Long Term Mitigation Scenarios

Technical Report

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

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

The study was supported by the following inputs:

LTMS Input Report 1: Energy emissions

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

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

LTMS Input Report 4: Economy-wide modeling

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

Structure of the Technical Report

This document contains the information provided by four research teams to the Scenario Building Team in the Long-term Mitigation Scenario (LTMS) process. The research teams comprised energy and non-energy modeling, economic modeling and analysis of climate change impacts (see Acknowledgements for the teams).

The Technical Report contains the following major sections:

1. A **Technical Summary**, summarising the information in the Technical Report
2. A **Technical Report,** providing the results of the; and
3. **Appendices**, containing further technical data, including some material presented to the SBT at previous meetings.

The inputs of the research teams will be published on the LTMS web-site as stand-alone reports. The documents feed into the Scenario Document and Technical summary as shown below. The Scenario Document and Technical Summary are the main documents that the Scenario Building Team is forwarding to the LTMS high-level discussions.

A) Scenario Document
B) Technical Summary
Technical Report and Appendix
Technical Inputs:
- Energy emissions
- Non-energy emissions
- Economy-wide modeling
- Climate impacts

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Acknowledgements

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1. 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) which are causing climate change: in fact this country is one of the highest emitters per capita per GDP in the world. We are both helping to cause the problem and its victims.

1.1 Why an LTMS process?

South Africa is an active participant in the international process of combating climate change and regulating the emissions of greenhouse gases. We are signatories to the United Nations Framework Convention on climate change as well as the Kyoto Protocol. We take the issue of climate change very seriously and have shown world leadership in the UN negotiations. Our actions must also speak as loudly as our words in the negotiations: 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 which 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, others are less likely to act and ultimately impacts will affect everyone.

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

Over the next number of years in the negotiations, South Africa will be required to engage deeply with the issue of mitigation obligations. We will need to be ready and prepared, armed with a detailed plan and sets of negotiation positions. This plan will have to contribute to the international effort to lower emissions while meeting the development needs, especially of our poorer communities. We need to connect energy needs, mitigation plans, and policies such as the Accelerated and Shared Growth Initiative (AsgiSA). We need to accurately determine the costs, benefits, and opportunities for mitigation activities. We will choose a time horizon of both 25 and 50 years, which are reasonable time frames for medium and long term planning when we speak of power generation, as well as for other emission sources such as from industry, transport and housing.

Mitigation is a delicate balance between development needs, available technology, cost to the economy, and policy intervention. South Africa has the opportunity to proactively define approaches and development paths that we – as a society – consider desirable. We cannot, for example, agree to a mitigation target which we cannot afford and will not reach. At the same time, there is a huge opportunity for international investment in climate-friendly technology, which can help us grow more and create new industries. In other words, we need to work out a range of paths which work for our country. This includes all major emitters: our electricity utility, our private sector, and our public sector.

1.2 Mandate and scope of work

In this context, the South African Cabinet mandated a national process of building scenarios of possible futures, informed by the best available research and information. This will help SA to define not only its position on future commitments under international treaties, but also shape its climate policy for the longer-term future.

Stakeholders from government, business and civil society agreed at the National Climate Change Conference in October 2005 to embark on this process, seeking to protect the climate while meeting the development challenges of poverty alleviation and job creation. For these reasons, a Long-Term Mitigation Scenario (LTMS) process was launched in mid-2006.

The focus of the LTMS process, as the name suggests, is mitigation, that is reducing emissions of GHGs. A certain amount of adaptation will be necessary, no matter what we do. But it is also true that there will come a point where it will not be possible to adapt our way out of the problem.

The Department of Environment and Tourism as the focal point for climate change in South Africa will convene and manage the process, which will be overseen by an inter-ministerial group. DEAT has appointed the Energy Research Centre at the University of Cape Town (ERC) to project manage the entire process. The ERC is undertaking the task of convening and contracting the process specialists and ensuring their independence. Similarly it is setting up the personnel of each of the four Research Support Units.

1.3 Objectives

The key objectives of the LTMS process are that:

- South African stakeholders understand and are focused on a range of ambitious but realistic scenarios of future climate action both for themselves and for the country, based on best available information, notably long-term emissions scenarios and their cost implications;
- the SA delegation is well-prepared with clear positions for post-2012 dialogue; and
- Cabinet can approve (a) a long-term climate policy and (b) positions for the dialogue under the United Nations Framework Convention on Climate change

Cabinet policy based on the scenarios will assist future work to build public awareness and support for government initiatives.

1.4 Summary of climate change impacts [1]

The IPCC Fourth Assessment Report provides the most recent and comprehensive estimate of the likelihood that human activities are causing currently observed temperature and climate change. Their essential conclusions are 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 2007)

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 2007)

This level of certainty translates to a >90% probability (9/10 chance) that human activities are responsible for the global warming observed since the 1950's.

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, land cover change and then a range of other less critical decisions. 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, thus providing us with published material that yields 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 between a 1.2° and 5.8°C rise 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

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[1] The full chapters can be found on the LTMS closed web-site, www.ltms.uct.ac.za .

assess sensitivities, vulnerabilities and risk associated with climate change at the national and sub-national levels. 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.

