/Flatpages/Oesskattingdekbrief.htm

and the latest data (up to 2006) from the Crops Estimates Committee.[18] Dryland grain production is the only form of crop agriculture considered. It makes up over 80% of the annually tilled land in South Africa. Irrigated grain production has been ignored in this model, because carbon storage in irrigated lands differs from that of non-irrigated lands. The areas used in the model are provided in Figure 4.10 below.

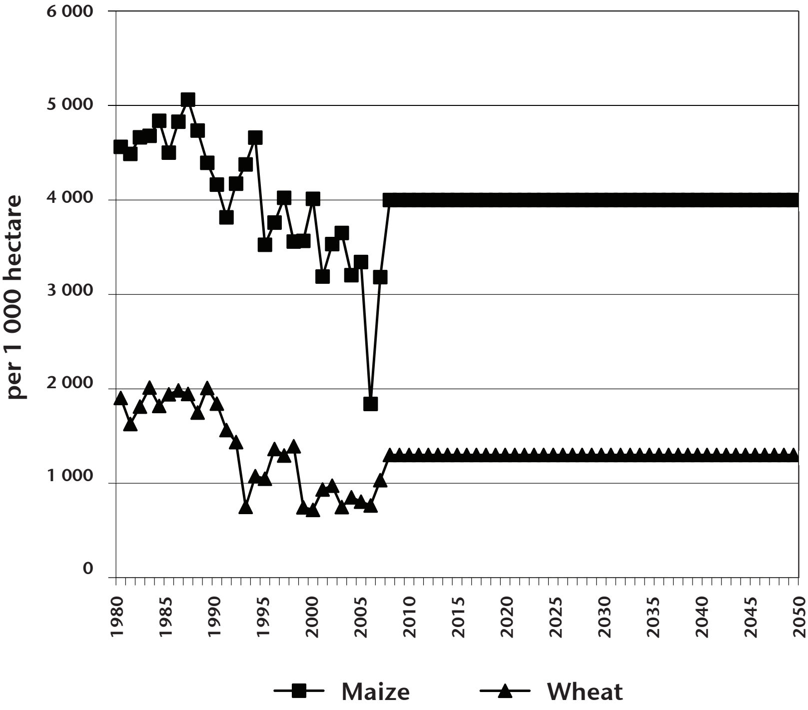

Figure 4.10: Area for production of maize and wheat

In the model, the calculations are based on the assumption that, in cultivated lands, carbon storage is reduced to half of the original (pre-cultivation) storage as a result of tilling, over a period of about 30 years. It also assumes that the recovery of stored carbon resulting from introducing the no-tillage system is not complete, but reaches 80% of the pre-cultivation level, again over about a 30-year period.

Since 1970, no new land has been cleared for agriculture. This is approximately true according to the national statistics, but in reality there

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[18] http://www.sagis.org.za/Flatpages/Oesskattingdekbrief.htm

is a continuous shifting in and out of production of a small fraction of the fields, especially in marginal areas.

For this model, mitigation starts from 2007. Two scenarios are considered:

- In the first scenario it is assumed that reduced tillage can be adopted on 80% of the lands.
- In the second scenario, the adoption of reduced tillage is much lower (about 30%, and differentiated between wheat and maize), according to the recommendation of the DoA Modelling results for reduced tillage adoption.

A first scenario assumes that, if more aggressive adoption is achieved (i.e. 5% growth every year until 80% adoption is achieved for both maize and grain), it will follow that a higher mitigation is achieved. The adoption for maize could not exceed 60%, but adoption for grain in the summer rainfall area could be as high as 90%. Therefore the assumptions used in the model could be made more accurate, but it would not change the model results significantly.

Reduced tillage turns the soil into a sink for a while, but eventually it becomes a source of GHG emissions, as no additional lands applied the no-till system and the effect of reduced tillage wears off. The rising baseline is because the carbon source behaviour of tilled lands gradually ends, as the available labile carbon is exhausted.

For the second scenario, the model has been changed to accommodate different adoption rates for wheat and maize. According to the DoA, reduced tillage for wheat has already been adopted for 16% of the areas, while for maize the adoption is still at 5%. The final adoption, 40% for wheat and 20% for maize, will be achieved in the period of 2007 to 2014. The central results reported in LTMS were avoided emissions of 100 Mt CO_2-eq over the study period, at a saving of R24 per ton.

Providing education through more effective agricultural extension services is required to achieve the adoption of reduced tillage. This service requires one extension officer per 10 000 ha, at a cost of R200 000 per officer per year. The period of implementation is from 2003 until 2014. In both scenarios, the 'annual CO_2-eq **emitted**' is lower for mitigation than for the baseline. For the first scenario it even becomes a sink for a while; therefore mitigation results in a larger decrease in emissions.

Model limitations and further research

New information regarding the assumptions and costs for adoption of the no-till system for maize has been obtained from Grain SA (Botha 2007). It will be incorporated into the next version of the model, but it is expected that the difference will be insignificant. There will be a small decrease in yield of maize in the first two years, but thereafter some increase in yield is expected. However, so far no local data on the yield increase could be found although successful application was reported by other African countries (Ashburner et al. 2002).

According to international literature, CO_2 emissions from machinery use decrease by 40% for reduced tillage and 70% for no-till, relative to conventional tillage (Paustian et al. 2006), contributing to further reductions in GHGs from reducing tillage intensity. This has not been included in this model, but should be considered in the energy models.

Furthermore, the increasing cost of diesel could play a role of a driver in the potential adoption of reduced tillage practices. Therefore it would be useful to estimate the potential savings in the long term.

The implementation of a national biofuel strategy will also affect the cultivated areas. It is assumed that marginal land would be used for growing these crops. A full lifecycle assessment of biofuel production is also needed to determine the true impact on climate mitigation.

The issue of the impact of erosion and the potential benefit of combating erosion in South Africa was raised at the non-energy workshop on 28 June 2007. Erosion is a serious environmental threat[19] but its relationship to carbon storage is very complex and not yet resolved nationally or internationally. Carbon is lost from the site where and when erosion occurs, but it usually accumulates at a lower point, for example in rivers and coastal sediments where it is protected by the anaerobic environment. Therefore it is unclear if there is a net loss or net gain (Scholes 2007).

Mitigation in the waste sector

According to the previous GHG inventory (Van der Merwe & Scholes 1998), the amount of waste generated in 1990 was 6933 Mt / annum, based on a generation rate of 0.87 kg / capita / day. It is estimated that

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[19] www.earthpolicy.org/Books/Seg/PB2ch08_ss3.htm

the disposal of solid waste contributed more than 2% to the total GHG emissions through emissions of methane from urban landfills.

Methane from landfills is produced in combination with other landfill gases (LFGs) through the natural process of bacterial decomposition of organic waste under anaerobic conditions. The LFG is generated over a period of several decades. It can start six to nine months after the waste is placed in a landfill. Methane makes up 40% to 50% of LFGs. The remaining component is carbon dioxide mixed with trace amounts of volatile fatty acids (VFA), hydrogen sulphide (H_2S), mercaptans (R-SH) and ammonia/amines ($R\text{-}NH_2$). The mercaptan and amine compounds have particularly strong and offensive odours even at low concentrations.

The production of LFGs depends on several characteristics, such as waste composition, landfill design and operating practices, as well as local climate conditions. Two factors that will accelerate the rate of methane generation within a landfill are an increased share of organic waste and increased levels of moisture.

The type of waste disposal site also significantly influences LFG generation. There are generally three types of waste disposal site: open dumps, controlled or managed dumps and landfills. Open dumps are usually shallow and characterised by open fills with loosely compacted waste layers. Managed dumps are similar to open dumps, but are better organised and may have some level of controls in place. LFG generation is negligible at open dumps, because of aerobic conditions as well as other factors such as shallow layers and unconsolidated disposal (i.e. waste disposed in different parts of the same landfill site on different days). Landfills are engineered sites designed and operated to employ waste management practices, such as mechanical waste compacting and the use of liners, daily cover, and a final capping. Minimum Requirements (DWAF 2001b) for the design and operation of landfills are mandated by government in terms of cover material, landfill design, and others. As the landfill uses a porous soil cover (bio cover) in its operations, a portion of the methane is oxidised as it passes through these soil layers and is converted to carbon dioxide.

In South Africa, gas management systems on dumps and landfills are not obligatory, but gas monitoring systems are required to track the potential threat of landfill gas migration. Only when such a threat has been determined or landfill gas been found to represent a potential safety hazard or odour problem, or if an operating or closed site is situated within

250 m of residential or other structures, is it required to implement a gas management system (PDG 2004: 8).

To achieve a sustainable waste management regime the approach to waste management should be minimisation, recovery, recycling and treatment, with landfilling being the last option. This waste hierarchy was put forward by government in the White Paper on Integrated Pollution and Waste Management (IP&WM) (DEAT 1999).

Energy recovery from LFG is not an optimal solution. There is a need to put mechanisms in place to divert organic waste from landfills (e.g. into composting) as a long term solution, with energy recovery from landfills a short-term solution, to deal with the current LFG generation.

Methodology for modelling mitigation in the solid waste sector

For this model only municipal solid waste (including commercial and domestic waste) is included. There is no need to consider other sources of waste (such as mining waste or hazardous waste) because their amounts of organic content are not significant.

Mayet's work on domestic waste generation was used to model solid waste production. He notes that the higher the income, the greater the per capita generation of waste. The economic model was used to tabulate disposable income per region. Dividing this total disposable income per region by the population figures gave a figure for disposable income per capita per annum. Mayet's model proposes three socio-economic levels, each with its own waste generation rate. Mayet's average generation rate based on income is given in Table 4.3 (Mayet 1993).

Table 4.3: Income level vs. domestic waste generation rate

Income level	*Average generation rate*	
	(m^3/capita/annum)	*(t/capita/annum)*
High[1]	2.7	0.43
Medium[2]	0.75	0.17
Low[3]	0.24	0.08

Notes: Disposable income per annum:

[1] R10 000+

[2] R5 000 to R10 000

[3] R0 to R5 000

Source: (Mayet 1993)

These rates were adjusted to the 2003 level by multiplying by the GDP increase since 1993 (corrected by inflation). This approach is similar to the modelling approach applied in the CSIR study (Phiri 2007b), which developed a model to support the planning of Johannesburg Waste Services.

The Mayet model was applied in the DWAF (2001b) report to calculate waste generation. The calculations in the report were based on assigning all major district councils one of the three socio-economic levels (low, medium or high) and multiplying population in this council by the above generation rates. Then the national value was calculated as 8.21 Mt / annum. It differed from information obtained from an intensive survey of waste received at landfills by 25% (see Table 1 in the LTMS Technical Appendix, ERC 2007a). The estimation of waste received at landfills is inaccurate. Many landfills do not have weighbridges and they base their estimations on guesses or on density estimations, which may be an order of magnitude out.

The emission rates assumed in the South African GHG inventory (Van der Merwe & Scholes 1998: Appendix 7-2) are used to determine the amount of methane generated.

The projections for population data, percentage of urbanisation produced for the MARKAL model and the same distribution into three socio-economic groups as used in the DWAF (2001b) report have been used to calculate waste generated until 2050. The distribution between socio-economic groups determined in the DWAF (2001b) (US EPA 2005) report has changed. To allow for increased waste production as a result of the increased wealth of the population, the annual growth in GDP as estimated for the MARKAL model has been applied to the calculation of the waste generation rates.

The amount of waste generated was multiplied by the percentage of urbanisation to determine the amount of waste in urban areas. It is assumed that waste generated in rural areas does not reach major landfills and therefore its contribution to generation of LFG is negligible.

It is expected that the waste services in urban areas outside of major cities will improve with time and thus a larger portion of the population will contribute to solid waste disposal. However, this trend will be balanced by a general reduction in the organic portion of the waste disposed of at landfills.

The South African GHG inventory (Van der Merwe & Scholes 1998: Appendix 7-2) assumed that 0.004 Mt of CH_4 / year was recovered for three projects, where methane was either used or flared. This reduction is only 1.1% of the methane generated. It is assumed that by 2003 this had increased to 10%. The final amount of methane emitted from urban landfills in 2001 was 13.5 Mt of CO_2-eq.

Mitigation options

In general, solid waste management is given a low priority in developing countries (Godfrey & Dambuza 2006), with the result that limited government funds are allocated to the solid waste management sector. The South African government, civil society and business communities committed to develop a plan for achieving a zero-waste economy by 2022 in an agreement known as the Polokwane Declaration (DEAT 2001). The requirements of the Polokwane Declaration were recently analysed (Ball 2006). The first goal of reduction of waste going to landfill by 50% by 2012 is unobtainable. It is further concluded that:

> the gap between landfill and zero waste to landfill can be bridged. However, this requires a strategy comprising a paradigm shift, time to allow this to materialise as well as well thought out and executed interim measures (Ball 2006).

There are four mitigation options that were considered: waste minimisation, composting and methane capture from municipal waste with and without use for energy. The parameters of these wedges, as discussed with the LTMS Scenario Building Team, are summarised in Table 4.4.

The following assumptions were made:

- The municipal waste minimisation mainly focuses on glass, plastics, tyres and metals and therefore its impact on LFG generated is excluded from the model. Furthermore, the production of LFG continues for many years after landfill site closure. This also justifies the exclusion of the impact of waste minimisation from model calculations.
- Composting will reduce the amount of organic waste available for LFG production and therefore will reduce the amount flared and used for energy generation.

The City of Johannesburg (CoJ 2003) set itself a target of diverting 25% of its green and garden waste. Since not all the cities in South Africa will undertake the same target, a more realistic national target of 15% is assumed.

Table 4.4: Mitigation options in waste sector

Sources	*Actions*	*Drivers*	*Start year*	*% of emissions reduction baseline/ required by science*	*Year for maximum penetration (baseline/ required by science)*	*Barriers*
Municipal Waste	Waste minimisation	Polokwane Declaration, (DEAT, 2001)	2007	5/20	2012/2010	Cultural preferences; cost
Municipal Waste	Composting	Lack of land for landfills, cost of fertilisers	2007	10/15	2020/2010	Only suitable for separately delivered garden waste
CH4 capture from municipal waste (use for energy sector)	LFG capture and use	CDM	2007	25/35	2020/2010	cost
CH4 capture from municipal waste	LFG flaring	Legislation	2007	10/20	2020/2010	cost

The large landfill sites that will use LFG for energy production can use only about 70% of methane generated. It is assumed that about half of the waste generated is in large landfills, so 35% of the emissions could be used for energy production.

The smaller landfills not suitable for electricity generation can flare the LFG, so the percentage reduction listed in Table 4.4 represents the landfills where energy generation is not feasible.

Projections for LFG use for energy in MARKAL are the same as assumed for this model.

Mitigation costs

The eThekwini municipality has developed an LFG utilisation project, which pioneered the CDM pathway for Africa by becoming the first Landfill Gas to Electricity project on the continent. The agreement for sale of 3.8 million tons of carbon credits to the value of approximately R100 million has been signed. The project will also have a revenue of some R91.4 million from sale of electricity (Strachan 2006). The capital expenditure for this project is R64 million and operating cost is R86 million / annum.

The City of Cape Town is considering the use of LFG (Haider 2007) and estimated that capping a 30 ha landfill will cost about R55.4 million. The further cost of implementation is R44.5 million. If instead of utilisation the LFG is flared, the cost will be lower (e.g. R12.4 million for active LFG extraction and flaring), but there is no income from energy sales.

The unpublished information (Jewaskiewitz 2007) provided a much lower estimate of about R14 million of capital costs and about R1 million of operation and maintenance costs for flaring 42 Mm^3 / annum of LFG from four largest sites in the Durban area. This can be translated to about R7 / t to R14 / t of mitigated CO_2-eq. The larger the site, the cheaper the cost per unit, but it is significantly lower than figures used by the EPA (see below). So the highest of the values provided was used as the first estimation for the model.

The cost of energy generation is covered by the MARKAL model and is not repeated here.

The latest study on composting by the CSIR (Phiri 2007a) provided a cost of R60 / t. It is based on the costs of the Roodepoort site in Johannesburg. This is cheaper than the cost of landfilling. When the revenue from the compost sale is added, this option offers a valuable opportunity for wealth creation for the local communities.

The City of Cape Town is negotiating a contract for composting where R90 / t will be paid to remove and then compost chipped garden waste. However, this value has not yet been published. A simplified assumption was made that the cost of composting is the same as the cost of disposal and therefore no additional cost for composting should be added when mitigation is compared to the baseline option. Since a feasible waste reduction by composting has been assumed (10 to 15%) and some of the cost of composting could be covered by the sale of the products, this assumption is realistic.

According to the global Marginal Cost Analysis by EPA, a reduction of about 40% in landfill emissions in South Africa could be achieved almost at zero cost (see US EPA 2005: Figure E-2). But the breakeven cost of composting is above \$200 / tCO_2-eq mitigated and for flaring it is about \$25 / tCO_2-eq mitigated.

Modelling results for solid waste

Only the mitigation cost of flaring is included for financial calculations (see assumptions on the costs in the section above). It is R14 / tCO_2-eq based on 10% discount rate, for flaring only. An additional set of calculations was provided for a number of Durban waste sites (Jewaskiewitz 2007). These calculations provided a range of costs from R4.06 to R9.26 / tCO_2-eq. However, for this project, it is suggested that the more conservative value of R14 / tCO_2-eq be retained. At this cost, 432 Mt CO_2-eq could be reduced by the mitigation wedge, relative to the baseline.

Model limitations and further research

A number of assumptions were made in order to simplify the mitigation model.

- The same distribution into socio-economic groups as used in the DWAF (2001b) was assumed for the whole study period of up to 2050. This distribution needs to be enhanced by a population statistics investigation and by the identification of a better definition for socio-economic groups.
- The calculations for the annual mitigated amount are based on the amount of waste generated during that year.
- The waste minimisation impact was not modelled.
- It was assumed that only half of the waste is disposed of at the large landfill sites suitable for energy generation.
- The cost of composting is equal to cost of disposal.
- The assumption for the rate of conversion of waste disposed, into methane emission, is reasonable, and a better figure cannot be obtained without modelling the decay of organic matter at each major site.

However, the waste generation figures look low and further investigation is required to obtain better data.

For this project the above assumptions are acceptable, as the accuracy of the model results has very little impact on the project results. For example, the energy generated from the LFG is about 0.17% of the national energy supply. So, if the modelled value is 100% higher as a result of the corrected assumption, it will have no noticeable impact. The emission from waste water is a fraction of the solid waste emissions and therefore its mitigation potential will have very little impact on the national totals. When the new GHG inventory is completed this assumption should be re-examined.

There is a need for further research in some areas. For example, only domestic waste disposed at municipal sites was modelled. However, industries such as the paper and pulp industry and the food industry also generate large amounts of organic waste. It is typically high in moisture content, thereby increasing the potential for leachate generation. Landfills not designed to capture and treat leachate on site cannot receive paper and pulp waste. In particular, the disposal of organic waste from the wine industry in the Western Cape is a problem waste stream. Future modelling of the waste sector should also include putrescible organics from industry.

Mitigation through fire control and savanna thickening

Situation in South Africa

Approaches to fire management in the fire-prone ecosystems of South Africa have changed several times. These changes in management objectives mirror changes in ecological thinking, from stable-state to variability in space and time. A study in the Kruger National Park (Van Wilgen et al. 2004) attempted to determine whether changes in management were able to induce the desired variability in fire regimes over a large area. It was found that:

> the area which burned in any given year was independent of the management approach, and was strongly related to rainfall (and therefore grass fuels) in the preceding two years. On the other hand, management did affect the spatial heterogeneity of fires, as well as their seasonal distribution.

This preliminary finding is being further researched in ongoing CSIR studies.

A recent comprehensive study on veldfire management (Forsyth et al. 2006) assessed the national capacity for fire management as well as costs, risks and economic consequences of wildfires, and a framework for integrated veldfire management was prepared. It is estimated that the annual cost of wildfire is about R743 million / annum, while the baseline cost of Fire Protection Associations is about R104 million / annum. So, even without considering GHG potential mitigation as a result of fire reduction, the investment in fire control is less than the estimated damage costs of wildfires. There are many other costs that were discussed. For example, the highest impact of fires is on forest plantations and therefore the forest industry spends about R150 million / annum on fire control operations. Consequently, the fire return frequency at forest plantations is about 200 years compared to five to ten years for savannas.

The improved fire control will lead to enhancement of savanna thickening, more commonly known as 'bush encroachment' in southern Africa. Bush encroachment is a widespread phenomenon occurring in savanna and grassland regions of the world. Its causes are still poorly understood. The three leading suspects are changes in the fire regime, changes in the grazing regime, and changes in the atmospheric carbon dioxide concentration. A Dynamic Global Vegetation Model (Bond, Woodward & Midgley 2003), was applied to try to tease out these effects. It was shown that:

> high fire intensities cause 'topkill' of the saplings so that they have to start sprouting from the root crown after a fire. If intervals between intense burns are long enough, allowing trees to grow to heights of 3–4 m, saplings escape the trap and become mature trees. (Bond et al. 2003)

The model also tested the impact of increased carbon dioxide on tree cover.

> The simulations suggest that elevated CO_2 could be having a widespread and pervasive effect on savanna vegetation by tipping the balance in favour of trees. (Bond et al. 2003)

It should be noted that this process was started a few decades ago and it is predicted that the area of savanna will increase in South Africa as a result of climate change, at the expense of grasslands.

A model to predict the outcome of these two linked processes (fire suppression and savanna thickening) has been developed and used (Scholes et al. 2000). It was updated by extending the calculation until 2050 and enhancing the economic model.

Methodology for modelling mitigation from land-use changes (fire control)

Fires in the grasslands, savannas, fynbos and plantation forestry in South Africa are modelled. Some frequency of fires is necessary in these vegetation types (other than plantations) in order to maintain their ecological health. Furthermore, the fires are to a degree inevitable, given the seasonally dry climate in South Africa. Nonetheless, the return frequency of fires can be reduced significantly below their current frequency without causing ecological damage, while at the same time realising savings in loss of life, livestock, grazing and infrastructure, in addition to a net decrease in greenhouse gas emissions.