Much of the impacts assessment work reviewed in this report does not deviate far from the recently published IPCC estimate that the most likely range (>66% probability) for global temperature response to CO_2 doubling (the climate sensitivity referred to above) ranges from 2 to 4.5ºC, with the median response not far below 3ºC. The approach of making assessments guided by the median climate sensitivity, as we have done here, may appear to be logical and justifiable, but it is important to point out that this approach *may significantly underestimate the risks of larger impacts* due to the uncertainty inherent in the climate sensitivity. We have found that, in general, the apparently less likely scenarios of climate change are poorly explored in the impacts literature, and thus that this high risk region remains largely unquantified.

Modelling studies project a range of impacts in South Africa, 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 in most sectors of the economy, but especially for urban and agricultural demands.

The summary presented here is a review of currently available information on observed climate trends, projected changes and the vulnerability to climate change across an array of key sectors that are known to show sensitivity to climatic drivers (The full report is available as a stand-alone document). Where possible, adaptation responses have also been reviewed per sector, and the costs of adaptation and damage costs due to a lack of action have been extracted – although examples of this level of work are currently very few. Together with the social and moral imperatives to meet international climate change commitments, this review of potential climate induced impacts in South Africa provides additional motivation for embarking on the Long Term Mitigation Scenario project (LTMS), as explained in section 1.1.

The results of this review can be summarised as follows.

1.4.1 Observed climate trends

Analysis of climates during the recent past (i.e. the last 10 000 years) indicate that the current levels of temperature have seldom, if ever, been exceeded. Significant dry spells in various regions of South Africa, even in living memory, have induced severe drought conditions that have had major disruptive effects on society, but these were not the result of anthropogenic climate change.

Overall rainfall in the region has shown some negative trends since the 1950's, but these are not statistically significant. There is some evidence of drying in the Limpopo province region, and a wetting in the north-eastern Karoo. In the latter regions rainfall has become somewhat heavier, and with longer durations between events.

Fewer frost days are occurring now than thirty years ago, particularly in the Highveld and inland plateau areas.

The effects of the sunspot cycle on rainfall are very small to undetectable, and not statistically significant at an acceptable level of statistical confidence.

1.4.2 Climate change scenarios and projections

The most recently developed climate scenarios include some key differences from the previous generations of scenarios used in key regional studies such as the SA Country Study on Climate Change. The most recently produced scenarios will need to be fully assessed by the impacts community to ascertain the implications for impacts, vulnerability and adaptation responses.

Temperature is likely to continue to increase across the country, with the greatest increases towards the interior, and strongest in the daily minimum. Average wind speed is likely to show a small increase across the region, most notably over the ocean.

Most recently developed downscaled rainfall scenarios project a general drying in most seasons in the SW parts of the western Cape, particularly during autumn and winter months and in line with a shorter winter rainfall season, concurring with the patterns identified in the SACSCC[2]. In summer and autumn the northern and eastern regions of the country, however, are likely to become wetter, especially over regions of steep topography around the escarpment and Drakensberg. This projection, based on developments in downscaling results to regional level, does not concur with the SACSCC scenarios which were biased towards drying projections. The projected changes in the intensity and frequency of precipitation events remain uncertain.

The research on climate change is not complete, and there is critical need to sustain the momentum and capacity achieved to date in order to enable policy and adaptation to evolve as the climate continues to change.

There is an urgent need to ensure continued and expanded observation of the core climate parameters, and to reverse the trend of a declining spatial coverage of the observational network.

1.4.3 Adaptation to climate change

It is clear that, even if GHG emissions are successfully reduced through effective international action, most sectors will need to adapt since much of the change that will occur in the first half of this century has already been pre-determined by past and current GHG emissions.

While the commitment of global climate to a certain amount of change raises the importance of the need for adaptation responses; however, these concepts are currently unnecessarily confused, thus limiting more rapid advances in planning and implementation.

Two types of adaptation are defined, namely ‘resilience-type’ adaptation, which addresses the potentially damaging effects of changing climate extremes on sectors, and ‘acclimation-type’ responses, which address strategies to cope with the gradual changes in background climate such as slow rates of warming that may ultimately require new behaviours and practices in human society.

Differentiating adaptation responses into shorter term ‘resilience-type’ adaptation responses and longer term ‘acclimation-type’ adaptation responses might allow adaptation strategies, implementing agencies and financing sources to be more effectively allocated to where needs are most urgent.

A number of potential barriers to implementing a adaptation plans include:

- low local human capacity to undertake this kind of planning;
- limited financial resources and competing priorities;
- longer time horizon than the political and development framework ;
- the absence of a legislative framework.

1.4.4 Impact on water resources and hydrology

South Africa is a water-stressed country with an average annual rainfall of 500mm (60% of the world average) and stream flow in South African rivers is at a relatively low level for most of the year. Due to forestry and agricultural use, only 9% of rainfall reaches rivers, compared to a world average of 31%. Total societal water requirements closely approached availability limits by 2000. Rainfall variability is also responsible for water-related disasters such as floods and droughts.

A general increase of evapotranspiration by ~5–15% is projected throughout the region for a double CO_2 future climate, with the lowest increases along the humid south and southeast coasts and parts of the arid Northern Cape, and highest increases are projected to occur on the central plateau. Direct implications could be severe for irrigators and reservoir operators, while the indirect implications through reduced soil moisture levels could impact runoff generating mechanisms and dryland agriculture quite markedly, although all those processes occur in interplay with rainfall changes.

As much as 97.3% of South Africa’s area displays increases in days with the topsoil at wilting point, including the Free State, southern Mpumalanga and KwaZulu-Natal showing a doubling and more of days at wilting point. Lesotho and the northeast coast of KwaZulu-Natal are likely to experience amongst the highest increases in dry topsoils in a future climate.

The annual number of stormflow events is projected to decrease in a future climate in the winter rainfall region, the coastal zone of the all year rainfall region, the northern and eastern parts of Limpopo province and almost the entire KwaZulu-Natal, Lesotho, Free State and coastal half of the

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[2] SACSCC – South African Country Study on Climate Change under taken in 2000.

Eastern Cape. These areas include some of the most crucial source areas of streamflows in southern Africa. Future increases in stormflow events per year are simulated over much of the Northern Cape, where few stormflow events occur in any case, as well as Mpumalanga, Swaziland and the remainder of Limpopo.

An increase in recharge events per year, by a factor of 1.5 to over 3, is projected for a future climate, in particular in the southern and eastern Free State, Lesotho, northern parts of the Eastern Cape and much of KwaZulu-Natal.

Much of South Africa is projected to have more variable streamflows despite higher predicted flows overall. However, parts of the Western Cape are projected to have considerably lower variability relative to the present, despite lower overall predicted streamflows. The Lesotho highlands also show decreases in streamflow variability.

Streamflows are projected to shift between one and two months earlier over much of Limpopo and the interior, while shifting a month later in parts of KwaZulu-Natal and Swaziland. It is highly striking that the transitional area between the summer and winter rainfall regions is seen to be in a state of considerable flux with climate change and is likely to present major challenges to water resource planner in those regions.

Future increases in sediment yields are projected over much of the interior in median and especially in wet years, with relative reductions in a future climate modelled along the east coast and the winter rainfall region.

South Africa is projected to have a higher relative irrigation water demand under a plausible future climate scenario, irrespective of its being a wet, average or dry year.

1.4.5 Impact on agriculture and forestry

The socio-economic value and role of agriculture in South Africa is substantial, including contributing 3.7% to annual GDP and its relatively unquantified but large role in supporting livelihoods.

Western Cape agriculture faces significant threats due to projected increasing water shortages, resulting in lower yields and greater yield variability. Additional heat stress will reduce productivity of both crops, especially chill unit-dependent deciduous fruit, and livestock.

Most vulnerable crops are those dependent on winter chilling (apples and pears), and those dependent on rainfall amount and distribution. Assuming continuing orchard irrigation but no other adaptive response, apple production areas will shrink with progressive warming and finally be restricted to the high-lying Koue Bokkeveld. By the end of the 21st century (with mean warming >3°C) this crop will likely disappear entirely.

Pears are less chill-dependent than apples. Initial moderate warming (1-1.5°C) could lead to slight gains (cooler Elgin region) or slight losses (warmer Ceres and Wolseley regions). With continued warming (2-3°C) losses are estimated at between 5% and 20% depending on cultivar and region. Should irrigation water not be sufficiently available, losses would be substantially higher for all fruit crops.

Grapevines are likely to be resilient to some warming and drying. With moderate warming (1-1.5°C), irrigated vineyards will maintain yields, and yield increases may result for medium/standard quality wine. Small reductions (2.5-5%) in yield and quality may accompany greater warming (2-3°C) especially in the warmer production regions (Olifants River, Worcester, Robertson). Non-irrigated vineyards will show slight losses under moderate warming, but more serious losses (10-15%) with stronger warming.

Wheat production potential varies widely across the region. Greatest impacts (absent adaptation) are expected in the most marginal areas (Sandveld and Rooi Karoo) in the north-west (low total rainfall, projected losses of 15-60% depending on the amount of warming and drying) and the Heidelberg Vlakte in the south-east (irregular winter rainfall, losses of 20-70%). Yield variability will increase over time. The most productive areas of Klipheuwel/Hermon and Goue Rûens are likely to sustain lower losses (5-12%).

Many autonomous adaptation options in agriculture are extensions or intensifications of existing risk management or production enhancement activities. Where crops are near climate tolerance thresholds, or where multiple stresses exist (e.g. soil degradation), or where producers' capacity for autonomous adaptation is exceeded, deliberate planned measures will become necessary. Secondary impacts on the broader rural and regional economy could be susbstantial for this region.

A distinct increase in prevalence of optimum climate conditions for major pests, codling moth (on apples) and chilo stem-borer (on sugar cane), is projected for each degree of warming. From these findings the implications of temperature projections alone are likely to profound for affected crops.

Net water requirements in the summer rainfall region are projected to increase throughout southern Africa. In the south and north predicted increases are less than 10%, but along the KwaZulu-Natal coast and the Lesotho/central Free State area they are around 30%.