The costs of complete fire prevention are unaffordable, and it is an unrealistic and unnecessary goal. However, fire frequency reduction is an attainable target. For this model, mitigation by 50% reduction in the fire frequency is projected.

Although a large quantity of carbon dioxide is generated as a result of fires, it is not generally a net emission, since typically it is re-absorbed in plants in the next growing season. Thus only methane and nitrous oxide emissions were calculated. The emissions for each land cover are calculated taking into account the fire return frequency, fuel load, combustion completeness and emission factors (for methane and nitrous oxide).

The social cost of fires is modelled as the sum of the cost of protection and the cost of losses incurred (damages). The cost of achieving fire reduction was calculated by summarising different components of cost (detection, equipment, salaries for people and personnel kits). The damage is calculated as the sum of loss of value of the vegetation (as fodder, wood or flowers), loss of livestock and loss of infrastructure. All these components are assumed to vary in value between vegetation types, and have different probabilities of loss associated with them. For instance, it is certain that grass forage will be lost if a fire should occur, but only about 1% of livestock is lost. Buildings in savanna regions are seldom burned, whereas buildings in fynbos regions are frequently burned, due to the much higher intensity of fires in the latter.

It is assumed that there is already a certain level of fire protection investment in the country, but the financial calculations model only the required increase in fire protection.

Methodology for modelling mitigation from land-use changes (savanna thickening)

It has been widely observed that the woody biomass in savannas ('bushveld') has increased over the historical period. This phenomenon has been noted in Africa, Australia and America. A key causal factor, as demonstrated by fire exclusion experiments, is a reduction in fire frequency and intensity. Frequent, intense fires formerly restricted the recruitment of woody plants. With the introduction of domestic livestock in large numbers, an increasing fraction of the grass production is grazed rather than burned, allowing the trees to become established. Once the trees mature, they further suppress grass growth, leading to the downward spiral known as 'bush encroachment'.

This process has negative economic consequences for grazers, but positive consequences for carbon sequestration, since densely wooded savannas store more carbon, both as trees and in the soil, than open savanna. The negative impact on grazers was included in the financial calculations below.

Increase in woody biomass is considered for two land cover types—fertile and infertile savanna. It is assumed that the growth from the original woody biomass to a climatically determined maximum is a function of fire return frequency and of rainfall.

The increase in carbon dioxide sequestration is proportional to increase in woody biomass (which is indexed by woody plant basal area). It is assumed that only 40% of savanna area would exhibit thickening (since much of the savanna has already thickened).

Modelling results for land-use changes

The emission comparison for the baseline and mitigation scenarios is 9.5 tCO_2-eq per year, as a saving of R21 per ton. For most of the study period, carbon is sequestered and only at the end are slight emissions projected.

In the original model, the economic calculations were made separately for fire reduction and savanna thickening. However, the main reason for savanna thickening is fire reduction, so costs of reducing fire provide a benefit of increased carbon sequestration by additional biomass created in savanna thickening. Therefore the costs and change in emissions and sinks are combined to derive total costs and mitigation values with final cost-efficiency results. In order to be consistent with other models, the previous data on costs and benefits were adjusted to the 2003 base year using the CPIX factor.

Furthermore, the original model considered the cost of the loss of grazing and found that about 10% of free-range cattle might be affected, although this is subject to rainfall conditions. In this version of the model this cost is ignored. It is assumed that savanna thickening will be an additional driver to move the free-range cattle to feedlots and these costs are already included in the model on enteric fermentation.

The results show significant sequestration achieved with the total reduction in costs compared to baseline option. Therefore this option results in the negative cost (benefit) of about R196 million.

It must be noted that this mitigation potential has a natural constraint, as bush encroachment will eventually reach its maximum capacity and thereafter no additional mitigation will take place.

Model limitations and further research

The existing model defines the area for different types of vegetation statically and cannot accommodate the changes with time. It is particularly important for plantations that change with time. However, plantations make a relatively small contribution to fire emissions and therefore this error would not be significant. The SANBI (South African National Botanical Institute) produced maps that show the areas under each type of vegetation. These areas differ slightly from those used by the model (Midgley 2007). In particular, the area for the sour grassland differs significantly. It is suggested that, to arrive at an agreed set of figures, both sets of data should be investigated.

Another limitation of the model is that it does not take into account the fact that the savanna biomass in the area where rainfall is less than 650 mm / annum is significantly lower than in the area with higher rainfall. If this is taken into consideration, the accuracy of the model would be improved.

The existing model does not include the benefits of the increased wood availability and other non-timber forest products that could be harvested. Presently, about 2% of total fuel consumption is due to residential demand by poorer households. Urban, poor, unelectrified households derive about one-fifth of their energy services from wood, whereas rural ones up to four-fifths. Uncertainties in biomass energy data are large (Winkler 2006b). Overall, biomass use for household energy is a small, little-known share of total energy demand.

In a recent review of strategy options for fuelwood, Shackleton et al. (2004: 4) noted that:

> The national demand for fuelwood was estimated at 13 million m^3 / annum in the mid-1980s and has never been updated since then. Estimates of household consumption rates range from 0.6 t/annum to more than 7.5 t/annum, typically between 3 and 4 t/annum.
>
> Fuelwood use is widespread, with over 95% of rural households using it to some degree.
>
> Demand is unlikely to grow from current levels in the light of the HIV/AIDS pandemic which has stagnated population growth for the next 10 to 20 years and due to increasing urbanisation.

> The gross annual value of demand to the national economy is estimated to be R3–4 billion. (Shackleton et al. 2004)

The fuelwood supply and demand was evaluated by Scholes & Biggs (2005) as one of the ecosystem services that could support achievements of the Millennium Development Goals.

However, more research is needed to model the long term feedback between mitigation policies and the sustainable use of wood as a fuel.

Mitigation in the forestry sector

Situation in South Africa

Indigenous forests occupy only 0.3% of the South African land surface. The other major indigenous wooded biome, savanna, occupies 26% of South Africa, and has a sparse to dense cover of low-stature trees and bush. They are important suppliers of a variety of goods and services, such as firewood, medicinal plants and wildlife habitat. Tree plantations of exotic species supply the bulk of South African sawlog and pulp needs, and support a major export industry. They occupy 1.5% (1 790 269 ha) of South Africa (Fairbanks & Scholes 1999), of which roughly half is softwood, and half hardwood. Only 1 425 714 ha were under commercial plantations in 2005.[20]

Forestry plays a major role in the first and second economy in South Africa. It employs close to 170 000 people and indirectly supports about 850 000 people. It contributes more than R12.2 billion annually to the local economy. However, the estimated environmental costs are in order of R1.8 billion (Chamberlain et al. 2005). Although the area covered by plantations has not changed significantly, through constant yield improvements in the processing of the timber the harvest was increased from 10 million cubic metres in the early 1980s to over 22 million cubic metres last year (Hendricks 2006).

The plantation area has expanded by roughly 11 900 ha per year since 1985. This is about 1.45 times higher than the average rate of 8 265 ha / year before 1985. However, this growth slowed down significantly in the last few years and was about 3 700 ha per year between 2000 and 2005.[21]

About 15% of the land surface of South Africa is climatically suitable for afforestation and only about 10% of this area is utilised.

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[20] www.forestry.co.za

[21] Based on data provided on www.Forestry.co.za

There are a number of constraints on the area planted to forests (Scholes et al. 2000):

- Forests increase the water use by the catchment. Under the new Water Act, forest enterprises have been required to pay for reduction in streamflow brought about by their activity.
- There is competition for suitable land from other, more profitable (or socially desired) land uses.
- Loss of biodiversity occurs, especially in montane grasslands, when afforested with exotic monocultures.

Strong justification for new afforestation based on economic growth needs has recently been provided by the Minister of Water Affairs and Forestry (Hendricks 2006). In the Eastern Cape, it was found that carbon storage in intact thicket was higher than in transformed landscapes and that rehabilitation of transformed thicket landscapes could take up more than 80 tons of carbon per hectare (Mills et al. 2005).

Methodology and data for modelling mitigation from afforestation (land use changes)

When plantation trees replace grasslands, the amount of carbon stored per unit ground area increases as the trees mature. It is temporarily and partially reduced again at the time of tree harvest. The time-averaged carbon density is higher than for grasslands and can be further raised through forestry practices (such as leaving the thinnings on site, prolongation of the rotation, and avoidance of loss of the litter layer at harvest). In addition, the efficient use of forest by-products (offcuts, thinnings and sawdust) for bioenergy generation can substitute for fossil fuel use, and the pool of long-lived forest products forms a carbon store itself (Scholes et al. 2000).

The modelling methodology and most of the data were derived from the previous mitigation study (Scholes et al. 2000). However, a new mitigation option is suggested based on the recent DWAF (2004) report. This study projects demand and supply of roundwood until 2030 and shows a shortfall of supply of over 14 Mm^3 / annum. To meet this demand, an additional 775 000 ha have to be afforested. Although this is almost double the 330 000 ha of afforestation in the mitigation option modelled in Scholes et al. (2000), it seems to be in line with the new strategy of the DWAF (Hendricks 2006). This projection seems unrealistic, considering the planned forestry extension of about 100 000 ha over the next ten years.

More afforestation plants eucalyptus, pine species and wattles. For the baseline scenario, the rate of expansion of the total plantation area is assumed to be 11 000 ha / year (based on an average value calculated from the data provided by the forestry industry (www.Forestry.co.za), which is higher than the historical rate of 8 400 ha / year (see section above). Although it was suggested that reforestation be included in the model, according to B Scholes (Scholes 2007) this will not noticeably affect the results.

For the mitigation option it is assumed that the net additional area will amount to an increase of 200% from 2008 to 2030, to allow an additional 760 000 ha (close to the value suggested in DWAF 2004). Since GDP growth will flatten down to about 3% after 2030 (see Figure 2.3, page 43), the same extension rate as prior to 2008 is applied after 2030. This mitigation option is unusual because it provides highest mitigation while supporting GDP growth.

Modelling results for afforestation

The spreadsheet analysis in the forestry sector showed an increased sink of 4 Mt CO_2-eq per year, or 202 Mt over the period. This could be achieved at a net saving of R39 per ton taken up.

The data for income and costs are based on data published for 2003 in the Financial Analysis and Costs of Forestry Operations Report for South Africa and Regions by the Forestry Economics Services (Meyer & Rusk 2003).

The costs include establishment, tending, protection, harvesting, transport, overheads and the opportunity cost of land and water. According to the data interpretation the income is lower than the costs. Since forestry is a commercial sector this is not plausible and therefore the assumptions on opportunity costs, data used and the calculations need to be checked with forestry representatives.

Mitigation actions: Economic instruments

Tax on carbon dioxide

In a carbon-restricted environment, in which countries agree to reduce their carbon emissions, carbon dioxide levels may be reduced by placing a tax on carbon dioxide emissions, thus giving a monetary value to 'clean' energy processes. In this scenario, an escalating tax is introduced on all carbon dioxide emissions from the energy.

The LTMS Scenario Building Team at its fourth meeting decided to analyse a broader set of economic instruments, as a separate basket of mitigation actions. The research teams analysed CO_2 tax (applied to the whole energy sector) and various incentives.

The full effect of the carbon dioxide tax will not be evident if the model cannot choose different options. In running the tax cases, the limits need to be freed up compared to GWC. All the tax cases therefore allow more building of nuclear and renewable sources of energy, as well as switching to more efficiency on the demand side. The model is not told explicitly to reach a certain level of these technologies, as in other wedges, but responds to the price incentive resulting from the tax.

The mitigation impact of different tax levels

Given the limited technologies and energy carriers currently available, there are limits to the impact that a carbon tax would have on the energy system as a whole. After a certain threshold, imposing a higher tax makes no difference to the level of carbon dioxide emissions, since all possibilities for switching to lower-carbon energy options have been taken up at lower levels of the tax. The development of new options, however, would increase the level at which the tax could usefully be applied. Figure 4.11 illustrates the modelled response of the energy system to different tax levels. Whereas a R50 tax has a negligible impact, from R100 the impact becomes significant, and increases rapidly until it slows down in the range between R100 and R200, around R140. From R200 to R300, and from R300 to R400, there are significant increases in emissions savings, although from R400 to R1 000 additional gains are insignificant. This is illustrated in Figure 4.12, in which it can be seen that the average impact of higher tax levels peaks sharply at around R140, and declines steadily after that. These are, of course, model results and the responsiveness of the South African economy to a carbon price signal is worth further investigation. It will only be more fully knowable once some form of carbon tax—or at least a proxy such as an energy surcharge—is implemented.

The marginal benefit of increasing the tax level provides some more detail: a large initial peak in the R100–R200 region is followed by a small number of peaks, culminating in a small R750–R800 peak, after which raising the tax level has minimal impact on emissions.

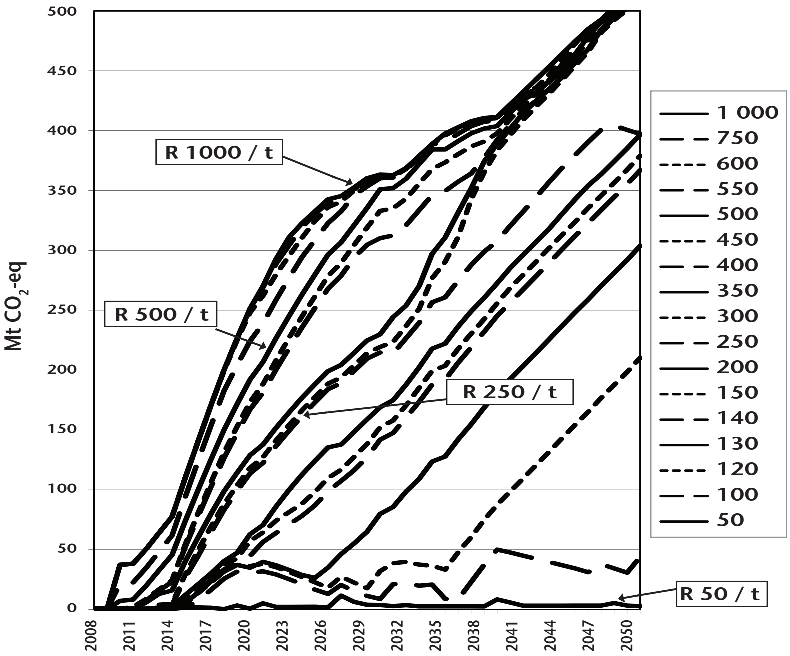

Figure 4.11: Mitigation impact of different tax levels

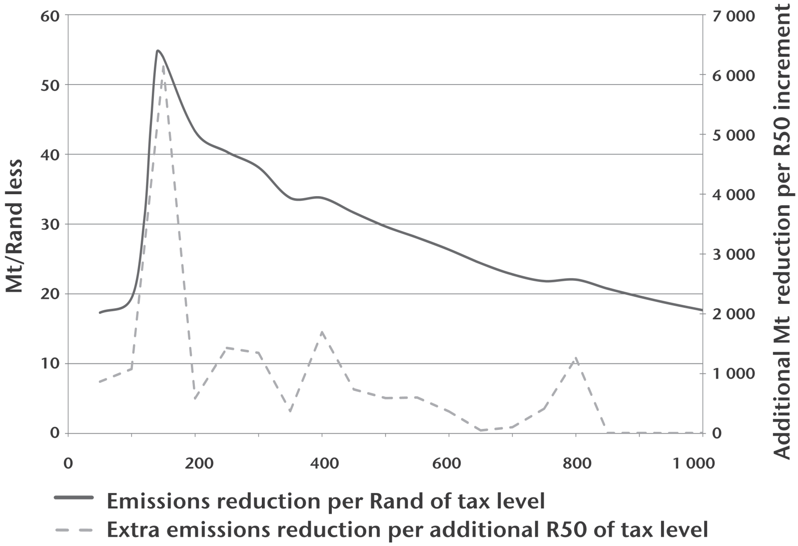

Figure 4.12: Average and marginal impact of various tax levels

Escalating tax

In the tax case which was modelled, an escalating tax rate is applied. The tax level starts at R100 / tCO_2-eq in 2008, and rises to R250 by 2020, in a period when the *rate of growth* of emissions might need to be slowed, even if absolute emissions still rise. It is then kept at that level for a decade, approximating a case where emissions stabilise (since the tax still induces changes in the system). After 2030, it rises more sharply in a phase of absolute emission reductions. It is capped at R750, a level which is maintained for the last decade. The main impact of the tax is to reduce coal use. As a result, the projected electricity grid is dominated by nuclear and renewables, as represented in Figure 4.13.

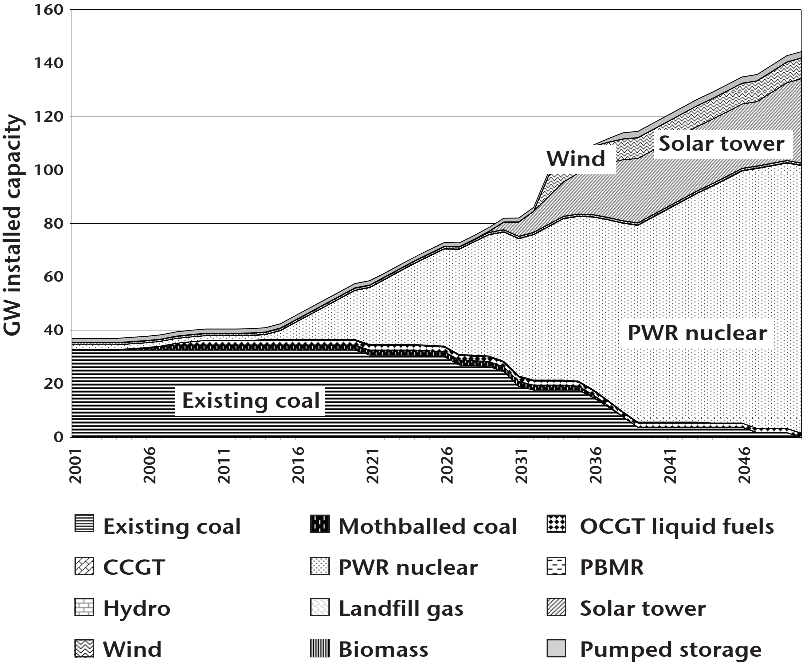

Figure 4.13: Electricity-generating capacity by plant type—escalating CO_2 tax (Some elements occur in numbers too small to be visible)

In addition, as can be seen in Figure 4.14, there is very little use of synfuels. No new plants are commissioned, and existing plants produce no fuel from 2035, as the tax escalates through the R500 level.

The application of the tax mitigates 12 287 Mt of CO_2-eq over the period, at a cost of R42 per ton.

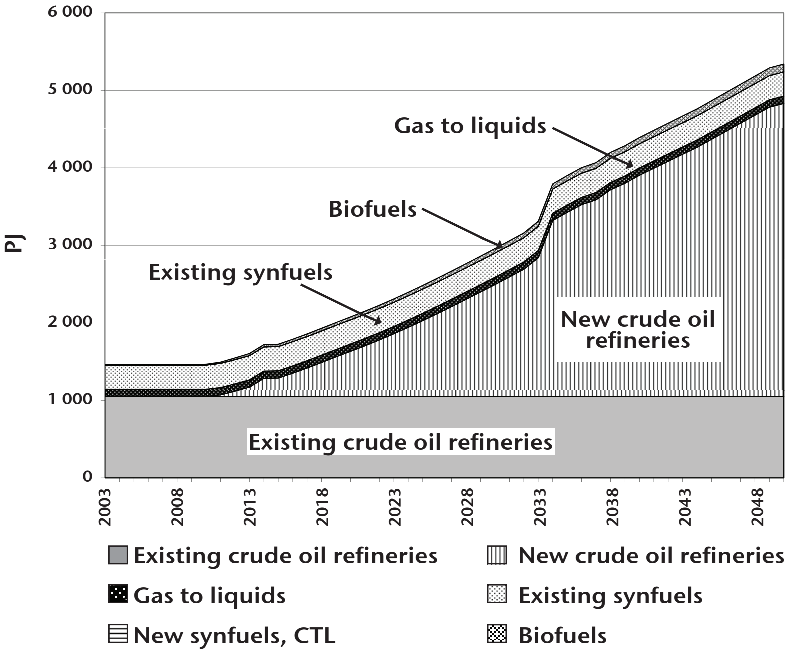

Figure 4.14: Growth of refinery capacity and synfuel plants—escalating CO_2 tax (Some elements occur in numbers too small to be visible)

Previous tax levels analysed

In previous analysis, carbon dioxide taxes of R100 and R1 000 / tCO_2-eq were examined. A tax of R100 / ton of carbon dioxide is placed on all carbon dioxide emissions. The emissions reductions are concentrated in the last two decades, when a slightly higher proportion of low carbon-dioxide emitting technologies is built—that is, higher proportions of nuclear and renewables plants. Towards the end of the period, as more renewable technologies emerge in the GWC case, the effect of the carbon dioxide tax declines and disappears.

The R100 tax reduces emissions by 1 804 Mt CO_2-eq from 2003 to 2050, while at R1 000, cumulative emission reductions are substantially higher at 16 361 Mt. The total mitigation costs as a share of GDP are on average 0.05% of GDP, while the R1 000 tax is close to 2% total mitigation cost. Total mitigation costs were added up in absolute terms, and divided by GDP projected over the period, to indicate the costs relative to the size of the economy (see Chapter 5, page 154, **Adding up costs as a share of GDP**).

Subsidy for solar water heaters

A subsidy for residential solar water heaters has significant socio-economic benefits. In many poorer households, it could provide a service—hot water—that is not yet available. In richer households, it can reduce electricity bills substantially. For each individual household, the emissions reductions are small.

If implemented widely across the country, SWH can contribute a sizeable wedge, with annual reductions of 6 Mt, adding up to 307 Mt CO_2-eq over the period. The mitigation can be achieved at –R208 / tCO_2-eq.