Projections for profitability of maize production are sensitive to temperature, rainfall and CO_2 fertilization scenarios. A 2°C temperature increase alone reduces profits by around R500/ha across the highveld maize region, but CO_2 fertilization may mitigate this loss almost completely on average. Even for a 10% rainfall decrease, the CO_2 fertilization effect increases profits by up to ~R1500 per hectare. CO_2 fertilization effects are however very uncertain and no local experiments exist through which these projections can be tested.

Forestry impacts are highly dependent on rainfall scenarios; recent history shows that drought during 1991/92 caused the loss of R450 million to the industry. With expected temperature increases by ~2050 of 2ºC and a reduction in rainfall of 10%, *Acacia mearnsii, Eucalyptus dunnii, E. grandiflora, E. nitens, E. smithii* and *Pinus eliottii, P. patula, P. taeda* and certain hybrids, show a reduction of between 40% and 100% in viable planting area, but these species and hybrids show an increase of between 50% and 90% in planting area if rainfall increases by 10% with 2ºC warming.

Given the uncertainty relating to summer rainfall projections, the forestry sector faces a wide range of potentially plausible scenarios, indicating the critical need for reducing uncertainties of rainfall projections in this region. However, threats of greater fire frequency with rising temperatures are clearly an important risk regardless of rainfall scenario.

1.4.6 Impact on ecosystems and biodiversity

The real economic value of ecosystems and biodiversity is increasingly being recognized and quantified. Globally, ecosystem services have been found to have a value equal to the global gross national product. In South Africa, which has the fifth highest level of plant species richness in the world, the economic value of wild ecosystems in the Cape Floristic Region biodiversity hotspot alone is ~R10 billion.

Updated climate scenarios and the application of modern modeling techniques indicate that some key ecosystems (e.g. the Nama-Karoo Biome) may not be as imminently vulnerable (i.e. by ~2050) to climate change impacts as reported previously. Nonetheless, medium and longer term risks for species-rich winter rainfall biomes remain serious, with several tens of percent of their endemic species threatened by extinction this century. Several savanna and arid grassland ecosystems found in the summer rainfall region may store between ~20 and 650% more carbon due to temperature, rainfall and CO_2 fertilization effects.

1.4.7 Impact on health

Southern Africa is grappling with socio economic and demographic issues that are historically unique to the region, coupled with huge health burdens of AIDS and a growing TB epidemic. Implicit in this discussion is the potential contribution of climate change, may have on the already delicate balance that exists between health, economic productivity, livelihood and prosperity.

The immediate health impacts of extreme climatic events with longer term psychosocial consequences and loss of livelihoods are well established and documented.

The gradual changes in temperature and precipitation that are observed and predicted in the region are less tangibly measurable. The increasing rain pattern and temperature favour the geographical expansion of the borders of vector borne diseases like malaria. This is supported by several mathematical models as well as surveillance and direct observations in many quarters. It is estimated that in Africa there are 124 million people who live in this zone and are considered to be at increased risk of climate related malaria epidemics.

Health effects can be attributed to the following external impacts:

- temperature;

- extreme weather – drought and floods;
- air pollution;
- vector- and rodent-borne diseases.

Adaptations are urgently needed that will guarantee adequate and reasonable healthcare delivery services particularly in rural setting, improved housing and infrastructure both in the rural and urban communities aimed at reducing the tendency towards migration and improving the lot of those that do flow towards the cities. These would include:

- multi-pronged approach to health;
- efficient and effective meteorological and weather forecasting services are one essential solution.

The climate change induced cost to the health sector is very difficult to estimate, given that there are multiple influences and impacting factors.

1.4.8 Impact on livelihoods

An assessment of the impact of climate variability on livelihoods (the various activities, assets and capabilities of people's daily lives) facilitates an integrated view of the multitude of ways in which human society may be affected by climate.

Natural capital, such as timber, plants, land and water will be affected by changing rainfall and temperature. Human capital, such as people's skills, knowledge, health and ability to labour, might be affected through increased pressure on food supplies, due to higher prices or lower productivity of land. Health is affected by changing pollution levels, the quality of water and changes to vector-borne diseases such as malaria.

As resource availability becomes increasingly limited, so does the ability to secure income and economic assets can be eroded over time. There is also evidence that extreme events place pressure on social networks as it becomes harder to maintain reciprocity under stress.

The impact of climate variability on assets links directly to the impact on livelihood activities. Production and income activities are likely to be significantly affected by climate variability, particularly in rural areas where changes in rainfall directly affect agriculture and natural resources that underpin many production and income activities. In South Africa, there is growing evidence of how changes in rainfall impact on livelihoods, often increasing vulnerability of farming systems. Extreme events, such as drought and flood, also affect production and income activities.

Change in climate and climate variability, is also likely to increase the risk to assets and activities. Increased temperatures and drier conditions for example, can increase fire risk which is currently a major threat in informal settlements and has the potential to cause major damage to livelihoods assets and well as threatening lives.

Adapting to climate change at the livelihood scale will be a critically important undertaking. It is particularly important to focus on the most vulnerable groups, so that their livelihoods are not eroded by climate events but rather become resilient to the expected changes in climate. This requires an integrated approach that addresses multiple sectors whilst combining the knowledge of vulnerable groups as well as specialist.

1.4.9 Impact on the urban environment

Climate change has the potential to reduce available supplies through reduced rainfall in mainly the western parts of the country and also to increase consumption patterns due to temperature increase.

The long term projections support the view that the frequency and intensity of future extreme precipitation events will increase during the twenty-first century, with result of more flooding episodes.

Whilst more gradual, the potential of sea level rise impacts are real, especially when accompanied by high tidal and storm events.

Heat waves are expected to increase in frequency and severity in a warmer world with the consequential mortality amongst the elderly and sick.

1.4.10 Indicative costs of climate change impacts

The following tables provide an indicative estimate of the potential cost firstly of damages due to inaction as a result of low levels of adaptive capacity through human and financial constraints. And secondly of the costs to accommodate the climate impacts in water resource planning and the conservation of biodiversity.

The cost on health and livelihoods are difficult to estimate, given that there are multiple influences and impacting factors.

Table 1: Cost of damages – i.e. the cost of inaction due to low adaptive capacity and resilience

Impacts	***Magnitude of costs***
Historical	
Flood damage event in the Western Cape due to extreme rainfall (2003)	100s of millions of Rands/event
Coastal storm damage along the Durban coast due to extreme weather event (2007)	100s of millions of Rands/event
Drought losses in forestry losses (1991/92)	100s of millions of Rands/event
Wildfire losses in forestry (2007)	>>R 500 million (initial estimate)
Potential	
Damage to residential property in the Western Cape due to sea level rise.	10 -100s of millions of Rand (2002 estimated values)
Increased temperature on winter rainfall agriculture: 2-3^{o}C	5-20% fruit crop losses (Varying losses depending location and crop type.)
Lower rainfall on winter rainfall agriculture over time.	Marginal areas – 15-60% crop reduction Productive areas – 5-12% crop reduction
Increased temperature across the highveld maize region (summer rainfall): 2°C	100’s of millions of Rand reduces profits by ~R500/ha

Table 2: The potential cost of acclimation adaptation

Interventions	***Magnitude of costs***
Small town water provision in the western Cape under climate change by 2035.	10s of millions of Rands per small municipality (up to 3.5 times more costly)
Conserving biodiversity – gene and seed banking.	100s of thousands of Rand
Conserving biodiversity – reserves and off-reserve management.	10 – 100s of millions of Rands

2. Methodology

A Scenario Building team was formed in June 2006, and will operate for a period of about 18 months. The Team is made up of directly interested stakeholders from the country’s major emitters, from government, as well as from other interested parties. A careful process of stakeholder selection ensured that the Team contains the correct people for the task. The team is facilitated by expert independent process facilitators with international experience in Scenario Building and climate change issues. The Team is supported by four Research Units, covering Energy Emissions, Non-Energy Emissions, Macro-Economic Modeling, and Climate Change Impacts. These support Units contains our leading researchers.

The Scenario Building Team started building the Scenarios based on research information and internal data in 2006. The final report of the Team will be made public.

2.1 Scenario building methodology

2.1.1 What are scenarios?

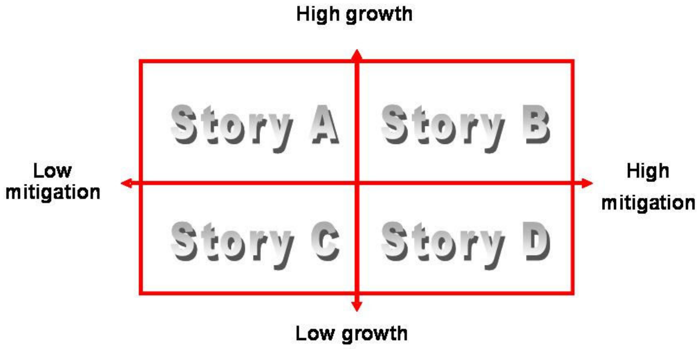
- A scenario is normally defined as a structured account of a possible future.
- Our scenarios are not so much future stories (as we have already described above) but *active options for future paths*, seen against growth and emissions. Our scenarios will be built on alternative dynamic paths that are based on key assumptions about the future and contain the actions required to achieve them.

2.1.2 Scenario planning in the LTMS

Scenario planning has already been influential in our history and has proved its ability as a process to shape policy and other choices. A scenario is classically a structured account of a possible future. A scenario describes a future that could be rather than one that will be. A group of scenarios are alternative dynamic stories that capture key ingredients of uncertainties of the future. They reveal the implications of current trajectories, thus illuminating options for action. These options for action are then presented to government in order to assist it in making the correct policy choices.

The scenario planning approach for the LTMS process is different to 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. The point is then thereafter for policy makers to define a strategy that is robust to all possible futures.