Subsidy for renewable electricity

A subsidy on renewable electricity, equivalent to 38 c / kWh, induces a significant change in which renewable electricity plants are built, resulting in the plan shown in Figure 4.15. The two solar thermal electric technologies appear as in other renewable wedges, but noticeably more wind technology is built. The overall size of the grid is over 150 GW by 2050.

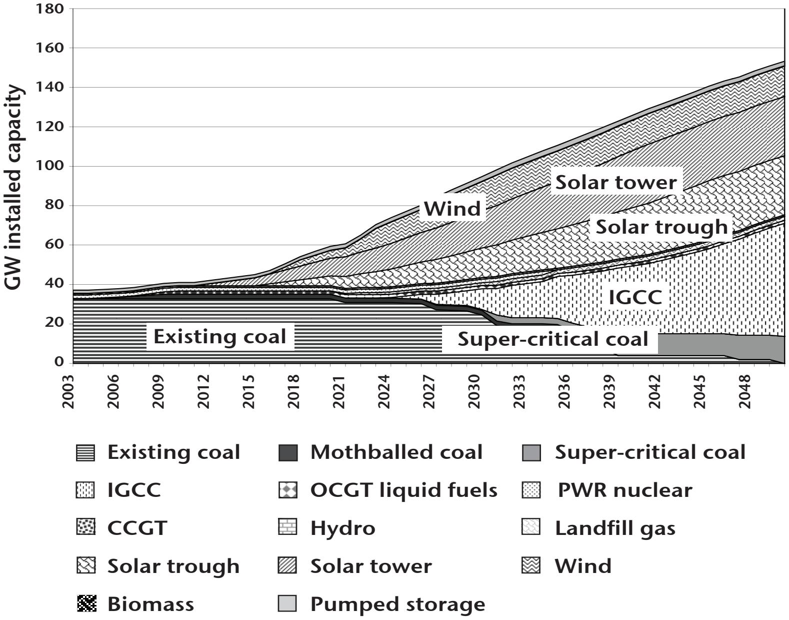

Figure 4.15: Electricity-generating capacity with renewables subsidy (GW) (Some elements occur in numbers too small to be visible)

These changes in response to the subsidy result in emission reductions of 81 Mt per year, adding up to 3 887 Mt CO_2-eq over the period. The average mitigation cost at 10% discount rate is R 125 / tCO_2-eq. Overall, the cost of abatement through this measure would be 0.77% of GDP.

It is worth noting that the absolute reductions flowing from the subsidy for renewable electricity are greater than in any of the other renewables cases, be they initial, with learning or extended, with the exception of the extended renewables with learning case.

Specifications of mitigation actions in summary

Table 4.5 summarises some critical model parameters for the mitigation actions implemented across different sectors. The way that the wedge is implemented in model parameters is briefly described. The time-scale and critical differences in goals in the GWC reference case and mitigation action are reported here.

Table 4.5: Specification of mitigation actions modelled

Mitigation action	*Model parameters*	*Time-scale*	*Ref. goal*	*Mit. goal*	*Quantity*	*Remaining comment/ qualifications*
Energy supply*						
Renewable energy for electricity generation	15% of electricity dispatched from domestic renewable resources by 2020, and 27% by 2030, from South African hydro, wind, solar thermal, landfill gas, PV, bagasse/pulp and paper. In an extended wedge, the bound on commissioning of new parabolic trough and solar power tower plant is increased to 2.5 GW / year.	2030 2050		27% (Remains at least 27% to end of period.)	Total electricity dispatched.	Linear extrapolation of 15% by 2020 gives 27% by 2030. 50% by 2050.
Nuclear power	27% of electricity dispatched by 2030 is from nuclear, either PBMRs or conventional nuclear PWRs—model optimised for cost etc. In an extended wedge, the bound on investment in new capacity for both PBMR and PWR were increased.	2030 2050		27%	Total electricity dispatched.	27% in 2030 to be comparable to renewable and clean coal. 50% by 2050.

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Mitigation action	*Model parameters*	*Time-scale*	*Ref. goal*	*Mit. goal*	*Quantity*	*Remaining comment/ qualifications*
Renewable and nuclear	This scenario combines the scenarios above; i.e. no electricity from fossil fuels by 2050.	2050				50% renewable and 50% nuclear by 2050
Cleaner coal for electricity	27% of electricity dispatched by super-critical coal and/or IGCC coal technologies by 2030; first plant could be commissioned by 2015. In an extended wedge, the bound on commissioning of new IGCC capacity increases from 2.5 GW / year in 2020 to a maximum 4.5 GW / year in 2030, where it remains until 2050, this allows an increased penetration of IGCC.	2030 2050		27%	Total electricity dispatched	27% in 2030 to be comparable to renewable and nuclear. In extended wedge, coal still restricted to supply max of 80% of total electricity demand.
Limited CCS	A cap is placed on the amount of CO_2 which can be stored annually, starting with 1 Mt in 2015, and reaching a peak of 20 Mt in 2024. Technologies with CCS include SCC, new PF, IGCC and CCGT.	2024		20 Mt	Annual CCS storage	

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Mitigation action	*Model parameters*	*Time-scale*	*Ref. goal*	*Mit. goal*	*Quantity*	*Remaining comment/ qualifications*
Carbon/GHG emissions tax	R100 (2003 Rands) per ton of CO_2 from electric power plants, introduced from 2008.					
Transport[**]						
Improve energy efficiency of private cars and light commercial vehicles	Vehicle efficiency improves by 0.9% to 1.2% per year (0.5% in base case)	annual	2001–2007: 0.4% annual improvement 2008: 0.9% annual improvement	2001–2007: 0.4% 2008: 1.2% annual improvement	Percentage improvement vehicle efficiency	
Hybrid vehicles	20% of private cars are hybrids by 2030 (ramped up from 0% in 2001 to 7% in 2015). Shares of petrol cars reduce to accommodate	2015 2030		7% 20%	Percentage of private cars which are hybrids	
Transport mode shift action: passengers	Passengers shift from private car to public transport, and from domestic air to intercity rail/bus. Currently, 51.8% of passenger kms are by public transport—this will move to 75% by 2050.	2050		75%	Percentage passenger kms travelled on public transport	Includes cost estimate of additional infrastructure in addition to existing carrying capacity—R10 million (2003) rand per million additional passenger km of carrying capacity.

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Mitigation action	*Model parameters*	*Time-scale*	*Ref. goal*	*Mit. goal*	*Quantity*	*Remaining comment/ qualifications*
Encourage vehicle downsizing (e.g. from SUVs)	SUVs limited to 2% of private passenger kms by 2030. In an extended wedge, SUV penetration is limited to 1% of private passenger kilometre demand in 2050.	2030 2050	4%	2% 1%	Percentage of private passenger kms travelled in SUVs	
Electric vehicles with renewable electricity	Electric vehicles are allowed to take up 10% of passenger kilometre demand between 2008 and 2015 increasing to 60% of demand in 2030. The penetration remains at 60% between 2030 and 2050. In addition, electricity generation from renewable sources is increased to 27% in 2030.	2030	0%	60%		Results are compared to a reference GWC grid, and one with 27% renewable energy

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Mitigation action	*Model parameters*	*Time-scale*	*Ref. goal*	*Mit. goal*	*Quantity*	*Remaining comment/ qualifications*
Residential						
Residential energy efficiency and development action	Significant penetration of SWHs, insulation/passive solar design, efficient lighting, appliance labelling and standards, geyser insulation, switching to LPG for cooking, and disseminating the 'Basa Njengo Magogo' coal firelighting method. [Note: SWH is also counted as a renewable energy in the supply section.] 20–60% of rich households and 10–50% of poor households have SWH by 2030; all new social housing built with insulation / passive solar by 2015; efficient lighting (CFLs, LEDs) installed in a maximum of 40% of poor households and 50% of rich households up to 2050; appliance standards introduced. Rich households have 80% geyser blankets and poor households have 70% of geyser blankets by 2030.	2030 2030		20–60% 10–50%	Percentage rich households with SWH. Percentage poor households with SWH	

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Mitigation action	*Model parameters*	*Time-scale*	*Ref. goal*	*Mit. goal*	*Quantity*	*Remaining comment/ qualifications*
Commercial						
Combined commercial sector energy efficiency action applied to new commercial buildings, and retrofitting of existing buildings	In new buildings: SWH, more efficient water heating (including use of heat pumps), more efficient HVAC, more efficient lighting (CFLs, LEDs, efficient fluorescents), variable speed drives, more efficient motors, more efficient refrigeration, use of building energy management systems, and efficient building shell design. In existing buildings, retrofit equipment (including lighting and HVAC) and apply energy management systems.	2015 2030	15%	30%	Reduction in final energy consumption over base case.	
Industry energy						
Combined industrial energy efficiency action	Improving the efficiency of boilers, HVAC, refrigeration, water heating (including installing heat pumps), lighting (efficient fluorescents, CFLs, HIDs), air compressors, motors, compressed air management, as well as optimising process control, using building energy management systems, improving building shell design, and introducing variable-speed drives.	2015 2030	15%	30%	Reduction in final energy consumption over base case.	In order to reach 30% savings, boiler efficiency improvements must be 40% (base case is 30%). Penetration rates for efficient boilers are as in base case: 2015: 51%, 2030: 80%, 2050: 100%.

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Mitigation action	*Model parameters*	*Time-scale*	*Ref. goal*	*Mit. goal*	*Quantity*	*Remaining comment/ qualifications*
Increase refinery efficiency	Increase energy efficiency in the use of electricity and steam by crude oil refineries by 15% by 2015.	2015	15%		Refinery efficiency improvement over base case	These efficiency improvements take place in the chemical/ petrochemical part of industry.
Increase efficiency of utilities in synfuel plants	Increase energy efficiency in the use of electricity and steam by synfuel refineries by 15% by 2015.	2015	15%		Refinery efficiency improvement over base case	
Non-energy (agriculture, waste, LULCF)						
Agriculture: enteric fermentation	Total cattle herd reduced by 30% between 2006 and 2011 at 5% a year; 5% of free-range herd to be transferred to feedlots from 2006 until 45% have been transferred; feed supplemented with high-protein, high digestibility feed with correct oil content.	2011		30% 45%	Percentage of reduction of size of national cattle herd. Percentage of free-range herd transferred to feedlots.	

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Mitigation action	*Model parameters*	*Time-scale*	*Ref. goal*	*Mit. goal*	*Quantity*	*Remaining comment/ qualifications*
Agriculture: Manure management	Percentage of feedlot manure from beef, poultry and pigs which is scraped and dried (does not undergo anaerobic decompositions) raised to 80% by 2010.	2010		80%	Percentage of feedlot manure from beef, poultry and pigs which is scraped and dried	
Agriculture: reduced tillage	Reduced tillage is adopted from 2007 on either 30% or 80% (more costly) of cropland.	2007 on		30% 80%	Percentage of cropland under reduced tillage	
Waste	Waste minimisation and composting.					
Land use: fire and savanna	50% reduction in fire episodes in savanna from 2004.	2004 on		50%	Percentage reduction in fire episodes	
Land use: afforestation	Rate of commercial afforestation will increase between 2008 to 2030 so that an additional 760 000 ha of commercial forests are planted by 2030.	2030		760 000	Additional hectares of land planted with commercial forests	

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Mitigation action	*Model parameters*	*Time-scale*	*Ref. goal*	*Mit. goal*	*Quantity*	*Remaining comment/ qualifications*
Industry-process emissions						
New coal-to-liquid synfuels plant with limited CCS (20 Mt)	Limited CCS (up to 20 Mt per year) from one of the new Secunda-type CTL plants which occur in the GWC scenario. CCS capacity starts at 1 Mt per year in 2007, and reaches 20 Mt per year by 2030.	2030		20Mt	CO_2 from CTL plant captured and stored per year.	
Methane capture from existing CCS plants	Capture CH_4 emissions from existing CTL plants from 2010.	2010		0	CH_4 emissions from existing CTL plants.	
Coal mine methane capture	Capture 25% or 50% (at higher cost) of methane emissions from coal mines, starting in 2020, and reaching goal by 2030.	2030 2030		25% 50%	Percentage of CH_4 emissions captured from coal mining.	
Aluminium: PFC capture from existing plants	Capture of PFCs from existing aluminium plant, starting in 2011, and reaching 100% by 2020.	2020		100%	Percentage of PFCs captured from existing aluminium plants.	

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Mitigation action	*Model parameters*	*Time-scale*	*Ref. goal*	*Mit. goal*	*Quantity*	*Remaining comment/ qualifications*
Taxes and incentives						
SWH subsidy	The cost of SWHs in the residential sector was reduced. The cost after subsidy in 2001 is 534.7 mil R / PJ / annum which reduces further to 336.77 mil R / PJ/ annum in 2050.	2050				
RE electricity subsidy	-106 R / GJ subsidy on electricity from power tower, trough, PV, wind, hydro, bagasse, LFG.	2050				
CO_2 tax	An escalating CO_2 tax is imposed on all energy-related CO_2 emissions, including process emissions from Sasol plants.	2050				The responsiveness on the demand side depends on the ability to switch to more efficient options or fuel-switch.

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* Energy supply lists no liquid fuel supply actions, except biofuels. Other liqud fuel-related actions are efficiency-related (Table 2), or non-energy actions (Sasol use of natural gas to supplement coal in CTL process, and Sasol CCS).

** Note: for actions on hybrids, modal shifts (passenger and freight) and SUVs, efficiency improvements as in the base case are used (0.4% improvement per year). Bounds on targeted sectors are kept tight; others are opened up by 30% (upper and lower bounds) to allow the model some flexibility.

Chapter Five

Emission reductions and costs in summary

The large number of mitigation actions (or wedges) analysed in this book is summarised in Table 5.1. It includes all the wedges, across the energy sector, non-energy (agriculture, waste and forestry) and industrial process emissions. For a brief description and key parameters of each wedge, see Table 4.5 on page 133, or see Chapter 4 for more detailed descriptions of all the mitigation actions. A graphic summary of all wedges is provided in Figure 5.1.

Summary of mitigation options and costs

Table 5.1 reports the key parameters of mitigation cost (R / tCO_2-eq), the cumulative emission reductions from 2003 to 2050 and the average share of GDP that the aggregate mitigation costs would represent. Columns 4 and 5 rank the mitigation actions by cost and emission reductions (for 2003 to 2050 cumulatively), respectively. In other words, the table makes clear which are the most cost-effective options and which are the 'big hits'. The wide variety of mitigation actions, including smaller wedges, is reflected in the range of emission reductions and costs reported and summarised for comparison.

Table 5.1: Summary table showing mitigation cost, total emission reductions and total mitigation costs in relation to GDP and the energy system

Mitigation action	Mitigation cost (R / tCO_2-eq)	GHG emission reduction, Mt CO_2-eq, 2003–2050	Rank costs — lowest cost is no.1	Rank emission reductions — highest reduction is no.1	Mitigation costs as share of GDP	Increase on GWC energy system costs
	Average of incremental costs of mitigation action vs. base case, at 10% discount rate	Positive numbers are reductions of emissions by Sources or removals of emissions by sinks	Rank cost	Rank ER	%, negative numbers mean lower costs	%, negative numbers mean lower costs
Combined energy cases						
Start Now	–R 13	11 079			–0.5%	–2.2%
Scale Up	R 39	13 761			0.8%	3.6%
Use the Market	R 10	17 434			0.1%	0.6%
Current Development Plans	–R 510	3 412			–2.4%	–11.4%
Individual Wedges						
Limit on less efficient vehicles	–4 404	18	1	36	–0.2%	–0.7%
Passenger modal shift	–1 131	469	2	16	–1.1%	–4.9%
Improved vehicle efficiency	–269	758	3	14	–0.4%	–1.9%

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Mitigation action	Mitigation cost (R / tCO_2-eq)	GHG emission reduction, Mt CO_2-eq, 2003–2050	Rank costs — lowest cost is no.1	Rank emission reductions — highest reduction is no.1	Mitigation costs as share of GDP	Increase on GWC energy system costs
SWH subsidy	–208	307	4	25	–0.1%	–0.4%
Commercial efficiency	–203	381	5	22	–0.1%	–0.6%
Residential efficiency	–198	430	6	21	–0.1%	–0.5%
Renewables with learning	–143	2 757	7	10	–0.4%	–2.1%
Industrial efficiency	–34	4 572	8	5	–0.3%	–1.2%
Agriculture: manure management	–19	47	9	34	n/a	n/a
Land use: fire control and savanna thickening	–15	455	10	17	0.0%	n/a
Cleaner coal	–4.8	167	11	28	0.0%	0.0%
Aluminium	0.2	29	12	35	0.0%	n/a
Renewables with learning, extended	3	3 990	13	6	0.0%	0.1%
Synfuels methane reduction	8	146	14	30	0.0%	n/a
Waste management	14	432	15	20	n/a	n/a

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Mitigation action	Mitigation cost (R / tCO_2-eq)	GHG emission reduction, Mt CO_2-eq, 2003–2050	Rank costs — lowest cost is no.1	Rank emission reductions — highest reduction is no.1	Mitigation costs as share of GDP	Increase on GWC energy system costs
Nuclear	18	1 660	16	12	0.0%	0.2%
Nuclear, extended	20	3 467	17	8	0.1%	0.7%
Agriculture: reduced tillage	24	100	18	31	0.0%	n/a
Land use: afforestation	39	202	19	27	0.0%	n/a
Escalating CO_2 tax	42	12 287	20	1	0.9%	4.3%
Agriculture: enteric fermentation	50	313	21	24	0.0%	n/a
Renewables	52	2 010	22	11	0.1%	0.6%
Nuclear and renewables, extended	52	8 297	23	2	0.8%	3.8%
Nuclear and renewables	64	5 559	24	4	0.6%	2.7%
CCS 2 Mt	67	306	25	26	0.0%	0.2%
CCS 20 Mt	72	449	26	19	0.1%	0.3%
Renewables, extended	92	3 285	27	9	0.6%	2.6%
Electric vehicles with Nuclear, renewables	102	6 255	28	3	1.1%	5.1%

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Mitigation action	Mitigation cost (R / tCO_2-eq)	GHG emission reduction, Mt CO_2-eq, 2003–2050	Rank costs — lowest cost is no.1	Rank emission reductions — highest reduction is no.1	Mitigation costs as share of GDP	Increase on GWC energy system costs
Synfuels CCS 23 Mt	105	851	29	13	0.1%	n/a
Subsidy for renewables	125	3 887	30	7	0.8%	3.7%
Coal mine methane reduction (50%)	346	61	31	33	0.1%	n/a
Synfuels CCS 2 Mt	476	78	32	32	0.0%	n/a
Biofuels	524	154	33	29	0.1%	0.5%
Electric vehicles in GWC grid	607	450	34	18	0.5%	2.3%
Biofuel subsidy	697	573	35	15	0.4%	2.3%
Hybrids	1 987	381	36	23	0.5%	6.3%

Single wedges range from large *savings* to the economy per ton of carbon dioxide mitigated, for example for passenger modal shifts at close to -R1 100, positive cost options, such as almost +R 2 000 per ton of CO_2-eq for hybrids.[22] Emission reductions in aggregate are obviously largest for combined cases, with the escalating carbon dioxide tax the largest reduction from a single wedge. Without repeating the detailed results of section 4 above, some general findings for different kinds of wedges can be seen in Table 5.1.

Energy efficiency is generally a negative-cost option; that is, the savings from reduced energy use outweigh the programme costs. Commercial (–R203 / tCO_2-eq) and residential (-R198 / tCO_2-eq) energy efficiency are more cost effective than industrial (-R34 / tCO_2-eq), but the latter provides greater absolute savings—by a factor of more than ten. Industrial energy efficiency shows savings of 4 572 Mt CO_2-eq over the period, one of the largest single wedges. Residential energy efficiency (including solar water heaters) is not only a good negative-cost mitigation option but also has important socio-economic benefits. While individual interventions are small, across a large number of households they add up to avoided emissions of over 400 Mt CO_2-eq over time.

In **electricity generation,** cleaner coal was found to be the smallest of the three wedges. Given that supercritical coal is the default new coal option and IGCC is built extensively in GWC, relatively modest emission reductions are possible here. Carbon capture and storage provide greater potential, if the challenge in scaling up storage can be achieved—a challenge also faced by synfuels and its dilute and concentrated streams of carbon dioxide.

Other options would similarly need to scale up. This is reflected in the extension of both renewable and nuclear wedges from 27% of electricity generated to 50% of electricity generated. The wedge representing the results of a subsidy of 38c / kWh for renewable electricity shows cumulative emission reductions that are greater than the other renewables cases (at 3 887 Mt CO_2-eq from 2003 to 2050), be they initial, with learning or extended. Only if one assumes technology learning *and* extends renewables to 50% do emissions go higher, to 3 990 Mt over the period. For renewables on their own, learning makes the difference between a positive and negative

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[22] Net negative-cost options are those where the savings (e.g. of energy) over time more than outweigh the initial outlay; positive-cost mitigation actions are those where the net costs have to be paid over the life of the intervention.

cost. The extended nuclear wedge is also a large wedge, with total emission reductions at 3 467 Mt CO_2-eq over the period.

Combining both renewables and nuclear showed that a combination can provide emission reductions of 8 297 Mt CO_2-eq from 2003 to 2050. But there is no single solution, as even a zero-carbon electricity sector by 2050 will not reduce absolute emissions, unless action is also taken elsewhere.

In the **transport sector**, shifting modes of transport is a major infrastructure option—from private to public transport modes for passengers, and from road to rail for freight. Passenger modal shift appears—on this analysis and its assumptions—more attractive than freight, and is a negative-cost mitigation option with reductions of 469 Mt CO_2-eq. Analysis of modal shifts includes infrastructure costs, but not a return on investment. Biofuels are reported as a separate wedge, the moderate scale of emission reductions reflecting the limits on the potential of biofuel in SA. Greater efficiency is possible in the transport sector. Promoting vehicle efficiency is a negative-cost option, saving R269 / tCO_2-eq. The results for electric vehicles show that the grid in which they operate matters. In a renewables-based grid, mitigation costs are six times lower per ton of CO_2 than in the GWC grid.

Non-energy sectors (waste, agriculture, forestry and other land-use changes) result in emissions reductions ranging from 47 to 455 Mt CO_2-eq for the period 2003 to 2050. While the reductions are smaller than some energy mitigation options, non-energy options provide some negative cost options (manure management, fire control and savanna thickening), but not the cheapest on offer (even ignoring transport). Also, some agricultural mitigation actions have significant positive costs (enteric fermentation, reduced tillage, afforestation). For waste, only the costs of flaring are considered, at R14 / tCO_2-eq.

The **waste sector** can provide substantial emission reductions at 432 Mt CO_2-eq for the 48-year period, not including waste minimisation. Reduction of fire frequency (rather than complete fire prevention) interacts with savanna thickening in that reduced fire is a major driver of thickening. Together, fire control and savanna thickening sequester carbon equivalent to 455 Mt CO_2, at a negative mitigation cost of R15 / tCO_2-eq. Mitigation from reduced tillage is limited—first, the effect of putting land under reduced tillage wears off and less land is put on low-tillage over time. Hence emissions in the mitigation case converge with the baseline. Afforesting an additional 760 000 hectares of land sequesters

202 Mt CO_2-eq at R39 / tCO_2-eq. This appears to be the most attractive option within these non-energy sectors.

However, the largest potential reduction in non-energy emissions is **carbon dioxide capture and storage** (CCS) from new coal-to-liquid synfuel plants, using similar technology to the current plants at Secunda. Compared to CCS on electricity generation, CCS from the synfuel process is attractive, in that roughly half the carbon dioxide is in concentrated forms, avoiding most of the cost of capture. The key constraint is whether sufficient storage is available. Analysis so far has assumed 23 Mt CO_2-eq per year from synfuels could be stored at most, which on its own is more than 20 times larger than the largest existing CCS project and ten times planned. With the limit, the mitigation potential is still large at 851 Mt CO_2-eq over the period.

All the wedges are shown graphically in Figure 5.1. All are shown over the period 2003 to 2050, with the rand value indicating the mitigation cost in R / tCO_2-eq. On a single page, the scale of different wedges can be seen more clearly in comparison. Note that all the top wedges are on a scale from 0 to 300 Mt CO_2-eq, with the exception of the carbon dioxide tax which goes above 600 Mt CO_2-eq by 2050. The medium-sized wedges are on a scale up to 50 Mt, and the smallest wedges up to 10 Mt CO_2-eq on the y-axis. The curved arrows indicate that all small wedges combined would yield one more medium-sized wedge, and similarly all medium wedges would add one more on the scale of the larger wedges.

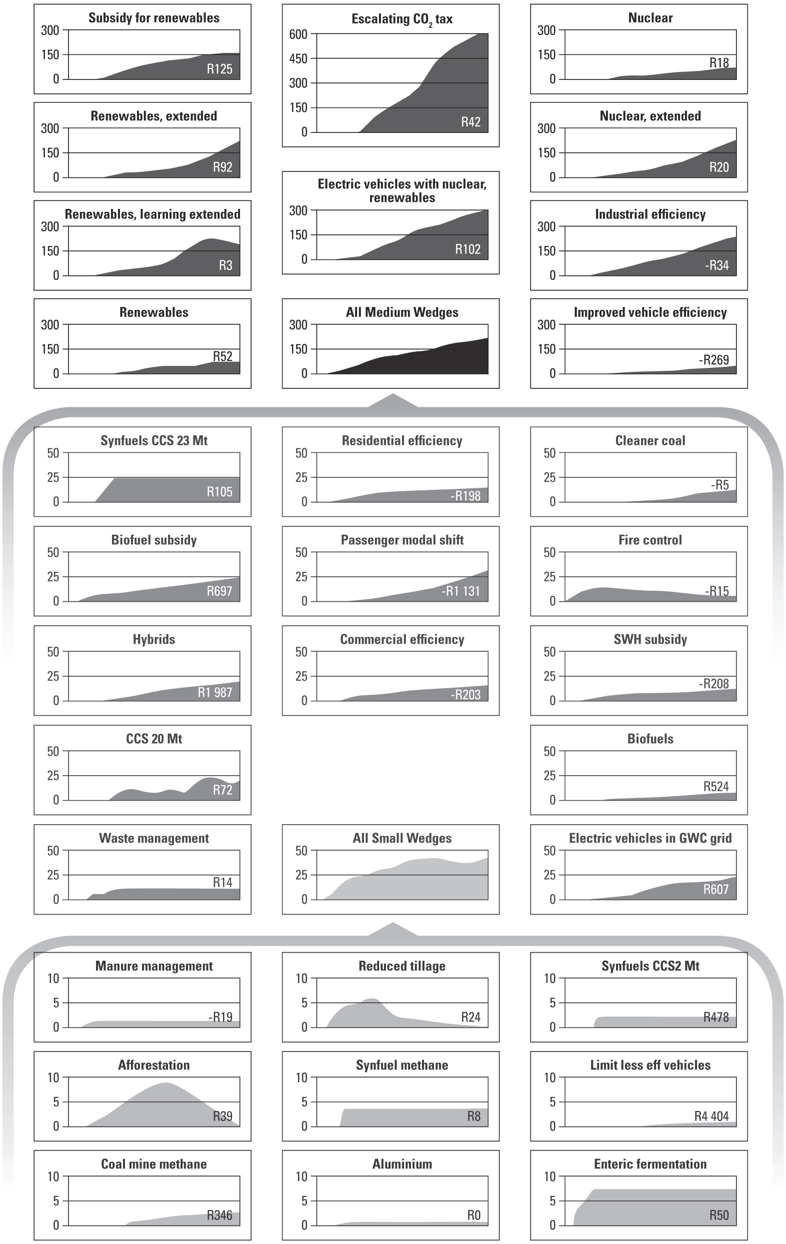

Figure 5.1: Individual LTMS mitigation options or wedges

The mitigation cost curve

The costs and emission reductions of most wedges are summarised in another format, a mitigation cost curve, in Figure 5.2. The units on the y-axis are R / tCO_2-eq, and on the x-axis Mt CO_2-eq. In other words, the height of a bar shows the cost-effectiveness of mitigation, while the width of the bar indicates by how much emissions are reduced. Since there are both negative and positive cost options, the x-axis extends above and below the zero line. While this presentation follows a common format for mitigation costs curves, in the LTMS mitigation cost curve wedges are not mutually exclusive—for example, more than one wedge includes renewable energy for electricity generation.

Since the range of mitigation costs is wide, some of the wedges have been cut off at the top. In these cases, at the extreme right- and left-hand sides of the graph, the mitigation costs have been included next to the label. 'R / t' is short for R / tCO_2-eq.

Figure 5.2 shows different 'break-points' as mitigation actions are arranged from lowest to highest cost. Read in this way, the mitigation cost curve suggests that wedges are grouped in four groups. A first group—from the lowest-cost wedge to reduced tillage—includes all the net negative-cost wedges and some with very modest positive costs (below R25 / tCO_2-eq). This could be called the 'efficiency plus low-cost' group. The next group starts with afforestation (costs increase to R39 / t) up to and including CCS on electricity generation at around R75 / tCO_2-eq. R50 per ton at 2008 exchange rates is less than €5 / tCO_2-eq—that is, already at the lower end of the range of prices in the carbon markets today. The group might be given the name 'technology improvement', but it also includes the escalating carbon dioxide tax. The third gro up covers extended renewables, the subsidy for renewables, and electric vehicles—that is, wedges grouped around R100 / tCO_2-eq. The fourth group represents the highest cost options, starting with coal-mine methane at R346 / ton, rising to almost R2 000 per ton.

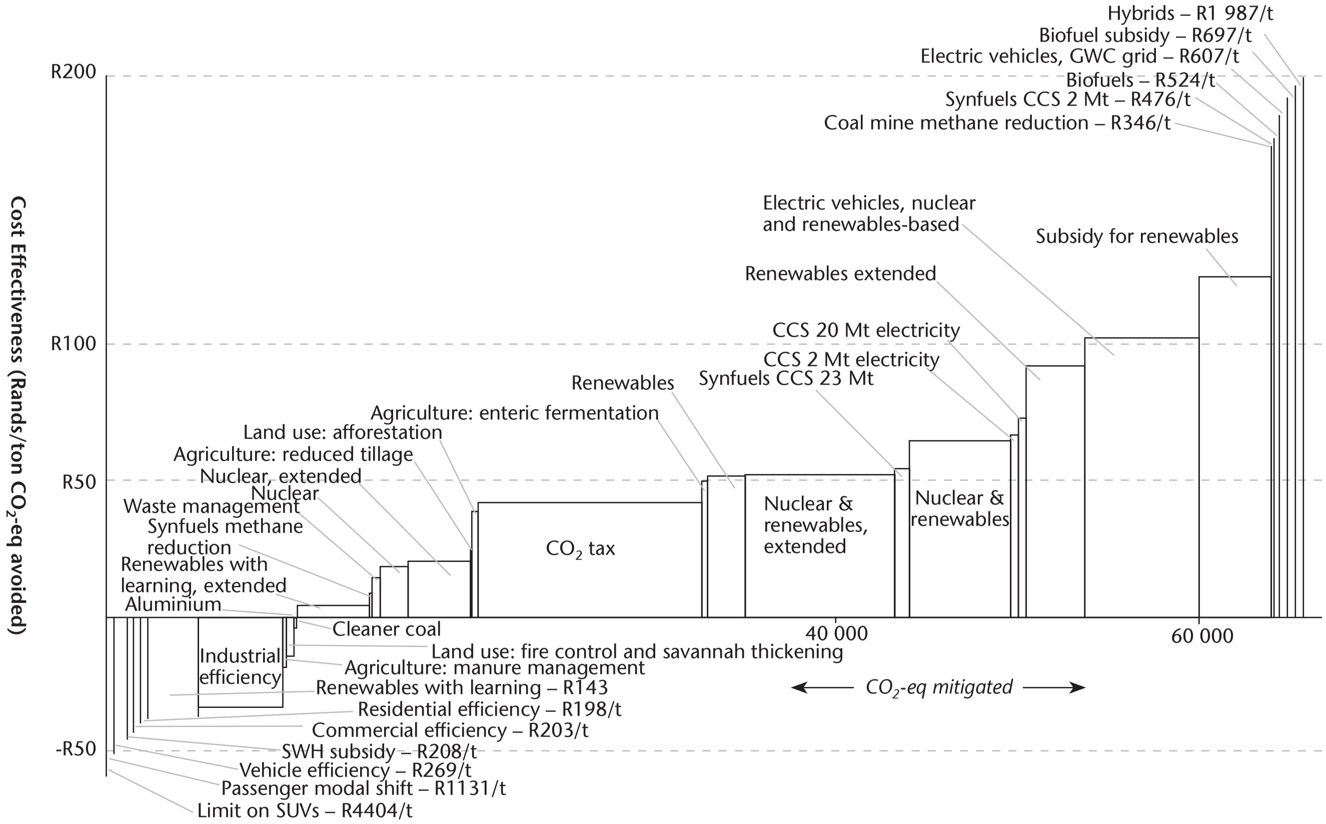

Figure 5.2: Mitigation cost curve for South Africa

Adding up costs as a share of GDP

The total mitigation costs over a 48-year period add up to substantial numbers. These numbers can be seen in relation to the size of the economy (GDP) or the energy system. These comparative figures have been reported for individual wedges in Table 5.1 as a 'share of GDP' and 'increase on GWC energy system costs'. This gives some sense of the scale of effort required, based on the methodology outlined in Chapter 2, page 34, **Costs of mitigation**.

For net negative cost wedges, there are overall savings and hence a negative share of GDP or benefit. Compared to the total costs of the energy system (both supply and demand side), the ratio is larger—because the overall system one is comparing to is smaller. The costing boundary is narrower. Small wedges would cost a small percentage of GDP, which is unsurprising since GDP is a large absolute amount of money. As wedges get combined into larger combined cases, and when positive cost measures are added, the share increases.

Assuming that the Stern threshold of overall costs at 1% of GDP (Stern Review 2006) is acceptable to the South African economy, it is of interest to see where this level is crossed. The analysis proceeded as follows:

- A set of wedges is run, starting with the most negative cost option (among the energy wedges).
- Another negative cost option is added.
- Wedges continue to be added, seeking to avoid double-counting, e.g. including an initial wedge and its extended version.

The results are shown in Figure 5.3 and the sequence of runs in the table below it. The first run (Run 00) includes SUVs, the wedge with the highest negative cost in Table 5.1. Run 1 then adds modal shift in passenger transport, Run 2 vehicle efficiency and so on. For each successive run, the previous wedges are also included.

The results are plotted showing the 'share of GDP' on the y-axis and cumulative emission reductions on the x-axis. The horizontal distance between two points shows how much mitigation the combined runs have produced. As the line moves up the y-axis, it can be seen when total mitigation costs are equivalent to 1% of GDP.

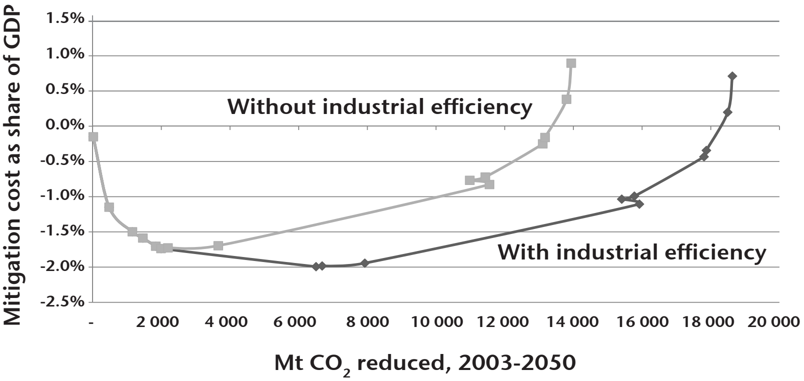

Figure 5.3 (above) and Table 5.2 (below): Mitigation costs as a share of GDP, for cumulatively combined wedges

	With industrial efficiency		*Without industrial efficiency*	
Wedge added in this run	*Mt CO_2, 2003–2050*	*% GDP*	*Mt CO_2, 2003–2050*	*% GDP*
Limit on SUVs	18	–0.15%	18	–0.15%
Passenger modal shift	480	–1.15%	480	–1.15%
Improved vehicle efficiency	1 157	–1.50%	1 157	–1.50%
SWH subsidy	1 462	–1.59%	1 462	–1.59%
Commercial efficiency	1 838	–1.70%	1 838	–1.70%
Residential efficiency	1 992	–1.74%	1 992	–1.74%
Industrial efficiency	6 505	–1.99%	n/a	n/a
Cleaner coal	6 683	–1.98%	2 194	–1.73%
Nuclear	7 926	–1.94%	3 659	–1.70%
Escalating CO_2 tax	15 922	–1.11%	11 556	–0.83%
Renewables	15 408	–1.04%	10 981	–0.77%
CCS 20 Mt	15 775	–0.99%	11 434	–0.72%
Subsidy for renewables	17 803	–0.43%	13 107	–0.25%
Biofuels	17 872	–0.34%	13 175	–0.16%
Electric vehicles in GWC grid	18 493	0.20%	13 800	0.38%
Hybrids	18 629	0.71%	13 936	0.89%

As is seen in the results, combining a set of negative-cost options—mostly energy efficiency in various sectors—would make the share of GDP more negative, so that the curve initially slopes downward.

Figure 5.3 shows that a range of positive-cost wedges, such as those in electricity generation or CCS, can be added and still remain below 0% of GDP. *On their own*, positive-cost wedges would have total mitigation costs that are a positive percentage, when compared to economic output. But, when *added up cumulatively*, the total cost of the package represented by the runs is still net negative. They become positive *overall* when electric vehicles and hybrids (both positive-cost with large reduction potential) are added in the last two runs.

The results depend on the wedges chosen. This becomes clear when the industrial energy efficiency is included, or excluded—as represented in Figure 5.3 by the two lines. Initially, the two lines are the same as the runs are identical. From the sixth run, they diverge. Industrial energy efficiency not only drives the overall costs further into negative territory but it also adds a large amount of emission reductions. With the big efficiency wedge, even when all the positive-cost wedges are added, the total still does not exceed expenditure equivalent to 1% of GDP.

Chapter Six

Strategic options for South Africa

What are the strategic options for South Africa to bend the curve of its emissions growth? What plans and strategies could be followed to get from the Growth without Constraints (GWC) scenario—in which our emissions quadruple by mid-century—to what is Required by Science (RBS)? The individual wedges or mitigation options are detailed in Chapter 4 and summarised in Chapter 5. They can be combined into strategic options in many different combinations. The LTMS Scenario Building Team focused on four strategic options.

Three of these options were modelled, as combinations of particular sets of wedges. They were called Start Now, Scale Up and Use the Market. Combining cases progressively moves emissions down from GWC to RBS, providing an analytical basis for the Strategic Options in the LTMS Scenario document. But, as will become apparent, none of these options fully closed the large gap between GWC and RBS—at least not for the full period. Therefore a fourth option was devised, Reach for the Goal.

Start Now

The strategic option of Start Now is to begin with what makes economic sense, the net-negative cost wedges. Net-negative cost wedges are mitigation actions that have upfront costs, but where the savings over time more than outweigh the initial costs. Energy efficiency is the classic example.

Start Now therefore contains large net-negative wedges, the biggest being industrial energy efficiency. In the transport sector, for example, the Start Now option assumes that greater efficiency of vehicles is promoted and vehicle size is limited. Technological change allows a shift to hybrid vehicles, while at the same time behavioural changes are reflected in passengers shifting from private to public modes of transport.

With those savings, it is possible to also include some wedges with a positive cost, in this case more renewable energy and nuclear sources for electricity. The analysis shows that quite substantial positive cost wedges can be included in the strategy. Energy supply sees a move away from coal-fired electricity, with renewables, nuclear and cleaner coal each providing 27% of electricity generated by 2050.

The emissions in the Start Now option are lower than in the Growth without Constraints scenario—there is a relative reduction in emissions, with an average of about 230 Mt CO_2-eq avoided each year. The combined wedges reduce a cumulative amount of 11 079 Mt CO_2-eq from 2003 to 2050. However, absolute emissions continue to rise, reaching around 1 000 Mt by 2050, well over double the level of the base year (2003). Another way of thinking about this is to consider how much of the gap between the two scenarios is closed. Start Now reduces the gap by 43% in 2050.

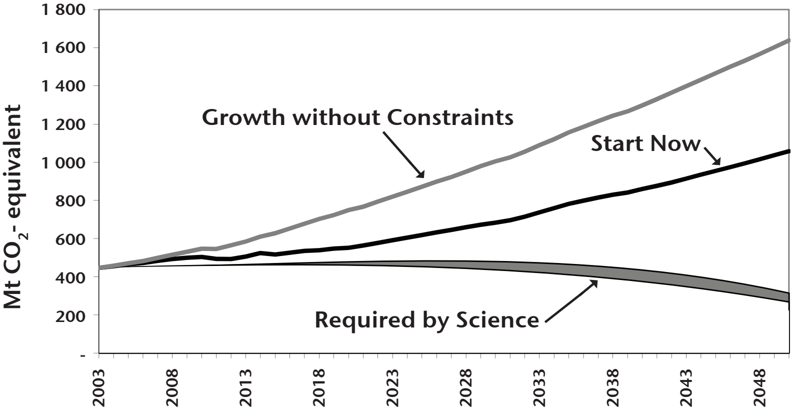

Figure 6.1: Emissions for Start Now compared to GWC

In plain language, the combined initial wedges reduce emissions very substantially, at a net saving to the country. The main qualifier is that the emissions are reduced relative to the high baseline in GWC. In absolute terms, emissions continue to rise in the initial combined case, as shown in Figure 6.1.

This combination of wedges could be taken for good economic reason, being overall a net negative-cost option and providing sustainable development co-benefits, quite independent of climate change. This option saves money over time, even if implemented up to 2050.

With substantial energy efficiency options and relatively (to the extended case) modest positive cost wedges, this can be done at -R13 tCO_2-eq (at 10% discount rate). The share of GDP is also a negative number, reflecting a net saving of 0.48% of GDP, or a saving of the total cost of the energy system of 2.18%.

To implement the Start Now option, the relevant sector would have to act to realise the wedges of emissions reduction. Each government department would have to consider policy and other actions needed to drive the emissions reduction action described in that wedge. Different sectors with their corresponding government departments would have to be involved in implementing sectoral plans. The actions with Start Now fall squarely into the rubric of sustainable development policies and measures (RSA 2006; Winkler et al. 2002).

In short, Start Now is the obvious and economically imperative strategy option, even though it is institutionally challenging. But it is not sufficient to reach the Required by Science objectives by 2050, nor is it likely to be regarded as an adequate or fair contribution in the multinational negotiations in the longer term—though it might be adequate for a second commitment period of the Kyoto Protocol. It runs the risk of creating an uncompetitive economy (as other economies and trade relations advance to climate-friendly technologies and trade rules), and leaving stranded assets in the economy. This is why it is called Start Now: the modelling shows it is a good start, with positive economy-wide results in the short term, and is good at least for the next decade. It would allow South Africa to demonstrate its commitment to making its development more sustainable—reducing emissions while not reducing GDP. Start Now is thus a good strategic option for the first part of an overall mitigation plan.

Scale Up

Given that Start Now closes the gap between GWC and RBS emission by less than half, the need for a strategic option that scaled up efforts was identified and two means of going further towards Required by Science were modelled. The first can be understood as a more ambitious action mandated by regulatory policy (in Scale Up) and the second as prioritising the use of economic instruments (Use the Market, see page 161, **Use The Market**). Both cases build on similar levels of energy efficiency as in Start Now, which already pushed the negative cost options to the limits of what was considered realistic in the LTMS process.