In the LTMS, four future stories are presented on the axes of Growth and Mitigation. These four futures lie in the four quadrants presented by the axes. Hence:



Classical scenario planning methods were used for background context to this process, using the classical two-by-two matrix, with key dimensions along the two axes. The vertical axis represents high growth (e.g. 6%) vs. low growth). The horizontal axis represents mitigation effort – from none to high. Note that this is not emission reduction, since higher mitigation effort does NOT necessarily mean decreasing emissions, but less than it otherwise would have been ('BAU'). *Absolute* emission (tons of CO_2/year) might still increase, although emissions would be lower *relative to BAU*. The diagram results in four quadrants, which represent the following:

- Top right quadrant - shows growing SA and high mitigation effort, which is where were would like to be.
- Bottom left quadrant – shows no growth and low mitigation effort with emissions still increasing.
- Top left quadrant - shows high growth and low mitigation effort.
- Bottom right quadrant - shows low growth and an high mitigation, although emissions may be decreasing as a result of economic hardship, not effort.

We chose these quadrants as they accurately represent the challenge of development on the one hand and its link to emissions on the other. We recognized that SA currently fits into Story A: we are growing the economy, but our emissions are also growing. Story B is perhaps where we want to be: a growing economy but with good mitigation efforts being made, and possibly will overall emission reduction. Story C is the worst of all worlds, a failing economy with no mitigation effort (we were here pre-1994), and story D presents us with a failing economy with emissions dropping as a result.

We did not choose to name these stories, and have called then simply 'Background Contexts', rather than Scenarios. We believe that these contexts will be useful when testing the actual Scenarios.

We then followed this Context setting with the building of what we have termed 'Scenarios', for the purpose of the LTMS exercise. The Scenarios in our case are alternative emission paths, with time horizons of 2025 and 2050. We set a framework of 5 Scenarios to start with.

In order to build the Scenarios, the following terms were discussed and agreed upon.

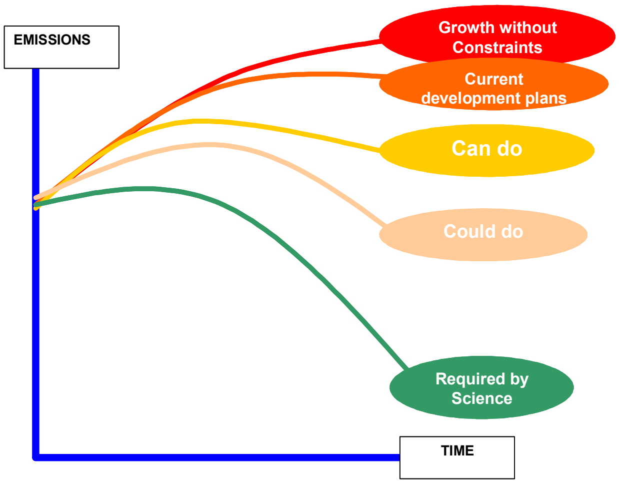
- **Assumptions**: primary drivers for each Scenario include assumptions and uncertainties.
- **Actions**: individual mitigation actions we may take.
- **Action packages**: Agreed combinations of actions, with GHG emissions trajectories.
- **Scenarios**: future 'stories', or paths, each populated with assumptions, action packages, sub-scenarios, data, incl costs, benefits, trajectories.

We then followed the following steps, generally:

- Scenario names and description.
- Once agreement has been reached, generate the Assumptions that attach to each Scenario. Assumptions are both international and local.
- Then list the actions and options for action that tie to each Scenario and its group of attached Assumptions.
- Then group these actions into action packages. These may of course reveal sub-scenarios to the Scenarios. Conduct macro-economic analysis of packages and / or scenarios.
- Through research and modeling, 'populate' the Scenarios.
- Conduct sensitivity analysis on selected parameters.

Three of the Scenarios were then built 'from the top down', meaning that they would be modeled extrapolations of certain emission paths. The first of these would show a prediction of our emissions path if we had growth without any carbon constraint. The second would show our current plan: growth but with some emission reduction plans. The fifth, a purely notional scenario, would show what (more or less) would happen if we restrained our economy towards an emission target required by the climate science in order to stabilise the climate. We called these the 'envelope Scenarios'.

The third and fourth Scenarios are those that plot alternative paths between our current emission and growth trajectories and what is required by the best science. In contrast, these two Scenarios are built from the 'bottom up'. Stakeholders defined mitigation actions, which were then modeled by the research teams. Based on these results, actions were combined into action packages. Action could be grouped on the basis of costs or interest (e.g. green, nuclear or coal agendas).



- **Red - Current Development Trends, without doing anything; no constraints**

- **Orange - Business As Usual, including our current actions**
- **Yellow - Can Do with own resources**
- **Pink - Could Do but only if assisted**
- **Green - Emissions reductions required science.**

Figure 1: Our scenario framework

2.1.3 The LTMS process: from scenario building to cabinet

One of the challenges that the LTMS process undertakes is, for the first time, to illustrate different emission paths for SA, and their different effects on growth and development. The specific challenge is to show these paths *accurately*, in the sense that cost and emissions results are reliable. Hence whilst the process is essentially creative (the paths that are constructed can be as fanciful, or as aggressive, as one wants, the results are conservative and based on good data. So for example no technologies that are at this stage unknown and therefore impossible to cost are included.

The reason for this creative/conservative approach is that the policy decisions that this process may influence are momentous for South Africa.