The Scale Up strategy sees a transition to zero-carbon electricity by mid-century, with nuclear power and renewable energy wedges each being extended to 50% of electricity generated by 2050. Cleaner coal technologies, particularly IGCC, already enter the Growth without Constraints reference case, so the emission reductions of that wedge are modest. In the Scale Up strategy, however, the technology of carbon capture and storage matures, and is scaled up by a factor of ten bigger than the largest currently planned facilities—that is, the limit of storing carbon dioxide is relaxed to 20 Mt CO_2 per year. Biofuels are extended as far as limits of arable land, water and concerns about biodiversity and food security allow. As the country moves towards a zero-emissions electricity grid, electric vehicles provide a new transport technology that reduces emissions. The resulting reduction in emission relative to GWC can be seen in Figure 6.2.

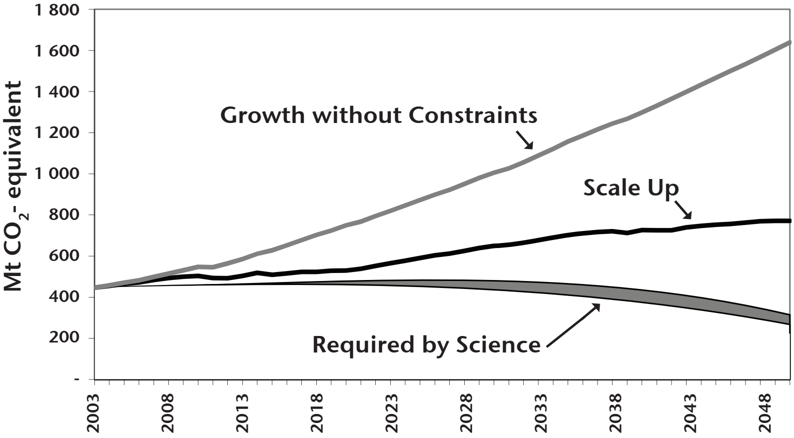

Figure 6.2: Emissions for Scale Up compared to GWC

The Scale Up option leads to total emission reductions of around 13 800 Mt CO_2-eq between 2003 and 2050 or an average of 287 per year. Emissions follow the Start Now profile fairly closely at first, and continue to rise, but in the last decade they level out (plateau).

Scale Up goes beyond the Start Now actions, adding further positive-cost actions without significantly extending the negative-cost ones. The greater emissions reductions in this combination come at a net-positive cost of R39 / tCO_2-eq. Because such a scaling up would take the cost of acting into net-positive cost territory, a careful analysis of the impacts of this cost on the economy is required. However, it can also be argued that this cost is potentially affordable, being at the lower end of the range of prices already seen in the carbon markets. The total mitigation costs represent a share of 0.77% of GDP.

Under Scale Up, the gap between emissions in GWC and RBS is closed by two-thirds (64%) in 2050. Scale Up still does not, however, result in a decline in emissions compared to the base year of the analysis—the 2003 emissions level almost doubles by 2050.

The implementation of the Scale Up strategy would require ambitious national climate policy and plans. Moving the energy economy, which currently relies on coal for three-quarters of primary energy, to zero-carbon electricity, is a massive undertaking. Under the Scale Up option, energy efficiency cannot be left to voluntary agreements, but must be guided by a policy framework and systems of penalties/incentives.

For the international negotiations, Scale Up can be described as an 'ambitious-transitional' strategy (Winkler & Vorster 2007). It is ambitious because it extends efforts well beyond existing plans. It is transitional in the sense that it might work in a multi-stage approach, but also in that the plateau arrives at a stage so late (2040–2050) as to be implausible in the long term context. Between 2025 and 2030 a further strategy should therefore kick in—otherwise emissions would still rise to 875 Mt CO_2-eq (the level of Scale Up in 2050). This is why it could be examined in conjunction with other options, including the use of market-based instruments.

Use the Market

The aim in the Use the Market strategic option is to get the market to work and promote the uptake of the accelerated technologies and social behaviour through incentives and taxes. The major wedges in Use the Market are an escalating carbon dioxide tax, and incentives for renewables for electricity generation, biofuels and solar water heaters.

The key driver of Use the Market is the escalating carbon dioxide tax. The level of carbon dioxide tax (see Chapter 4, page 126, **Tax on carbon dioxide** for the full range of taxes considered) included in the Use the Market option assumes that, over time, the price will rise from levels currently seen in carbon markets of R100 / tCO_2-eq. The rising tax level is designed to approximate a phase of slowing emissions growth, stabilising emissions and ultimately reducing absolute emissions through a high carbon tax of R750 in the last decade.

The tax represents a price change which makes the use of fossil fuels much less attractive, and induces an indirect effect of greater investment in low-carbon technologies. Under the Use the Market strategic option, no new CTL (coal-to-liquid) plant is built, but only new oil refineries—five of them. CTL plants would only be built if a significantly higher oil price is assumed, and also if it is assumed that CCS was implemented at large scale or CTL became more carbon-efficient by combining with other mitigation options such as biomass, other renewables or nuclear.

The tax drives electricity supply away from coal to nuclear and renewables. No new coal plants are built and existing coal power supply declines rapidly from 2025, so that by 2040 only 4 GW of coal capacity is left. A total of 14 new conventional nuclear plants are built, adding 25 GW of new capacity by 2050. The renewables plants come in smaller units, but add a total of 118 GW by 2050–61 GW of solar trough, 42 GW of solar tower and 15 GW of wind. The price subsidy tilts the balance of alternatives towards renewables. By 2050 the total grid capacity is 151 GW, compared to 120 GW in the Growth without Constraints reference case.

While the carbon tax shows expected results on the supply side, the response on the demand side in the model is smaller than one would expect in reality. In particular, emissions from the industry and transport sector continue to rise throughout the period. Industry continues to use coal directly and makes only a limited switch to gas, and then only late, in the last decade. The use of petrol, diesel and jet fuel continues unabated in the transport sector, with the other options still too limited. For example, passenger cars can become electric, but electric trucks are not yet modelled. The challenges of mitigation actions that could not be modelled—given the state of knowledge at the time of the LTMS process—are taken up in the fourth strategic option, Reach for the Goal. To model the fuller effect of the measures, the model is allowed to shift to more efficient or lower-carbon fuels options. For example, greater uptake of energy efficiency as in industry and commercial is allowed, compared to GWC, and the bounds on solar water heaters are set to higher levels, as in the subsidy case.

At the tax levels considered in this option, Use the Market results in emissions reductions beyond those seen in Scale Up by using economic instruments. The effect of using both taxes and incentives on shifting patterns of domestic investment and thus in resulting emissions is shown in Figure 6.3.

Use the Market reduces emissions by 17 434 Mt CO_2-eq between 2003 and 2050. The scale of relative emission reductions is twice that of any other wedges shown at an average of 363 Mt CO_2-eq per year (see Figure 5.1, page 151) and larger than the other two strategic options. Emissions in 2050 are 620 Mt CO_2-eq.

Since this is the largest wedge considered in this analysis, the extent to which it bridges the gap between GWC and RBS is worth examining. Compared to GWC (see Figure 6.3), emissions fluctuate around base year levels up to 2036. However, in the second half of the period, emissions grow again. Over time, combined economic instruments go most of the way to closing the gap, 85% in total. However, with the rising trend from 2025 to 2050, in the end year the gap is only closed by 76%.

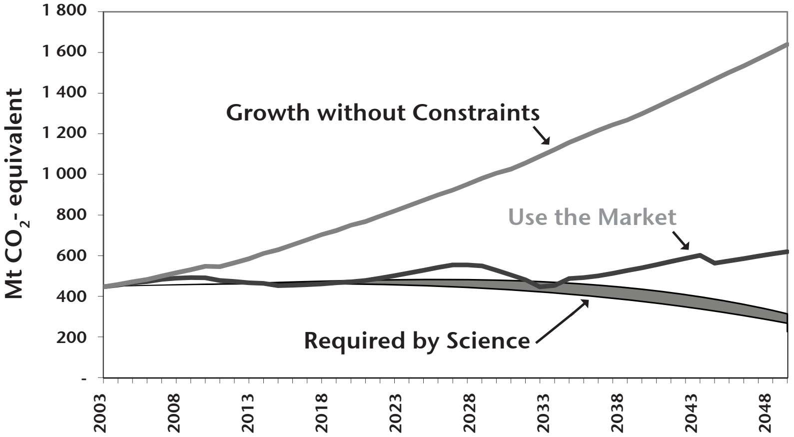

Figure 6.3: Emissions for Use the Market compared to GWC

Clearly the actions that would be taken in response to a combination of taxes and subsidies would constitute a significant effort. To put them in one context, the annual reductions are slightly larger than national emissions in GWC in the base year for the energy sector, 2003 (at 352 Mt). In this strategic option, the assumption is that the price mechanism of a carbon tax and incentives provided for climate-friendly investments drive large-scale change.

Reach for the Goal

The emissions reductions from the three combined cases are shown in summary form in Figure 6.4. As the LTMS Scenario Building Team considered these options, it became clear that a strategic option would be needed that was not modelled in the same way, but of equal importance to the other three options.

Figure 6.4 summarises the emissions trajectories projected for Start Now, Scale Up and Use the Market, relative to emissions in the reference case—the Growth without Constraints (GWC) scenario. It also shows in summary form how far each option gets towards the Required by Science (RBS) scenario.

Start Now and Scale Up follow a fairly similar emissions trajectory for much of the period, with the scaled-up efforts making a bigger difference in the longer term. A key difference is that emissions in Start Now continue to rise consistently, whereas the extended wedges show emissions levelling off towards the end. However, the levelling off occurs at an emissions level substantially higher than current emissions. Use the Market, driven primarily by a higher carbon dioxide tax, initially follows the -30% to -40% from 2003 levels in RBS. Up to 2035, this combined case is in the same region as the RBS 'cloud'. However, the combined economic instruments increase again from 2035 to 2050. By the end of the period, they are approaching the level reached by the extended wedges.

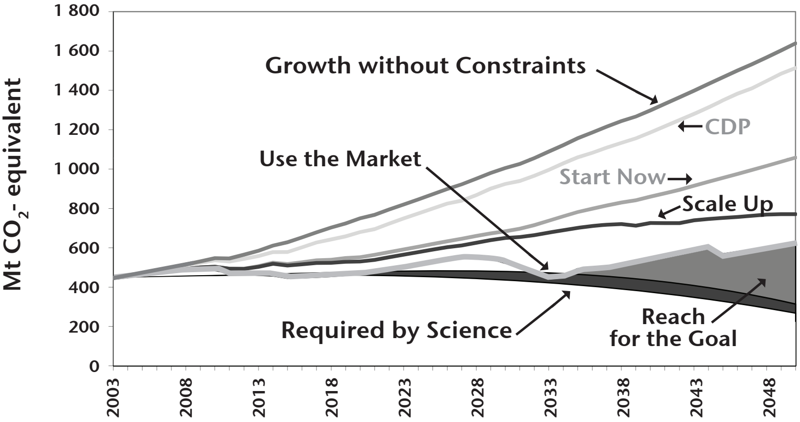

Figure 6.4: Emissions in GWC, RBS and strategic options—Start Now, Scale Up and Use the Market

How much do strategic options that can be modelled close the gap between GWC and RBS? Figure 6.4 illustrates the challenge that this poses, even for the most ambitious strategic options modelled. By 2050, the gap between GWC emissions and the RBS average is 1 349 Mt CO_2-eq, for that year alone. Combining wedges, Start Now reduced the gap by 581 Mt or 43%. Scale Up in 2050 close two-thirds of the gap (64%). While emissions in Use the Market are reduced below RBS earlier in the period, by 2050 it is 76% of the way to closing the gap—that is, it closes the gap three-quarters of the way. The fact that no single modelled option gets from GWC to RBS means other options are needed.

A different perspective is to consider the emissions levels relative to the base, which for the LTMS research was 2003. Emissions increase in absolute terms in all of these cases—by 2.4 (initial), 1.7 (extended) and 1.4 (economic instruments) times. The combined wedges make significant reductions compared to GWC and close the gap, but in none of the cases do absolute emissions decline by 2050.

The fact that the gap between GWC and RBS is not fully closed by any modelled option reflects both the scale of the challenge and a limitation of the approach. Clearly, the challenge of reducing emissions at the scale Required by Science is large, as spelled out above. The limitation of modelling is that mitigation options need to be well known. To include a mitigation option in an energy model, for example, the costs (capital and operational), efficiency, life-time and a number of other parameters need to be specified (see Table 2.5, page 21). Yet the expectation is that, over time, new technologies, resources, systems and policy options would become available. By 2025, we would expect some technologies to exist that are currently not known at all. By that very fact, they cannot be modelled—but, when extending analysis to 2050, these options could be important. Similarly, behavioural changes may have occurred—whether driven by taxes, greater awareness of climate impacts or other factors that are currently not represented in the modelling.

The LTMS Scenario Building Team therefore decided to consider a fourth strategic option, Reach for the Goal. While it is acknowledged that the components of this strategic option cannot be modelled with any accuracy as was done with the other options, some of its salient characteristics were outlined, with important policy implications. The components of Reach for the Goal were research and development (R&D) for new technologies; searching for lower-carbon resources; increased attention to people-oriented measures; and a transition to a low-carbon economy and society.

R&D in new technology

The first set of actions refers to 'new' technologies not included in the modelling for LTMS. The Scenario Building Team chose a range of technologies not yet in the market, but which are at this stage 'known', whether in the laboratory or already deployed in demonstration, and subjected them to the following test (see Raubenheimer [2007] for further details):

- Which show the most potential in achieving large emissions reductions?
- Which carry the lowest perceived technological risk?
- Which are likely to achieve extensive transfer internationally?
- Which appear to contribute most to the high emissions areas: electricity generation, transport, and industrial efficiency?

The LTMS process included an initial consideration of a set of technologies, identifying a possible list of these technologies that might, in its assessment, be implementable in the nearer future (by 2015): urban/micro wind-distributed generation; biomass gasification; heat pumps; solar water heating for cooling systems; energy density of biomass; solar chimney; net metering; increased energy efficiency; system efficiency; light emitting diodes; induction heating; 1 watt standby power; air to super-fast rail; regenerative braking on trains; system integration of technologies; light metals for the automotive and aerospace industry; materials recovery and recycling; fast neutron reactors; micro generation; new communication technologies; storage for electricity; and social policies.

The discussions also emphasised that, in Reaching for the Goal, technologies should be seen as systems. Stand-alone technologies are integrated into larger systems, and taking a system view can increase savings. Technology interacts with human behaviour. An example would be a decentralised grid, in which citizens can generate their own electricity and pass surpluses back to the grid.

The discussions identified further research and development (R&D), building on the Department of Science and Technology's climate change R&D strategy, as a key policy implication of the Reach for the Goal strategic option. These technologies require aggressive R&D effort, which should begin at the same time as the Start Now Strategy. Bringing these technologies to the market, at scale, backed up by investment, and driven by appropriate policy, would be critical to Reaching for the Goal.

Searching for lower-carbon resources

The second set of actions refers again to technology, but with the stress on resource availability. Imported hydro-energy from the Congo or East Africa could provide another major mitigation option, in the context of the Southern African Power Pool. This option was not included in the LTMS analysis, with its national focus, but has been analysed elsewhere (Winkler 2006a). In that analysis, imported hydro-electricity was a negative-cost option (with imports being cheaper than the cost of domestic power generation) and avoiding 167 Mt CO_2-eq over a shorter study period (2000–2025). The key challenge for implementation would be political and the resolution of security problems with imported hydro-electricity from our African neighbours.

Another resource identified for investigation was natural gas, which could be derived from coal-bed methane in the Kalahari and elsewhere. Significant gas found in the region would play a significant role in switching from coal. Gas imported from Mozambique already improves the efficiency of existing coal-to-liquids at Secunda. With sufficient amounts of gas, gas to liquids or combined cycle gas turbines might become a larger option.

Renewable energy resources could also be tapped on a greater scale. The potential for solar, wind and biomass was included in several modelled wedges, but other resources, such as wave and tidal energy, could in future become more viable options. This would depend on technological advances that concentrated the dispersed source of energy for human use.

People-oriented measures: Incentivised behaviour change

One of the most compelling results of LTMS is that, although most of the significant emissions reductions need to be within the energy sector, the technology- and resource-based actions, even when all carried out together, do not ‘close the gap’. Hence one must turn to the least studied of the possible options—social behaviour.

Changes in social behaviour, whether driven by policy, education, or awareness, may yet prove to have large-scale and low-cost mitigation effects. This may be so across a number of sectors.

- Human habitation, urban planning and the built environment are all areas where social change and new patterns, approaches and expectations will likely have significant mitigation effects.
- The distance between work, home and other life functions is also a factor.
- Modal shifts to public transport, moves away from individual car ownership towards the operation of shared vehicles, and other transport shifts deserve study. Business, commerce and consumption are currently heavily linked to the transport of people. Much of this could potentially be replaced by, for example, Internet-based interfaces.
- Food production and consumption, as well as the localisation of these activities, are also examples worthy of study.
- Population growth, but more importantly the growth of an urbanised population with high commodity expectations, could also be studied to see which changes may result in emissions reductions and how these might be driven.
- Tree planting and greening of towns is important.

Greater attention to the possibilities for inducing behavioural change is an important area for further work.

Transition to a low-carbon economy and society

A biggest contribution to Reach for the Goal might well involve a redefinition of our competitive advantage. Perhaps the most difficult, but also most fundamental approach to mitigation would be to change our economy away from its energy-intensive path. This would involve a transition to a low-carbon economy and society.

A transition to a low-carbon economy is consistent with the best available scientific information internationally. The IPCC's most recent assessment has made clear that other sectors need to change as well. Changing development paths is a major contribution to mitigating climate change (Sathaye et al. 2007). Climate policy alone will not solve the climate problem.

Energy-intensive industries have been at the heart of the South African economy (DME 2002). Mining is inherently energy-intensive. Many energy-intensive industries were established on the basis of low energy prices, although some—notably mining—are inherently energy-intensive. Our economy industrialised around these resources. Low electricity prices have been used to attract aluminium smelters, which import their feedstock from elsewhere, and export most of the final product.

The LTMS results suggest that energy efficiency and a cleaner fuel mix are significant mitigation actions, but in the long run the challenge is to consider the energy-intensity of our economy, structurally.

Over time, most economies shift from primary and secondary sectors to tertiary ones. South Africa's GDP has already shifted from mining through manufacturing to services. Associated with this shift is a decrease in energy intensity. Yet policy still tends to define competitive advantage around energy-intensive sectors.

Energy is included as one of the sectors in which the Department of Trade and Industry's NIPF identifies 'pockets of actual or potential technological leadership based on its historical industrial strengths' (DTI 2007b). But, in a carbon-constrained world, the kind of energy and the intensity of its use in the economy may need to change.

The results of individual wedges in this analysis suggest that taking action in individual sectors may not be enough. Energy efficiency and a cleaner fuel mix are significant mitigation actions. It seems that economies tend to shift from primary to tertiary sectors over time anyway, but this shift could be accelerated by industrial policy.

Climate change may mean that we need to redefine what we mean by competitive advantage. This could have several dimensions.

One dimension would be to focus on parts of the economy that are not as sensitive to energy price rises. Specific policies that can help to build a low-carbon society have been studied (LCS 2006; UNDP & GEF 2002). A transition to a low-carbon economy in South Africa might involve shifting incentives—removing incentives for attracting energy-intensive investments and using the resources to promote lower carbon industries.

Can a transition to a lower carbon society be integrated into broader industrial policy? Integrating climate change policy into broader policy will require rigorous engagement by and with sectors that currently spend little of their costs on energy. Instead of investing in energy-intensive sectors, which were at the heart of our economy over the twentieth century, South Africa would move towards a low-carbon economy. Industrial policy would favour those sectors that use less energy per unit of economic output. Such a change would have to be integrated into the DTI's National Industrial Policy Framework and Action Plan (DTI 2007a; 2007b).

Non-energy-intensive sectors would see little threat to their competitiveness—by definition, other factors make up most of their costs. Such industries could be encouraged to switch to low- or zero-carbon fuels and to invest more in energy efficiency. Shifts in industrial policy would need the support of significant institutions in the major-emitting industrial sectors.

A second prong of a low-carbon strategy would be to shift industrial development into new areas, particularly those creating employment and making use of local resources. Much as Brazil has become a world leader in biofuels, South Africa could deliberately seek to build new competitive advantage in climate-friendly technologies, such as solar thermal electricity. This could be built into the public expenditure programme (DTI 2007a). The aim would be to become a market leader, with government providing supporting measures.

Governments are often considered poor at choosing technology winners. So a programme of this nature might not pick a single technology, but spread public investment across a portfolio of zero-carbon technologies. That in itself would be a departure from current patterns of public spending, which have invested significantly more in nuclear power than renewables.

This issue may need an international perspective, asking the question where energy-intensive industries might best be located. It may take a crisis before the paradigm of economic policy shifts. Many of those involved in the climate debate see the issue as a major crisis. As more key decision-makers in the economy and broader society widely share a sense of a real crisis, a transition towards a lower carbon society might become possible.

A low-carbon economy will not emerge overnight. Changing the structure of the economy is a long term task, but then climate change is a long term problem. Another way of thinking about this is to consider changing development paths (Winkler & Marquard 2009)—but the question remains to what extent such paths are consciously chosen or the result of uncoordinated decisions. Certainly, a transition to a low-carbon economy will require a paradigm shift in industrial policy. It will require considered provision for sectors sensitive to changes in energy prices. Building up new, climate-friendly industries will be needed to sustain employment and investment. Cleaner energy will be needed to contribute to a cooler climate (Winkler 2009). To enable a just transition, provision will have to be made for emissions-intensive sectors, if they are to be phased out over time.

Economy-wide implications of strategic options

One of the key questions that the LTMS research sought to inform was what the implications of mitigation actions would be on the economy.[23] The analysis presented in this book so far has already provided answers to this question in various ways—consideration of the mitigation costs (in R / tCO_2-eq) for individual actions, the total costs expressed as a share of GDP or as a change in energy system costs, and by plotting costs against cumulative emission reductions on a mitigation cost curve (see Chapter 5).