The LTMS results would have to stand up to the tightest scrutiny, in order to ensure reliability. For this purpose the Scenario Building Team becomes an oversight body to constantly test the data inputs and choices. The purpose of the team is hence both Scenario Builder and test-bed for the results. It takes the responsibility, at the release of this report, for the veracity and reliability of the results.

The SBT is a sherpa team, made up of a number of experts from all sectors. Each member of the team was chosen not for the organization/sector they represented, but for the individual contributions they could make and the rigour they could personally bring to the process. The list of SBT members is reported in Appendix 1

The SBT would, on completion of its work in building these robust and accurate Scenarios, present the results to a 'high level' team. This report is the product of the SBT, and is presented to this High Level Group (HLG). The HLG is intended to include leaders of civil society and labour, captains of industry, and members of the Inter-Ministerial Committee on Climate Change. Its task will be to first assess the results of the SBT process, and then to consider the more political and macro-economic implications of the LTMS results. In short, it will return to the background contexts, assess where South Africa will be in 2025 and 2050, and then interrogate which scenario would best fit that future, and what the implications for South Africa would be. The HLG will then present its recommendations to Cabinet.

The overall process can then be graphically presented as in Figure 2.

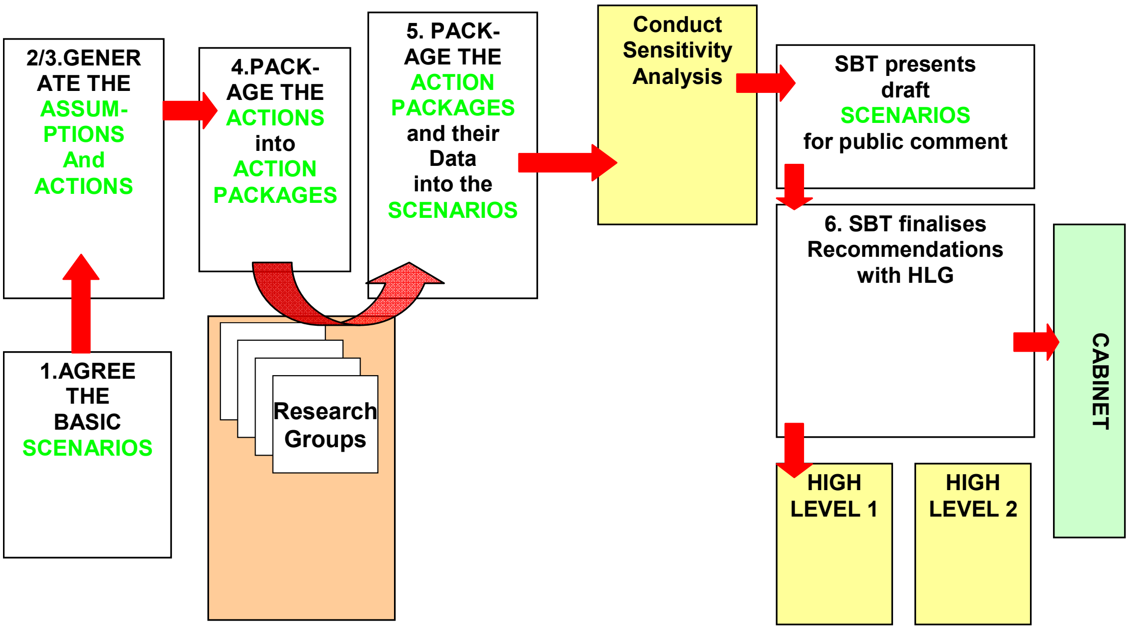


Figure 2: Diagram of the LTMS process

2.2 Research methodology

The work of the research teams is located within the overall scenario building methodology described above. Research teams feed information about scenarios and mitigation actions to the Scenario Building Team. They provide data needed by the SBT to populate the scenarios.

Some of the information included in the research methodology, together with many key drivers, were included in a document circulated prior to SBT3. The document was revised substantially based on comments at the meeting and interactions afterwards. References in the following text to the 'SBT3 document' refer to the finalized version.[3]

The research teams gathered large amounts of data to conduct energy modeling, analysis of non-energy emissions, macro-economic modeling and assessments of vulnerability and adaptation. It is not possible to list all data comprehensively. Some data is reported here because it is known to be important in determining the overall results and / or there was significant debate about some data.

For all scenarios, key common drivers were identified, such as GDP, population and technological change and other factors detailed in Appendix 4.

In terms of gases, energy modeling will consider the three 'big' greenhouse gases, CO_2 , CH_4 , N_20, as well as other GHGs – carbon monoxide (CO), oxides of nitrogren (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), but at this stage these are not accounted for in our energy modeling.

Potentially, emission in energy and non-energy sectors are related. For example, non-energy emissions from coal mining would depend on the total coal demand, which in turn is driven in part by demand for electricity. There is not full linkage between energy and non-energy emissions. However, all sectors have made use of the same projections for GDP and population, to ensure consistency. In addition, projected growth in synfuel and coal industry emerging from the energy modeling (GWC case) has been used for extrapolating non-energy industrial process emissions.

Methodologies for macro-economic modeling and analysis of impacts, vulnerability and adaptation studies will be included in future reports.