These cost estimates are important, but are limited in two ways. First, some of the costs consider only the impact on particular sectors. In economic terms, the results from the MARKAL energy model, for example, would be considered a partial equilibrium, minimising costs within the energy sector but not across the whole economy. Second, the costs are all direct costs of taking the action. The indirect costs include up- and downstream effects and require economy-wide modelling.

Understanding economy-wide analysis

The economy-wide analyses for LTMS (Kearney 2008; Pauw 2007) were undertaken with a Computable General Equilibrium (CGE)[24] model for South Africa, calibrated to a snapshot picture of the South African economy as captured by a Social Accounting Matrix (SAM) for the year 2000.[25] The methodology for the economy-wide modelling was outlined in Chapter 2, page 38, **Economy-wide modelling**.

To understand the results, it is important to recall that the purpose of the analysis is to provide an indication of some of the short-term economic trade-offs or costs that should be considered by policy makers. The basic

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[23] This section of Chapter 6 draws primarily on the work by done by Pauw (2007) for LTMS using a comparative static, with a dynamic approach conducted subsequently by Kearney (2008). The results are also summarised in the LTMS Technical Summary (ERC 2007b), Technical Report (Winkler 2007), and the Technical Appendix (ERC 2007a), all of which are included in the CD-Rom accompanying this book. The original input reports by Pauw and Kearney provide the most detailed description for interested readers.

[24] The CGE model programme was developed by Scott McDonald from Oxford Brookes University, U.K.

[25] Compiled by the PROVIDE Project, Department of Agriculture (see www.elsenburg.com/provide).

hypothesis is that mitigation is costly in terms of short-term economic growth but allows sustainable development in the long term. Getting a handle on short-term costs is important in that a shock to one part of an economic system will have ripple effects which may or may not produce unintended consequences that are not obvious initially. Unintended consequences may create 'winners' and 'losers'. It should be important to policy makers to identify not only gains but also potential losses so as to devise appropriate policy to deal with them.

Given the complexity of such analysis, economy-wide modelling was applied in the LTMS research to the strategic options, not to individual wedges. The macro-economic factors of interest were impacts on economic output (GDP), employment levels and income distribution.

Applying the analysis of LTMS options

The economic impacts of each of the strategic options Start Now, Scale Up and Use the Market, were analysed in a comparative static setting against a benchmark that can be interpreted as growth without constraints or GWC (Pauw 2007). These results were later verified and extended using a dynamic CGE model (Kearney 2008). Results from the energy modelling (MARKAL model) were used as scenario input parameters.

For the Start Now and Scale Up scenarios, three sets of input parameters were extracted from MARKAL so as to investigate: **structural shifts** in the output mix of the electricity (coal-fired plants, nuclear power stations, renewable energy and gas turbines) and petroleum (crude oil refineries, CTL plants, GTL plants and biofuels) sectors; **energy efficiency** enhancements in various mining, industrial and commercial sectors (this affects the energy intensity of production, in particular the amount of coal and electricity used for a given level of output); and **investments** (capital outlay) required under each mitigation action relative to GWC investment levels.

The results from the economy-wide modelling were treated as follows in the economy-wide modelling framework:

- **Structural shift** involves a move towards alternative energy supply processes in the electricity and petroleum industries such as biofuels and nuclear power. Thus, output in one energy supply process is increased at the expense of another. For electricity this could be switching from coal-fired plants to nuclear and renewables. These two electricity generation processes have very different skill compositions and labour intensities. Renewables are assumed to be relatively labour-intensive compared to coal-fired and nuclear plants (AGAMA 2003). Nuclear, on the other hand, is highly skill-intensive and has a low labour intensity when compared to other electricity generation processes.

- **Energy efficiency** lowers input prices for downstream energy users but reduces output by energy suppliers. Hence there are opposing impacts to be considered. Energy efficiency gains generally have positive economic effects due to their associated production price decreases. However, these gains may be offset by increased use of other energy sources due to fuel switching (for example, electricity in transport). Both energy efficiency and fuel switching are considered as part of this study, so the outcome depends on the degree to which these two processes cancel each other out in terms of economic effects.
- **Investments** (capital outlay) offer a short-term demand stimulus associated with the installation of an energy-efficient production process. However, the final outcome depends on how the investment is financed and to what degree investment goods are imported. When investments increase, additional financing has to be raised. The model adjustment selected for this study assumes that this is achieved through increasing household and enterprise savings rates. Thus, households' disposable incomes decline, which reduces final demand, while the increase in investments increases final demand. Compositional effects arise due to the fact that the structure of household demand is different from that of investment demand in terms of the types of commodity consumed.
- **Carbon dioxide emission tax** is modelled here not directly as a tax on CO_2, but indirectly as a tax on the prices of coal, crude oil and natural gas of a given emissions tax level. If a carbon dioxide emissions tax is levied on electricity generation processes, it then becomes economically sensible for electricity producers to alter production processes by installing additional capital. The increase in the implicit tax of coal will cause electricity generation in coal-fired plants to become more expensive. One can also expect a switch from coal to nuclear power and renewable energy for electricity generations. The tax similarly affects coal for synfuels and, albeit to a limited extent, induces changes in energy demand, e.g. some fuel switching to gas in industry. The extent of the distorted economic effect depends critically on how tax revenues are employed by the government. A number of options can be explored from food subsidies to direct or

indirect tax relief and emission mitigation subsidies, which will all offset the initial negative impact of the tax to varying degrees.

These simulations were then applied to the LTMS strategic options. For the purposes of the economy-wide analysis, the three modelled strategic options were interpreted as follows.

- **Start Now** sees net-negative-cost wedges, especially energy efficiency, implemented particularly in industry (but also in commercial and residential buildings). There is a relatively moderate shift towards renewables, for instance electricity supply from coal declines to 46%, with nuclear and renewables each contributing around 27% in 2050.[26] There are also changes in transport to more efficient vehicles and shifting to public transport.
- **Scale Up**: Mitigation is extended, adding more efficiency and further positive-cost wedges. There is a transition to zero-carbon electricity by mid-century. Various options are extended, including carbon capture and storage, extending biofuels as far as possible, and introducing electric vehicles.
- **Use the Market** comprises economic instruments—both taxes and incentives. The key driver is a carbon dioxide tax, starting at current carbon prices and escalating (R250 / tCO_2 to R750).[27] Note that the CGE modelling does not include the incentives that are included in the energy modelling, namely for solar water heaters (SWH), biofuels and a feed-in tariff for renewable electricity introduced. Efficiency allows (limited) response on energy demand side, together with some fuel switching to gas. Tax quickly reduces coal in electricity and synfuel sectors.

Complementary to the Use the Market scenario we also include a stand-alone analysis of the impact of carbon dioxide emissions taxes, ranging from R25 to R1 000 per ton, on the economy. As such, this economic impact assessment is not linked to the MARKAL model in the same way as the Start Now and Scale Up scenarios, but adds to the MARKAL analysis in that it links the productive sectors to other agents in the economy,

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[26] These are the shares defined in the energy modelling, for 2050. In 2015, the time-frame for the economic impacts analysis, the shares of renewables have increased to 8% (from various technologies) and nuclear 5% (PBMR and PWR combined).

[27] Note that the final level of the carbon tax—after discussion in the Scenario Building Team—is lower. In the period of reporting economy-wide results, it ranges between R100 and R250 / tCO_2. In the overall study, it starts in 2008 at R100 / tCO_2, rises to R250 initially, then stabilises and only reaches R750 in the last decade (2040–2050).

particularly workers, households and government, and allows a more comprehensive analysis of the economy-wide impact of such measures.

Fundamental to the mitigation actions discussed here is the substitution of carbon-based production processes for more environmentally friendly ones. The CGE model allows for such substitution between output from coal-fired electricity plants, renewables and nuclear in the electricity sector, as well as between the output from crude oil refineries, CTL, GTL and biofuels in the petroleum sector. The ease with which switching can take place affects the model results in that the higher substitutability allows for lower price effect, and the less disruptive the outcomes. In these results we report on simulations that assume a moderate degree of substitution. This causes energy prices to rise, especially in the latter periods when substitution away from carbon-based processed is 'pushed hard' and longer. If we were to assume perfect substitutability, for example, prices would not have risen as much, if at all. The approach, although more conservative, is considered more appropriate given the general consensus that mitigation actions will probably lead to rising energy prices. A lower substitutability also reflects the fact that commodities produced using different processes are ultimately not homogeneous, and that some adjustment costs will have to be borne by the economy.

Results for LTMS strategic options

The results from the economy-wide analysis for each of the three modelled LTMS strategic options are summarised in the following description of results, as well as in tabular form (Table 6.1, page 181).

'Start Now' and 'Scale Up'

Under the Start Now scenario **GDP** remains at very similar levels to that of the base case in the initial period (2005–2015) buoyed somewhat by the positive effects of lower prices as a result of increased energy efficiency. Start Now increases GDP by 0.2% in 2015. The Scale Up scenario initially starts off with a higher GDP level (1% in 2015) than the Start Now scenario, mainly due to the higher investments associated with the former. This outcome, however, is sensitive to the way in which investment and its financing are treated, and therefore does not offer significant changes. It can also be expected to change if substitutions were pushed further and beyond their reasonable limits, which causes energy prices to rise sharply. For example, although the electricity price is marginally lower than under the reference case level by 2015, it starts to rise sharply thereafter due to the substitution away from coal-fired plants. The implications of higher degrees of substitutability might be examined in future work in a dynamic framework.

As far as **the labour market** is concerned, we make the simplistic assumption (but consistent with stylised facts) that there is excess capacity (unemployment) among semi- and unskilled workers (low-skilled), hence their employment levels are flexible and wages are fixed. Skilled and high-skilled workers, on the other hand, are fully employed at flexible wages, reflecting a skills constraint in the South African economy. The main report shows the employment and wage effects for these two groups of workers respectively.

Under the Start now scenario, employment effects are small and ambivalent—they are positive for unskilled (1%), skilled (1.2%) and highly-skilled (1.7%) workers in 2015, but negative for semi-skilled (-2% in 2015; and -2.5% in 2010). While the decline is not large, *any* job loss is of concern and would have to be offset by other measures.

An extensive literature in energy research demonstrates job gains from energy efficiency (Biewald et al. 1995; DME 2004; Geller, DeCicco & Laitner 1992; Jochem 2000; Laitner 2001).[28] Although this is due to direct employment in such programmes, it is, however, mostly due to the savings on energy expenditure. This is a finding across different energy economies. Given the results above, the negative results for semi-skilled workers require further investigation.

Under the Scale Up scenario, low-skilled employment is above the reference case in the initial period, with semi-skilled employment peaking at 3% by 2015. Wage changes under the Start Now and Scale Up scenarios are very similar for skilled and high-skilled workers within the period up to 2015. Generally the trajectory of employment/wage changes relative to the reference case is similar for low-skilled and high-skilled workers, and also reflects the similar trends in GDP.

Welfare is evaluated at the household level using an index that takes into account changes in disposable income (after tax and savings have been deducted) as well as movements in household-specific price indices. The difference between the Start Now and Scale Up scenario is the investment required to implement mitigation actions. In the standard set-up we assume that households' savings will decline when, as happens under

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[28] The study by Laitner et al. (2001) cites much of the early work. See also http://www.aceee.org/pubs/ed922.htm.

the Start Now scenario, required investment levels decline. Given higher savings rates, high-income households benefit the most from a reduction in required savings rates as this will boost their disposable income and significantly more so than any of the other household groups. In contrast, high-income households experience the largest welfare declines in the Scale Up scenarios for exactly the same reason as they gained the most before. The negative welfare effects under this scenario are generally small for other household groups, at least up to 2015.

In the dynamic CGE modelling (Kearney 2008), the results of the comparative static approach were mostly confirmed. Taking into account the changes in investment for the next period does lead to some minor differences in results. For Start Now, the GDP impacts were negative over the period, but only just—less than $\frac{1}{10}^{\text{th}}$ of a per cent. Earlier on, the investments in efficiency are still counted, while savings continue later. If industries become more energy efficient, less upfront investment is needed. In that sense the result is plausible, but in general energy efficiency is good for consumers and the economy at large. The pattern of socio-economic impacts is confirmed—decreases in semi-skilled jobs, particularly for lower-skilled households, are a concern; although other household types benefit from increased employment. In terms of welfare, most households are better off due to lower energy prices.

The Scale Up strategic option has a high growth effect, averaged over the full period. The higher levels of investment in this option have good results over the period: GDP impact is even more positive (from 1 to 1.3%). The higher GDP is (at least in part) due to the increased investment requirement for the mitigation case. The option has positive impacts on jobs, either 1% according to the static analysis, or very small, but still positive, according to the dynamic analysis. Welfare improves for low-income groups, with the only negative a decline in welfare among richer households, which derive most income from capital, not wages in the increased investment. Again, the welfare results are confirmed by the dynamic modelling.

Use the Market

The Use the Market scenario takes a very different angle from the Start Now and Scale Up scenarios as far as energy efficiency is concerned. The focus in this scenario is much more on economic instruments (taxes and incentives), which not only affect the energy supply side but also induce greater efficiency and fuel-switching on the energy demand. According to the MARKAL model, electricity use in mining, manufacturing and commerce does not decline as much as in the other scenarios, while the use of electrified transport is increased even more than in the Scale Up scenario. As far as investment is concerned, the Use the Market scenario initially (by 2015) requires investment levels of up to 20% above the reference case investment levels. As with other options, the results are sensitive to assumptions and therefore a range of tax levels were explored (see Chapter 4, page 126, **Tax on carbon dioxide**). The carbon dioxide emissions taxes that form a core part of the Use the Market scenario are implemented as an incremental tax in the MARKAL model, ranging from about R250 per ton of emissions in 2008 and increasing to R750 by 2050.[29]

As one would expect, employment effects are negative, with **employment** levels of low-skilled workers and wage levels of high-skilled workers rising slightly for lower-skilled workers in Use the Market (+3% semi-skilled, 0% for unskilled workers in 2015), but negative for higher-skilled workers (-2% for skilled and -4% for highly skilled).

Welfare declines are experienced by all households, although poorer households escape the worst effects up to 2015. The production subsidies do little to alleviate this worsening inequality, which suggests that some alternative form of support for low-income households should perhaps be considered rather than the subsidisation of production processes that are, from a purely economic point of view, less efficient.

Due to the offsetting impacts, the net impact of the mitigation scenarios on GDP is relatively small, particularly in the shorter time-frame (up to 2015) considered in the economy-wide modelling. The scenarios do not make heroic assumptions about technological change in the far-away future, which could alter the outcomes favourably as energy prices may not rise as much as is postulated here. Carbon dioxide taxes on their own generate negative economic outcomes. However, when the proceeds are used to offer food subsidies, the net impact is positive as long as the tax is lower. These results are more or less in line with those found elsewhere. However, when tax relief is offered, the threshold for a net-positive impact is much lower and if the proceeds are used for a production subsidy the impact is always negative. Finally, the modelling exercise does not evaluate whether society is better off with reduced emissions or not; all we have achieved is to put an economic price tag on it.

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[29] See footnote 27 on revised tax levels.

The CGE model is well suited to evaluating the impact of emissions taxes. For this particular LTMS strategic option, the economy-wide modelling approach was therefore applied using the CGE methodology directly as well. This differs from the other options (and the results above), where results from energy modelling are an input to CGE modelling.

As a proxy for an actual carbon dioxide tax, these simulations were modelled as an equivalent tax on the use of coal, crude oil and gas in production. An increase in the cost of these intermediate input goods acts as an incentive to producers to switch to alternative production processes. As before, the ease with which industries can switch from, say, coal-fired electricity plants to renewables, as well as the production costs of alternative processes, will affect the extent to which energy prices increase as a result of such switching. We assume a moderate degree of substitutability and find that, in response to a carbon dioxide emissions tax, **energy prices** rise significantly.

The effects of a rapid decline in the coal sector and sharply rising energy prices, driven initially by a high carbon dioxide tax, cause GDP to decline significantly, even in the shorter time-period considered in the economy-wide modelling—that is, up to 2015. GDP declines by 2% in 2015. Earlier runs of the model in longer time-frames did not find a feasible solution beyond 2030, which indicates that the suggested carbon dioxide emission tax is too high and/or the time-frame too long. Consistently with other applications for South Africa, we conclude that lower tax rates are more realistic. In a range of R25 to R75, it appears possible to offset negative economic effects through complementary policies.[30] However, the break-point in economic effects appears to occur between R100 to R200, for example in relation to Stern's 1% of GDP benchmark. Table 6.38 in the LTMS Technical Appendix (ERC 2007a) shows that employment changes (assumed food-price recycling) stay positive up to R100 for semi-skilled and R200 for unskilled workers. At R100, wage changes are still slight (and ambiguous in sign).

In the range of R25 to R200, it may be possible to offset the negative impact of introducing taxes by means of recycling the additional government revenues. Various options are considered including a renewables and nuclear subsidy, a biofuels subsidy, a food subsidy, a general VAT subsidy, an income tax subsidy and a general increase in welfare transfers. Of all the alternative revenue recycling options, the food

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[30] See the main report, and also Van Heerden et al. (2006).

subsidy appears to be the best option, while the two production subsidies yield the worst results. At low levels of taxation, the food subsidy may actually cause GDP to increase marginally.

Production subsidies should not be dismissed because they fail to reduce the negative impact of a carbon dioxide tax on GDP. If the aim is to mitigate the rise in energy prices they can be very successful.

Overall, policy-makers may wish to consider a range of carbon dioxide taxes between R25 and R200 / ton of carbon dioxide. This can be thought of not simply as a present-day range, but at a rising carbon price over time. Present values for CDM projects are that SA can expect Euro 6 to 10 / tCO_2—that is, R60 to R100 / ton, and in European emissions trading, prices are higher. Hence assuming R200 / t in future is not a big leap—although of course a tax level is a different 'price' to a CDM credit.

For Use the Market, the accounting for investment in the dynamic economy-wide modelling approach (Kearney 2008) made a major difference. Impact on GDP is mildly positive (0.73%) instead of the previous -2%. The earlier result was due to large increases in energy prices which seriously hurt the economy. In the dynamic analysis, these price increases are now overshadowed by higher investments. The impact on jobs is shown to be very small, but positive, in the dynamic analysis whereas in the static modelling, an increase in jobs for low-skilled workers had its counterpoint in a decrease for skilled workers. Income from employment increases for all household groups. The differences in welfare effects are marginal in the static analysis but, taking into account dynamic effects, all households are better off. For low-income households, the reinvestment of revenues is important to ensure their welfare does not suffer. Various options (food subsidies, reducing the VAT rate, general welfare transfers) for recycling revenue have been examined in both economy-wide studies.

Summary of economy-wide modelling results

A summary of the economy-wide results is shown in Table 6.1.

Table 6.1: Condensed summary of results of economy-wide modelling

	Structural Shift	*Efficiency*	*Investment*	*Impact on GDP*	*Employment / job impact*	*Poverty / welfare*
	Description of inputs to economic model			Results		
Start Now	Moderate shift towards renewables; e.g. electricity supply from coal declines to 46%, with nuclear and renewables each contributing around 27% in 2050 (9% renewables and 5% nuclear by 2015). Also: changes in transport to more efficient vehicles and shifting to public transport.	Net-negative cost wedges, esp energy efficiency, implemented esp in industry.	Relatively little additional investment required, few positive cost mitigation options added.	Small / negligible (+0.2% GDP in 2015).	Small and ambivalent — positive for unskilled (1%), skilled (1.2%) and highly-skilled (1.7%) in 2015, but negative for semi-skilled (-2% in 2015, -2.5% in 2010) — which is of concern. Only short-term costs of mitigation are considered and not the longer term productivity gains.	Household welfare increases relative to reference case for all household groups. High income HH benefit as high-skilled labour gains and low-skilled labour loses. Savings reduce investment requirements; also avoid negative consumption effects of higher savings.

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	Structural Shift	*Efficiency*	*Investment*	*Impact on GDP*	*Employment / job impact*	*Poverty / welfare*
	Description of inputs to economic model			Results		
Scale Up	Transition to zero-carbon electricity by mid-century. Significant shift towards renewables and nuclear; e.g. output share of coal-fired electricity plants declining to 2%. Add carbon capture and storage, extend biofuels as far as possible, introduce electric vehicles.	Mitigation extended, adding more efficiency and further positive cost wedges.	Significant investment required, between 5 and 10% above the reference case.	Initially higher (+1% in 2015)	Increase: +1% in 2015 Semi-skilled jobs peak at 3% in 2015	Generally negative with positive impacts for low skill labour if biofuels is pushed hard. High income HH lose (opposite of above).
Use the Market — comparative static approach	Uses economic instruments. Key driver is a CO_2 tax, starting at current carbon prices and escalating. Tax quickly reduces coal in electricity and synfuel sectors and shifts in fuel and towards efficiency. [Incentives included in energy modelling for SWH, biofuels and renewable electricity not assessed in CGE modelling]	Driven by tax, but efficiency allows (limited) response on energy demand side. Plus fuel switching to gas.	High investment required initially, 20% above reference case.	Negative (-2% in 2015) as taxes result in energy price increases unless countered by fiscal policies. Recycling revenue can off-set economic impact at lower tax levels.	Jobs *increase* for lower-skilled (+3% semi-skilled, 0% for unskilled in 2015). *Decrease* for higher-skilled workers (-2% for skilled and -4% for highly skilled).	Negative for all households, except poorer households which gain initially from food subsidy; impact depends on fiscal options, low income households can be targeted directly.

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	Structural Shift	*Efficiency*	*Investment*	*Impact on GDP*	*Employment / job impact*	*Poverty / welfare*
	Description of inputs to economic model			Results		
Use the Market — dynamic CGE approach	As above, but allowing for capital stock to be updated in the model.			Mildly positive or 1.4% over 2011–2019 (mid-year 2015, to compare to static results) as increased investment in previous periods enhances the productive capacity of the economy in the next; (+0.8% of GDP as an annual average).	Jobs changes show marginal increases for all skills categories (2011–2019); very close to 0% for annual average over the full period, 2003–2050.	All households better off; high-income households benefit only slightly more than others.

Table 6.2: Broad characteristics and results of underlying scenarios, as used in economy-wide modelling

Component	*Broad modelling approach*	*Broad impact*
Energy-efficiency gains	Energy efficiency in an economic sector is modelled as a reduction in demand for primary or transformed energy sources per unit of output. The analysis considers mining and industrial energy efficiency, commercial energy efficiency and energy efficiency in the freight and passenger transport sectors.	Generally there are small but positive overall production effects in the economy. Output and employment losses in the coal mining and electricity generation sectors are generally offset by gains in other sectors that benefit from lower production costs, resulting in unambiguously positive but small employment effects.
Structural change	In these scenarios the economic implications of a relative shift in energy supply away from carbon-based or emissions-intensive production processes towards cleaner, more environmentally friendly production processes are investigated. Three main mitigation scenarios are considered, namely a renewables-intensive and a nuclear-intensive scenario for electricity generation, and a biofuels scenario for liquid fuel supply.	Compositional impacts differ across the three scenarios. Driven by import content, skill content and linkages to the rest of the economy of new and phased-out energy supply. Nuclear: economic output (GDP) effects are small but employment impacts negative due to higher labour productivity. Renewables: economic output effects are largely negative due to price increases; employment effects are positive, particularly for lower-skilled workers. Biofuels: small but negative due to low share of biofuels. Output—employment ratios and skills intensities in nuclear power plants are different from those of other electricity generation processes. Hence we expect to see some relative shifts in employment levels and/or skills distributions.

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Component	*Broad modelling approach*	*Broad impact*
Carbon taxes	Taxes are assumed to be distortionary since they cause a reallocation of resources away from efficient (albeit dirty) allocation. In a CGE model of this class welfare losses arising from taxes can be expected. However, depending on how revenue from taxes is used, some of these welfare losses may be mitigated. The aim of carbon taxes is to reduce emissions by incentivising producers to switch away from processes associated with high levels of emissions. The economic welfare losses of rising energy prices therefore have to be weighed against the social welfare gains of reduced emissions. These social welfare gains are not measured in standard CGE models; what we are concerned about here are only the short-term economic costs.	Taxation induces switching away from CTL and coal-fired electricity plants. Although switching comes with a cost in terms of GDP, increasing tax levels act as incentives to switch further away from coal-based processes, which is a desirable outcome from a mitigation point of view. The dynamic modelling approach, which takes into account increased capital stock from investment in the previous period, suggests that the negative effects may not be as large as suggested in the comparative-static analysis. This requires further comparison and analysis. We compare the GDP effects under a variety of fiscal options including a renewables and nuclear subsidy, a biofuels subsidy, a food subsidy, a general VAT subsidy, an income tax subsidy and a general increase in welfare transfers. Impacts remain negative, in particular with the suggested carbon tax rates. At low levels of taxation the food subsidy may however cause GDP to increase marginally. Production subsidies should not be summarily dismissed because they fail to reduce the negative impact of a CO_2 tax on GDP. If the aim is to mitigate the rise in energy prices, they can be very successful. However, ultimately, because GDP declines more when a production subsidy is introduced, this suggests that the subsidisation of a less efficient production process is not a long term economically viable option on its own. The food subsidy benefits low-income households most; hence the ability to fiscal target is important. At levels beyond R200 per ton of CO_2, and despite using the most efficient of the revenue recycling options available, there will be negative economic impact on economic output.

Economy-wide results for sector-specific interventions

The economy-wide analysis (Pauw 2007) provided additional information on particular interventions, some of which are specific to sectors. The long-run economic effects of energy efficiency in productive sectors, and changes in the energy supply fuel mix, are examined here. Again, the results parameters of interest are economic output, jobs and income distribution, for efficiency wedges and changes in the structure of electricity or liquid fuel supply. Table 6.2 summarises the results described here.

Industrial energy efficiency is assessed in terms of saving both electricity and heat. Electrical efficiency can increase the wages of skilled workers by 0.5% and 0.7%, while employment among abundant low-skilled workers rises by 0.5%. For thermal savings, skilled wages increase by 0.5% and 1.1%, and low-skilled employment increases by 0.3% and 0.8% in the two periods.

While the small change in employment means that there are no major income distribution effects, some positive welfare effects are reported. Aggregate household expenditure levels increase across all representative household groups in the model. GDP increases only marginally by 0.4 and 0.5% in 2020 when electricity is saved, and up to 0.9% when other fuels are saved.

The commercial sector predominantly uses electricity and hence the focus is on electrical efficiency. Because energy makes up less of the input costs (commerce is less energy-intensive), changes in skilled wages, low-skilled employment and household expenditure levels (welfare) are all smaller than in industry, but nonetheless positive (around 0.1 and 0.2%).

Overall, energy efficiency gains have small but positive overall production effects in the economy. Output and employment losses in the coal mining and electricity generation sectors are generally offset by gains in other sectors that benefit from lower production costs, resulting in unambiguously positive but small employment effects. Household welfare effects are also small but positive, with the distribution of gains depending on the type of energy efficiency modelled. Distributional effects are too small to raise great concern about the socio-economic implications.

The economy-wide analysis also considered structural changes in the energy output mix. For electricity supply, the fuel mixes of the renewables and nuclear 'ordinary wedges' are examined in the economic model. For liquid fuels, biofuels are considered.

A shift to nuclear power causes an increase in high-skilled employment at the expense of a relatively large number of low-skilled jobs. The overall employment level in the economy declines marginally as a result. Even small job losses are of concern. The renewables intensive process, which is characterised by a higher labour intensity than any of the other electricity generation processes,[31] results in employment gains relative to the reference case. Further details on the effects of individual wedges are described in the full report (in particular, see section 13.4.2.3 of the Appendices to the Technical Report).

The overall changes in employment are small in relative terms, ranging between -0.2% and +0.2% change from the economic reference case. Where there are job losses, they would need to be offset. Household income changes are also small and almost negligible. Given the importance of fighting unemployment, however, any changes in absolute job numbers deserve attention.

In the biofuels alternative a slightly greater reliance on biofuels is modelled, but—given the small overall contribution of biofuels—even a large increase in biofuels output does little to alter trends in production and employment. A visible effect under the biofuels scenario is a slightly higher increase in agricultural output relative to the reference case. This comes at the expense of coal mining output. A biofuels scenario, as modelled here, is unlikely to have any significant economy-wide welfare implications.

Conclusions on the economy-wide analysis

The economy-wide analysis shows that mitigation action has implications beyond the direct costs. It particularly focuses on narrower views of the economy—implications for GDP—but also on broader socio-economic factors—that is, job creation at various skills levels and income distribution. South Africa should consider the broader implications of action on mitigation carefully, given the national priorities on development and poverty eradication.

The modelling shows that the Start Now option has a relatively small impact on the economy, at least in the shorter period considered robust for economy-wide results. This can be offset somewhat by the positive effects of increased energy efficiency. While the impact on jobs is negative, this again is of a small magnitude and within the margin of error of the analysis. Nevertheless even small job losses are of concern, and would need offsetting measures, particularly for semi-skilled workers. At the

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[31] For a more detailed discussion of this point, including references, see the full report on economy-wide impacts in the Appendices to the Technical Report.

same time, household welfare rises on average by a non-trivial degree. The effects are not the same for all household types, since the greatest effect is to draw on household savings to finance new investment, which mostly comes from more affluent households. The Start Now strategy requires less saving, so high-income households benefit the most. One could call this an unintended consequence.

The Scale Up strategic option shows a modest positive impact on GDP initially. Employment broadly follows the GDP increase in 2015. The employment of low- and semi-skilled workers increases. However, there is a negative impact on household welfare on average, with differentiation—slightly positive for low-income households but significantly negative for high-income households. Since greater investment is required in the Scale Up option, this again has to come from high-income households. The negative welfare effects under this scenario are generally small for other household groups, at least until 2015. An interesting result is that Scale Up mitigation has a better distributional profile than the more modest efforts in Start Now.

It is also worth recalling that the overall mitigation costs of Scale Up are equivalent to 0.8% of GDP. This share of GDP is well below the benchmark suggested by the Stern Review on the economics of climate change. The Stern Review suggested that 1% might be acceptable, and that the costs of inaction would likely be much higher, at 5% to 20% of GDP. These are global figures, and developing countries may deem 1% of GDP too high an opportunity cost.

The strategic option of Use the Market includes taxes and incentives. Economic models see taxes as a distortion away from equilibrium. Hence the impact on GDP is unsurprisingly negative. This finding is important, particularly from the comparative-static CGE modelling, which finds a negative impact on GDP. However, it is equally important to note that a dynamic CGE modelling approach found a modest increase in GDP, as investments in prior periods build up productive capacity. The complex interactions between energy and economic models, including both static and dynamic varieties, are a critical area of future research.

Jobs increased in the comparative static analysis for lower-skilled workers, have no change for unskilled workers, but decrease the higher the skills level. In the dynamic model, the employment effects are very small, and close to zero over the full period up to 2050.

Welfare effects in the static analysis are negative overall, except for poorer households for whom they are neutral. Taking into account dynamic effects, all households are better off. For low-income households, the reinvestment of revenues is important to ensure their welfare does not suffer.

Another important finding of the LTMS process was that revenue recycling is critical to a full understanding the economic impacts of the Use the Market option. This finding has been reported in the literature (Sanstad & Wolff 2000; Van Heerden et al. 2006) and was confirmed by the analysis for LTMS (Kearney 2008; Pauw 2007; Winkler 2007). At least at lower tax levels, spending revenue elsewhere could offset some of the negative impact on economic output. Given that the carbon tax is the biggest single wedge modelled, policy designs that have the potential to yield triple dividends (growing the economy, creating jobs and improving income distribution) merit further analysis and consideration by decision-makers.

The LTMS strategic option of Use the Market included both taxes and subsidies. The potential to balance the financing required for subsidies within this case with tax revenues on the one hand, could be used to incentivise more mitigation. For example, in Use the Market, much greater use of solar water heaters is incentivised. Instead of setting a target for renewables (as in the other two options), the cost gap is closed by 38c / kWh for renewable electricity. Tax revenues from Use the Market, discounted over the period at 10%, amount to R553 billion. To put this into context, Eskom's investment programme over the next years is likely to require R343 billion. Some tax revenues could be used to offset potential negative impacts on the poor, notably in the form of insulating them from higher energy prices (e.g. through an extension of the poverty tariff). From a tax policy perspective, it would be attractive to consider a set of measures that together remain revenue-neutral.

Chapter Seven

Sensitivity analysis

In scenario analysis, it is helpful to consider the sensitivity of results to critical parameters. The LTMS results for mitigation actions, their costs and other parameters are sensitive to the assumptions made, as in any modelling. The assumptions, data and methodology used in the LTMS research are reported in detail in Chapter 2. In the LTMS, sensitivity analysis was undertaken for the discount rate, assumptions about GDP and future energy prices.

Sensitivity to energy prices

Future energy prices were an important set of parameters on which sensitivity analysis was conducted. The LTMS team modelled the sensitivity of key results to different assumed future prices for oil, gas and other petroleum product; as well as coal and nuclear prices. The future price of crude oil was modelled at two different price levels:

- First, starting from \$55 / bbl rising in 2003 to \$100 / bbl in 2030 and extrapolated at the same rate beyond.
- Second, from \$55 / bbl rising in 2003 to \$150 / bbl in 2030 and extrapolated at the same rate beyond.

The ratios of increase in oil prices were then used to make an equivalent adjustment to import prices for other liquid fuels, as well as local and import prices for natural gas. This was run together with the oil prices—that is, one sensitivity on crude oil, all imported petroleum products and natural gas.

The coal price sensitivity increased coal prices at the ratio of the *first* oil price sensitivity. Nuclear fuel was treated similarly.

Price changes were modelled in each instance for four cases: Growth Without Restraints (GWC), and the three main strategic options, Start Now, Scale Up and Use the Market. The four price changes above were modelled. Significant impacts resulted from oil and coal price changes, but there were no significant impacts from the change in price of nuclear fuel. The impact on GWC was minimal in terms of emissions, with the exception of coal—an increased coal price resulted in a total emissions reduction of around 1 400 Mt, mainly resulting from the non-construction of synfuels plants—very little new capacity is built. The major impact however is on total system costs, as reflected in Table 7.1.

Table 7.1: Sensitivity of total mitigation costs to future energy prices

	% increase in total system costs	*Increase as a % of GDP*
Coal price increase	6%	1.2%
Crude price increase 1	15%	3%
Crude price increase 2	31%	6%
Nuclear fuel price increase	0.1%	0.0%

The most notable impact results from a significant oil price increase, which reflects probable prices in an oil-scarce world such as a post-peak oil world. These increases in system costs dwarf the costs of even very costly mitigation options. As a result, with increased prices for primary energy commodities, mitigation costs *decrease*, since both energy efficiency and alternative energy options avoid the consumption of fossil fuels. An exception to this is nuclear fuel—an increase in nuclear fuel prices makes little difference to emissions or costs.

These figures, in the three tables below, are derived by comparing each of the three strategies to new baselines with the higher energy prices. The first table compares the cost-effectiveness of strategies 1 to 3 with their cost-effectiveness in each of the price increase cases (coal, crude 1 and 2, and nuclear fuel).

Table 7.2: Sensitivity of mitigation cost per ton to future energy prices, R / tCO_2-eq

	GWC reference case	*Increased coal price*	*Crude price increase to $100*	*Crude price increase to $150*	*Increase in nuclear fuel price*
Start Now	-36	-46	-63	-93	-35
Scale Up	19	12	-15	-54	19
Use the Market	17	6	0.6	-19	19

The impact of price changes on cost-effectiveness is shown in Figure 7.1.

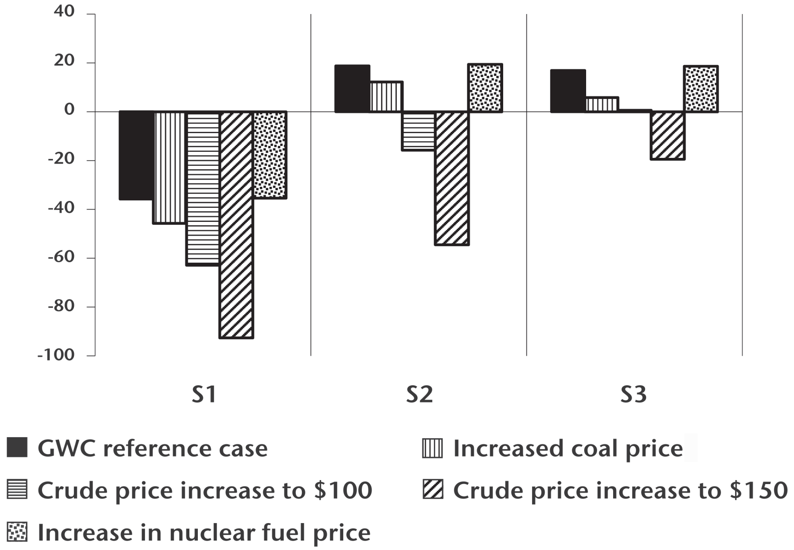

Figure 7.1: Impact of price on cost-effectiveness

Aside from the slight differences in the nuclear case (due to a slight shift from nuclear power), increased fuel prices reduce the cost of mitigation. The same trend is reflected in the change in percentage of GDP required by the energy system, whereby increased hydrocarbon prices result in a lower additional fraction of the GDP required by the energy system for mitigation. Again, the nuclear fuel case is an exception to this, involving a slight increase in Scale Up and Use the Market.

Table 7.3: Sensitivity of mitigation costs as share of GDP assuming different future energy prices

	GWC reference case	*Increased coal price*	*Crude price increase to $100*	*Crude price increase to $150*	*Increase in nuclear fuel price*
Start Now	-1.0%	-1.2%	-1.6%	-2.4%	-1.0%
Scale Up	0.3%	0.0%	-0.7%	-1.8%	0.3%
Use the Market	0.1%	-0.4%	-0.5%	-1.3%	0.2%

The impact of price changes on mitigation costs as a share of GDP is shown in Figure 7.2.

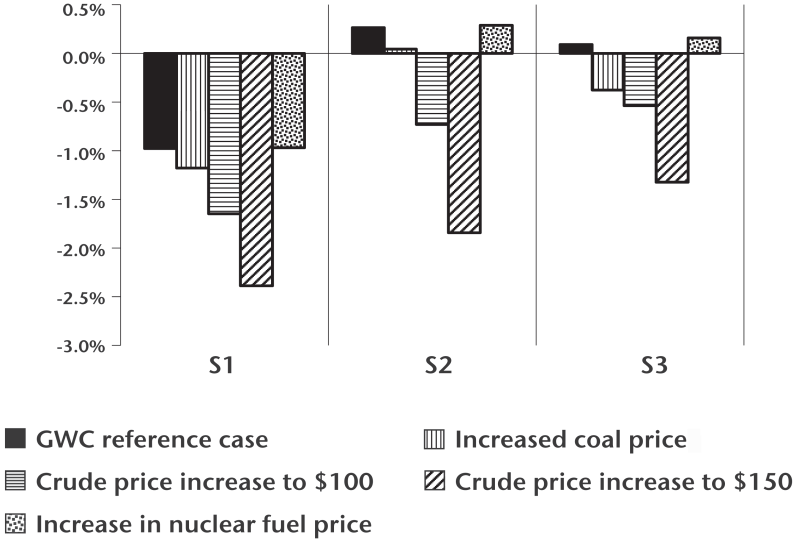

Figure 7.2: Impact of energy prices on mitigation costs as share of GDP

The resulting mitigation is slightly lower in the increased price cases, although these differences are slight—except for the increased coal price case—due to the lower use of synfuels in the new baseline, excluding this as a mitigation option.

Table 7.4: Sensitivity of mitigation relative to reference to future energy prices

	GWC reference case	*Increased coal price*	*Crude price increase to $100*	*Crude price increase to $150*	*Increase in nuclear fuel price*
Start Now	11 611	11 309	11 565	11 560	11 621
Scale Up	14 126	13 175	14 048	14 039	14 139
Use the Market	20 200	19 340	18 630	18 407	20 281

The reasons for these shifts are more evident by comparing emissions from the strategies directly with emissions from the high-price strategies, as detailed in Table 7.5.

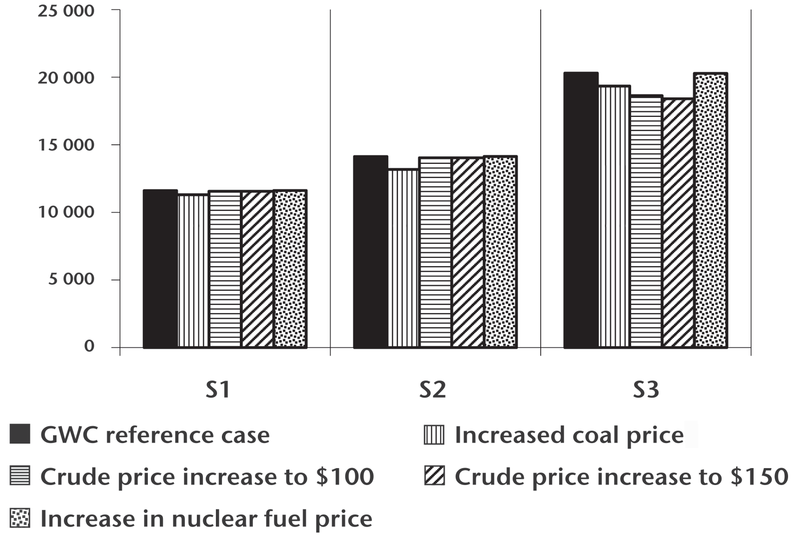

Figure 7.3: Impact of energy price changes on relative emission reductions

The main findings of the sensitivity analysis are summarised in Table 7.5.

Table 7.5: Summary of sensitivity to energy prices

Scenario	*Increased coal price*	*Crude price increase to $100*	*Crude price increase to $150*	*Increase in nuclear fuel price*
Start Now	Significantly less emissions from synfuels use (1 400 Mt), another 400 Mt saved due to shift away from coal for electricity generation.	Insignificant — slight shift away from natural gas and liquid fuels for electricity generation.	Insignificant — slight shift away from natural gas and liquid fuels for electricity generation.	Insignificant
Scale Up	More modest decline in coal use, some from electricity, and some from less synfuels—CO_2 reduction totalling 356 Mt.	Insignificant — slight shift away from natural gas and liquid fuels for electricity generation.	Insignificant — slight shift away from natural gas and liquid fuels for electricity generation.	Insignificant

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Scenario	*Increased coal price*	*Crude price increase to \$100*	*Crude price increase to \$150*	*Increase in nuclear fuel price*
Use the Market	Slight decline in synfuels emissions, big decline in industry coal use emissions as industry switches to gas (net 500 Mt less CO_2).	Significantly **more** CO_2 emissions (2.730 Mt), from increased use of synfuels and coal in industry (no switch to gas).	Even more CO_2 emissions (3 840 Mt) due to higher use of synfuels, increased coal use in industry.	Insignificant

The most significant factor is the impact of price shifts on synfuel use: increased coal prices exclude synfuels from the high coal price cases, but in cases where synfuel use is minimised (carbon tax), a high crude oil price *increases* the use of synfuels, thus raising emissions. The second significant impact of price changes was on the industrial use of gas—high coal prices cause an earlier shift to gas, causing a drop in emissions, whereas higher gas prices mean that gas is displaced by coal, leading to higher emissions. Again, higher nuclear fuel prices do not have a significant impact on emissions.

Table 7.6: Sensitivity of selected wedges to high coal prices

Numbers in brackets are with existing energy price assumptions, see text	*Mitigation cost (R / tCO_2-eq)*	*GHG emission reduction, Mt CO_2-eq, 2003–2050*	*% increase on GWC costs*	*Mitigation costs as share of GDP*
Cleaner coal	-11 (-5)	195 (167)	-0.02% (-0.01%)	-0.01% (0.00%)
Industrial efficiency	-46 (-34)	4 675 (4 572)	-1.70% (-1.24%)	-0.39% (-0.26%)
Subsidy for renewables	105 (125)	4 590 (3 887)	3.23% (3.65%)	0.73% (0.77%)
Nuclear, extended	7 (20)	3 186 (3 467)	0.17% (0.68%)	0.04% (0.15%)
Renewables, extended	72 (92)	3 698 (3 285)	2.10% (2.64%)	0.48% (0.56%)

Having seen the sensitivity of the strategic options to future energy prices, the LTMS research team conducted further analysis for Cleaner Coal, Industrial Efficiency, Subsidy for Renewables, and Extended Nuclear and

Renewables wedges at a higher coal price. Improved Vehicle Efficiency, Electric Vehicles in GWC Grid, Hybrids and Passenger Modal Shift wedges were run with the higher of the two oil prices. No variation on the uranium price was conducted since the above sensitivities showed little response—since most of the investment in nuclear power is in capital expenditure and not fuel costs. The results are contained in Table 7.6 and Table 7.7. The results with existing assumptions for energy prices are included in brackets in each cell for comparison.

Table 7.7: Sensitivity of selected wedges to high oil prices

Numbers in brackets are with existing energy price assumptions, see text	*Mitigation cost (R / tCO_2-eq)*	*GHG emission reduction, Mt CO_2-eq, 2003-2050*	*% increase on GWC costs*	*Mitigation costs as share of GDP (%)*
Improved vehicle efficiency	-720 (-269)	758 (758)	-3.86% (-1.90%)	-1.19% (-0.41%)
Electric vehicles in GWC grid	-997 (607)	471 (450)	-3.30% (2.27%)	-1.02% (0.48%)
Hybrids	1 244 (1 987)	371 (381)	2.56% (6.27%)	0.74% (0.52%)
Passenger modal shift	-1 907 (-1 131)	456 (469)	-5.86% (-4.89%)	-1.79% (-1.05%)

As with the sensitivity analysis above, the general trend is for mitigation costs to drop, due to the increased fuel costs in the higher priced GWC. The most startling result is for electric vehicles, which switch from quite a high positive cost to a large negative cost with a high crude oil price, due to avoided consumption of crude oil products. The impact on mitigation is more equivocal, with small fluctuations in both directions.

Sensitivity to GDP

The most influential driver of overall emissions in the modelling is GDP. For clarity, economic growth drives overall emissions, but for emissions *reductions* (i.e. mitigation) and its costs, other parameters may be equally or more important for the results.

Politically, the GDP growth rate was assumed to lie between 3% and 6% for the central results reported in this book (based on the consideration described in Chapter 2, page 41, **Gross domestic product**). Any percentage growth sustained over a long period of time becomes exponential. Projections of 4.5% to 6% GDP growth over long periods of time are probably not realistic—actually growth is never smoothly exponential.

The energy modelling team conducted initial sensitivity analysis with GDP at 3.9% (instead of peaking at 6% and then declining to 3% towards 2050). GDP growth and demand in the commercial, transport and industrial sector are linked with elasticities, therefore lowering the GDP growth lowers demand in these sectors. Demand in the residential sector is driven by population growth and therefore remains unchanged.

This sensitivity analysis shows large emission reductions (174 Mt CO_2-eq per year, or 8 332 Mt over the period)—in other words, larger than any of the other options examined here. At a 10% discount rate, this case showed a 'saving' of R227 / tCO_2-eq. This saving is due to reduced economic activity, which lessens energy demand and therefore requires less investment in the energy system overall. Over the period 2003 to 2050, the saving in the energy system from reduced economic activity would be lower by almost R40 billion.

If one keeps the structure of the energy economy fixed, energy demand remains closely linked to GDP growth. Any constant percentage growth over a long time is exponential, unless the emissions intensity of the economy changes.

Sensitivity to discount rate

The first sensitivity was to discount rate—three different discount rates were calculated offline for mitigation costs. The results reported in this book are for the central discount rate of 10%. Results for each wedge for discount rates of 3% (deemed appropriate for mitigation in the long term by the IPCC) and 15% (closer to a commercial discount rate), were integrated into the analysis. The results for the other two discount rates are included on the CD-Rom accompanying this book, and can also be found in the LTMS Technical Report (Winkler 2007). The results are summarised for all wedges in Table 7.8.

For most wedges, the lower discount rate shows a higher mitigation cost. Future benefits are not taken into account as much, while a significant part of the mitigation costs is upfront and therefore not discounted. In the case of residential energy efficiency, for example, the future savings are discounted more at 15% than at 3%. By corollary, higher discount rates in many—though not all—cases mean lower mitigation costs.

Table 7.8: Sensitivity of mitigation costs to discount rate

Mitigation action	*Mitigation cost (R / tCO_2-eq)*		
	3%	*10%*	*15%*
Combined energy cases			
Start Now	-R82	-R13	-R2
Scale Up	R90	R39	R20
Use the Market	R6	R10	R7
Current Development Plans	-R1 088	-R510	-R293
Individual Wedges			
CCS 2 Mt	R202	R67	R33
Cleaner coal	-R21	-R5	-R2
Commercial efficiency	-R494	-R203	-R113
Escalating CO_2 tax	R128	R42	R19
Subsidy for renewables	R331	R125	R63
Biofuel subsidy	R1 115	R697	R524
SWH subsidy	-R459	-R208	-R121
Industrial efficiency	-R97	-R34	-R17
Nuclear	R44	R18	R9
Nuclear and renewables	R172	R64	R33
Renewables	R100	R52	R30
Renewables with learning	-R38	-R143	R4
Residential efficiency	-R402	-R198	-R120
Improved vehicle efficiency	-R946	-R269	-R113
Hybrids	R6 009	R1 987	R927
Passenger modal shift	-R3 936	-R1 131	-R480
Electric vehicles in GWC grid	R1 838	R607	R289
Electric vehicles with nuclear, renewables	R290	R102	R50
Limit less eff vehicles	-R14 457	-R4 404	-R1 856
Biofuels	R1 019	R524	R346
CCS 20 Mt	R194	R72	R38
Nuclear, extended	R75	R20	R8
Nuclear and renewables, extended	R168	R52	R24
Renewables, extended	R296	R92	R42

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Mitigation action	*Mitigation cost (R / tCO_2-eq)*		
Renewables with learning, extended	R104	R3	R89
Agriculture: enteric fermentation	R73	R50	R37
Agriculture: manure management	-R32	-R19	-R12
Agriculture: reduced tillage	R27	R24	R20
Waste management	R17	R14	R12
Land use: fire control and savanna thickening	-R16	-R15	-R14
Land use: afforestation	R15	R39	R57
Coal mine methane reduction (50%)	R786	R346	R183
Synfuels CCS 2 Mt	R653	R476	R364
Synfuels CCS 23 Mt	R122	R105	R87
Synfuels methane reduction	R6	R8	R10
Aluminium	R0.15	R0.16	R0.18

Chapter Eight

Conclusion: The challenge ahead

The Long Term Mitigation Scenario (LTMS) process was a pioneering effort to generate evidence-based scenarios to inform national climate policy and international negotiating positions. The process was initiated by a Cabinet mandate in 2006 and reported back to Cabinet by mid-2008. On the basis of the technical research and facilitated stakeholder process undertaken in-between, a strategic direction and policy framework was adopted at the highest level. The decision that South Africa's emissions should peak, plateau and decline over the following decades was an unprecedented step for a developing country in the multilateral negotiations under the UN Framework Convention on Climate Change and its Kyoto Protocol.

The gap

The central challenge that emerged in the LTMS process is the gap between two scenarios—Growth without Constraints (GWC) and Required by Science (RBS). South Africa can either pursue a development path as if there were no carbon constraint, or seriously address the full implications of what the science of climate change—the physical basis, climate impacts and mitigation—is telling us.

The LTMS research left no doubt that the gap between the two scenarios is huge. Without constraints, we are likely to see greenhouse gas emissions quadruple by 2050. Such an approach would be unacceptable internationally and is a high-risk approach, not least due to damages of climate change if the world does not act. If all countries, including the major emitters in the developing world, adopted a Growth without Constraints approach, climate change impacts in South Africa would be extensive. It is also a high-risk approach on other grounds, such as rising oil prices, carbon constraints in trade, and advancing impacts. The LTMS Scenario Building Team was unanimous in finding that this was not an option that could be pursued. RBS is the only option—the question is no longer whether to aim at that goal, but how to get there.

The challenge of getting to RBS is massive. Chapter 6 of this book has outlined several strategic options aimed at bridging the gap between GWC and RBS. Three modelled strategic options illustrate how South Africa could go about closing the gap—but the most ambitious still leaves more to be done.

Next steps identified in the technical work

The good news is that strategic mitigation options can be implemented immediately. The 'no-brainer' options are included in the Start Now strategic option: energy efficiency, especially in industry; electricity supply options, including renewable energy and nuclear power; carbon capture and storage (CCS); transport efficiency and shifts; and people-oriented strategies, supported by awareness. These potential strategies show good emissions reduction results with costs to the economy ranging from affordable to significant. Furthermore, significant mitigation action can have net public benefits, such as reduced air pollution, savings in energy bills and increased employment. In terms of policy options, South Africa can choose both regulatory and economic instruments. New technologies, resources, behaviour and a low-carbon economy will be needed to completely close the gap between GWC and RBS.

The LTMS modelled three strategic options and emphasised that some new options would be needed to reach the goal of RBS. The many individual wedges could be combined in other combinations. Hence the Scenario Document focused on the major next steps. In essence, the LTMS identified four major areas—energy efficiency, electricity generation, transport and CCS—as the 'big hits' for mitigation, which would form the core of a broader portfolio. The team emphasised that some of the 'smaller' wedges were important in terms of balance of the overall portfolio and in terms of having significant socio-economic benefits. The focus on modelled options should also be understood together with the need to invest in research and development, parallel with implementing existing options as soon as possible.

The 'next steps' identified in the LTMS are worth citing in detail.

Energy efficiency is a component of all the strategic options in the Required by Science scenario. Energy efficiency can deliver large and smart mitigation. Indeed, all the suggested strategies can be thought of as 'energy efficiency plus'. Although economically obvious, voluntary agreements only work to a degree. Hence tough motivators will have to be introduced, some of which have already been suggested in the Energy

Efficiency Strategy (DME 2005). Detailed design of such motivators requires urgent work and rapid implementation.

In electricity generation, the technology choice is fairly clear: there are two key domestic alternatives to coal. (Energy imports are another option but these come with key uncertainties—e.g. political stability for hydro-electricity from the Congo, and questions as to whether the Kalahari gas reserves are real.)

The challenges for nuclear power outlined in policy[32] include radioactive waste disposal, maintaining non-proliferation, and economic viability. If these can be resolved, the expansion of nuclear power is an obvious choice. The nuclear building programme will be financed, like other capital investment projects, through raising debt. For the pebble bed modular reactor (PBMR), government has committed to finance 51% of the capital requirements over the next three years.

An equivalent scale of investment is needed in various renewable energy technologies. The challenge here is to scale up in the next years, so that implementation at a larger scale is feasible and more affordable in future. The central problem is cost—and much depends on what technology learning happens in other countries (see the Technical Report). Renewable energy technologies face challenges due to intermittency of the source and dispatchability, which at larger shares may require additional investment in the system, such as storage. The Solar Power Tower shows most promise and may even have base-load potential.

Cleaner coal appears to reduce emissions by relatively small amounts, unless accompanied by Carbon Capture and Storage (CCS).

Transport is the fastest growing emitting sector. It poses the most complex challenges, because it encompasses fuels, vehicle technology and infrastructure, as well as behavioural changes. Biofuels cannot solve the problem at any scale. An overall package needs to be designed, addressing a range of interventions in the sector. This package would have to look at the two large mitigation wedges as principal motivators: modal shifts in the way human and freight movement is achieved, and technology transfer away from petrol and diesel. Electric vehicles and hybrids provide efficiency gains over conventional engines, and hydrogen cars emit no GHGs at the point of use. The extent of mitigation will depend on the

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[32] At the time of the LTMS process, the DME had published a nuclear energy policy and strategy for public comment. This was subsequently adopted (DME 2008), with the key issues identified remaining.

energy source from which the electricity, biofuel or hydrogen that powers them is derived. Central and decentralised options need to be covered.

Carbon Capture and Storage (CCS) is important and requires some attention and support. It is clear that CCS is a large part of the solution for both CTL and coal-based electricity, and hence is included as a major component of our energy security strategy. CCS needs to address challenges and uncertainties, including technical, geological, economic, environmental impacts and the regulatory framework—but above all, it needs to prove whether it can scale up by a factor of 10 or 100.

These are the big mitigation interventions. But there are also many smaller activities that deliver cost-effective mitigation, such as manure management in agriculture. Others are important to their sectors for their own reasons, such as fire control. A balanced portfolio should include wedges that have socio-economic/sustainable development benefits, notably in the residential sector. A number of government departments will have to address those activities which show most promise in their sectors.

Several strategic options require immediate support and further research, including (a) social behaviour change, (b) emerging technologies, (c) resource identification and (d) inducing a transition to a low-carbon economy. Achieving changes in social policy and behavioural change would require focused public-awareness raising.

The damage costs of climate change impacts under different concentration scenarios require further research as the state of knowledge matures (SBT 2007).

The LTMS team therefore recommended to decision-makers four clear 'big hits', together with important smaller wedges and long term R&D. None of the technologies, policies and measures highlighted by the LTMS is a 'magic bullet', but rather a portfolio of mitigation actions that should be established. These strategic choices about investment and technology will need to be guided by a long term policy framework that would send a 'loud, long and legal' signal to South Africa, and indeed beyond.

The national response to the LTMS

The central findings of the LTMS team were disseminated more broadly in the form of a scenario document (SBT 2007) and a technical summary (ERC 2007b), which contained the essential results of the technical work reported in this book. The findings were discussed with government, business, NGOs and civil society in a series of outreach events in late 2007 and the first half of 2008 (see Raubenheimer 2007). The Department of Environmental Affairs and Tourism (DEAT) took the findings through consultations in government and further engagements with stakeholders, in the lead-up to a presentation to a cabinet *lekgotla*. Having mandated the LTMS process at the outset, Cabinet considered its results in July 2008.

After discussions during its July *lekgotla*, Cabinet agreed on an ambitious plan, driven by the aim of limiting temperature increase to 2°C above pre-industrial levels and doing a fair share in the international context. Taking a long term view, the goal is to make a transition to a low-carbon economy, presenting this as the best option for job creation and development in a carbon-constrained future. Cabinet stated clearly that emissions need to peak (at the latest by 2020–25), then plateau for a decade or so, and then decline.

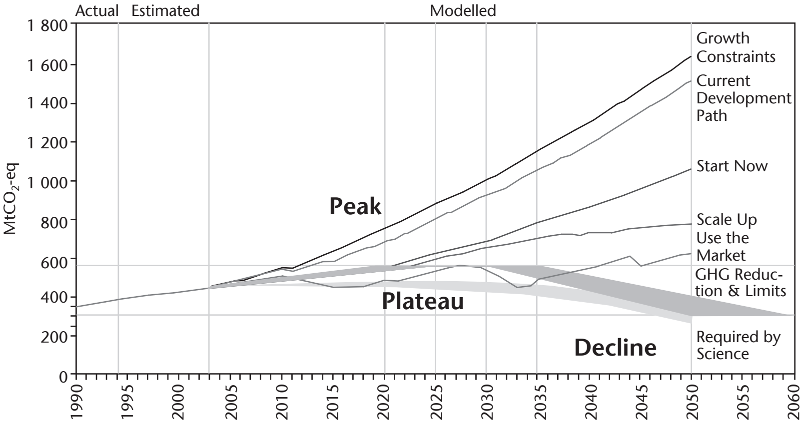

Figure 8.1: Cabinet direction—peak, plateau and decline of South Africa's GHG emissions

Source: (RSA 2007)

The strategic decision to outline the 'peak, plateau and decline' emission trajectory shown in Figure 8.1 was the first theme in Cabinet's response. The other five themes emphasised the need to build, strengthen and scale up current initiatives, to implement the 'Business Unusual' call for action; prepare for the future; address vulnerability and adaptation; and to ensure alignment across government (Van Schalkwyk 2008).

The strategic direction set out by Cabinet included immediate priorities, such as setting more ambitious domestic targets for energy efficiency, renewables and transport. Cabinet acknowledged that mandatory action would increasingly be needed. In developing formal policy, state-led regulation will play a key role, complemented by getting the economic incentive structure right. Policy-makers understand that the country's new competitive advantage will lie in becoming world leaders in climate-friendly technology. An escalating price on carbon is designed to trigger action in many sectors, building on work by National Treasury (National Treasury 2006). The SA government as a whole indicated that it seeks long term change, making a major transition from an energy-intensive to a low-carbon economy. Greater investment in long term research and development will be crucial on the road to a low-carbon society. Together, the implementation of the strategic options outlined in the LTMS is designed to enable South Africa to turn climate change mitigation into a 'pro-growth, pro-job and pro-development strategy' for the future (RSA 2007).

This Cabinet decision represents a decision by government at the highest level. The high-level political support for the LTMS results might have been in doubt with the transition from a Mbeki to a Zuma administration. Several factors, however, indicated that there would be policy continuity and little change in the decisions taken by Cabinet in the July *lekgotla*. The first was that the ruling party, the African National Congress, had already taken a resolution on climate change at its policy conference in Polokwane in December 2007. That resolution resolved to:

> … set a target for the reduction of greenhouse gas emissions as part of our responsibility to protect the environment and promote sustainable development, and to participate in sharing the burden with the global community under a common framework of action. (ANC 2007)

The sense of continuity was confirmed by then President Kgalema Motlanthe's restatement of the LTMS strategic direction at a second Climate Change Summit in March 2009, shortly prior to the April elections. 'Government has agreed to a strategic policy framework for our emissions to peak between 2020 and 2025, and then stabilise for a decade, before declining in absolute terms towards mid-century' (DEAT & DST 2009). And strong policy statements were made by then ANC President Jacob Zuma at the Socialist International:

> We believe it is correct and proper for the world to take climate change seriously. Science tells us that an increase in global average temperature above 2°C poses a danger to all of us, but in particular the poor. To avoid the worst impacts of climate change we need to limit the temperature increase to 2°C above pre-industrial levels. We are already approximately 0.7°C above pre-industrial levels. (Zuma 2009)

In short, the LTMS strategic direction and policy framework have garnered high-level political support.

Overall, LTMS represents a watershed in SA climate policy. At the national level, the challenge is now implementation. The national Climate Change Summit in 2009 launched a process to implement the strategic direction set by Cabinet based on LTMS in a 'legislative, regulatory and fiscal package' (DEAT & DST 2009). The policy development process was outlined, to result in a White Paper by the end of 2010 and formal policy by 2012.

The LTMS impact internationally—going far fast

The LTMS has had significant impact on international negotiations around climate change. Having done its 'homework' for the negotiations on the future of the climate regime (to be concluded in Copenhagen, December 2009), South Africa was in a position to present the results of its work. LTMS outlined mitigation potential and squarely identified the mitigation challenge. The reception of presentations at COP-14 in Poznań, Poland, from other negotiators acknowledged that this was an unprecedented step by a developing country. Some countries, including several from the African group, saw it as a model for assessing mitigation potential—or the potential to avoid emissions in the first place through sustainable development.

Having done its own assessment, the country can identify which mitigation actions can be undertaken with its own resources (certainly negative-cost wedges, but maybe more) and which require international support (the most costly mitigation options). In the negotiations under the Convention, South Africa proposed a registry of nationally appropriate mitigation actions by developing countries (RSA 2008). Many of these could be sustainable development policies and measures (Winkler et al. 2002) and it will be important to quantify the co-benefits (Winkler, Höhne & Den Elzen 2008). Based on LTMS, the country has a good basis for proposing such actions, doing its own analysis of how the resulting mitigation adds up—and how this compares to its own baseline.

The LTMS process took seriously what is required by science—indeed this has become the goal for all strategic options. There is a clear understanding that South Africa must take co-responsibility for the future and join the world community in taking action to stabilise GHG concentrations at the lowest levels possible. Given its huge challenges of inequality, poverty and development, the country needs a burden-sharing discount. It will not take absolute cuts immediately, as industrialised countries must. But along with others, the decisions arising out of LTMS indicate strong political will to take greater responsibility and quantifiable action commensurate to our level of development and national circumstances. There is a set of 'no-brainer' actions with which South Africa must start now. But the climate crisis will require more than that.

The modelled strategic options show very substantial deviations below baseline. Both Scale Up and Economic Instruments are ambitious-transitional[33] strategies for the country, and would be a huge contribution to the multilateral negotiations. Use of regulatory and economic instruments is not an either/or choice and, indeed, the policy development process outlined aims to culminate in legislative, regulatory and fiscal packages. For the financial incentives, international support will be critical to help shift the patterns of domestic investment.

Identifying the support required does not mean South Africa should wait to start on mitigation. The LTMS clearly identified a set of mitigation actions that need to Start Now. Cabinet fully endorsed pursuing this option, in parallel with investigation of what else is needed. But, in order to scale up efforts and fully utilise the markets, cooperation will be needed. It is no longer a question of either/or, but a question of both/and—indeed, an imperative of pursuing all options that have the potential to mitigate climate change. The overall goal must be for South Africa to become a low-carbon economy and society.

As a developing country, South Africa is stepping up to make a fair and meaningful contribution to solving the challenge of global climate change. Acknowledging the aim of limiting temperature increase to 2°C is a major step for a developing country and demonstrates bold leadership. It is also fully consistent with the findings of the IPCC, which found that the absolute reductions will be required of developed countries and

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[33] See Winkler & Vorster (2007).

deviations below baseline from developing countries. Only by all agreeing to their respective responsibilities will it be possible to agree a long term goal, which the planet so urgently needs.

As an African proverb says: ‘If you want to go fast, go alone; if you want to go far, go together’. The challenge that climate change poses is that we need to go far fast. Together, we can.

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