2.2.1 Energy modeling

Energy models are a powerful way to explore various alternative energy futures quantitatively, but are all subject to specific constraints. In this case, the research team chose to use the MARKAL (short for Market Allocation) model, a model developed by the International Energy Agency. 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 specified by the modelling team, the model determines the optimal configuration of the energy system in terms of an objective function, usually to minimize costs subject to constraints. The model ensures that energy system requirements are met, e.g. that energy demand is equal to supply; that a specified reserve margin is maintained; that plants for peak and base-load are distinguished; that technologies have a limited life, etc.

The strength of the MARKAL models lies in answering questions about the most cost-effective technology solutions for energy systems. Both fuel costs and the cost of energy technologies are considered (Howells & Solomon 2002). Constraints, 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 from projections of useful energy demand.

The optimisation process is based on an assumption that investment decisions in the energy sector are made by all actors in the energy system on a rational economic basis, and thus without careful design, the least-cost option will take over the entire energy market – something not observed in practice, due to non-economic policy considerations and issues facing policymakers, and other decision-makers, such as energy security concerns, energy poverty, accounting rules, or

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[3] 'LTMS inputs & actions FINAL Jan 2007.doc', circulated to stakeholders by Tokiso on 31 January 2007.

organizational culture. Model outcomes are thus constrained by bounds – upper and lower limits on investment in specific technologies applied by the modeling team.

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

1. 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.
2. Independent variables such as GDP and population.
3. The structure of the energy system.
4. Historical data on the existing energy system.

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

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

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

The MARKAL model used for the LTMS process was extended to allow analysis beyong 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 reasonably well represented, with the characterisation of upstream, transformation / conversion and end-use sectors (industry, residential, commercial, transport, agriculture); the model was well balanced, with an appropriate amount of characterisation across the different sectors; most technologies have been 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 that model development appeared 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 has passed international peer review.

The key drivers for energy demand are economic growth, population and technological changes (see discussion of key drivers in Appendix 4). In most sectors, GDP is a primary driver, but in the residential sector, population is important. For transport, GDP would be more important for growth in energy demand for freight services, while population plays a role for passenger transport. More detail on projections of demands are elaborated for each sector in Appendix 5. GDP has been discussed previously and the shape of projected GDP agreed at SBT3. SBT4, however, raised the issue of the *composition* of GDP. Further work was done on this and is reported in Appendix 4, especially a new section 4.2 on GDP composition.

2.2.1.1 Energy demand

The broad patterns of energy demand over time are shown in Table 3, which has projections of the fuel use by sector for the 'growth without constraints' case, to provide an overiew. This appendix describes demand in for each sector in a little more detailed, followed by the major supply industries, namely electricity generation and liquid fuel supply.

Table 3: Fuel use by sector in the GWC case, selected years

	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

More detailed analysis of demand for various sectors are reported in the Appendix.

2.2.1.2 Power plants

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 moth-balled Coal-fired plants that have plans to come online before 2030, such as Groot Vlei and Komato, are in the model. New plants that are under construction, such as the New Braamshoek plant and the CCGT plant planned for Coega are also explicitly in the model. Existing municipal plants are collectively included in the model as a single unit.

All new coal plants are assumed to have Flue-gas desulphurization (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 is applied such that over time new technologies decrease in cost due to economies of scale and 'learning by doing'.

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

Since electricity generation accounts for some 40% of GHG emissions in South Africa (RSA 2004), the mitigation potential in this sector is high. Consequently, the data on costs and other characteristics of new power plants are of interest. The values which stakeholders agreed to use for this process are summarised in Table 4. More detailed descriptions of the energy technologies were provided in Appendix 5 of the SBT3 document.

These values were derived by comparing values in previous work – the first Integrated Energy Plan (DME 2003), the second National Integrated Resource Plan (NER 2004) and previous work done at the ERC (Winkler 2006). The full range of values found are reported in Appendix 2 of the SBT3 document. More detailed explanations of why certain values were chosen is listed in new 'Notes' columns in these tables, in which a comparison to ISEP 10 data is now also included.

The values reflected in Table 4 were first circulated to stakeholders prior to SBT3, which was held on 29 November 2006. At that meeting, agreement could not be reached and a small group was set up to discuss the matter further. The intention was to complete these discussions by mid-December 2006. Extensive efforts were made both by stakeholders and the research team to obtain the most accurate data possible. After several interaction, a teleconference on 26 January 2007 reached agreement on a set of numbers with which to proceed. The energy modeling team will now proceed to complete the reference case and start modeling of mitigation actions based on the data reflected here. It is reiterated (as stated at SBT3 and since) that stakeholder retain the right to return to data issues in the process, with evidence from the literature or official plans.

Table 4: Characteristics of new electricity generation technologies

	Capex: pv capital expend-iture ***(R/kW in yr - 2003 R)***	***Ffixed 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)***	***Effic-iency*** ***(%)***	***Lead time*** ***(years - construc-tion lead time)***	***Avail-ability factor*** ***(%)***	***Capa-city factor*** ***(%)***
PF dry-cooled with FGD	R9 980	R125	R7.5	642	30	34.6	4	88	
Fluidized bed combustion (FBC) greenfield with FGD	R11 511	R205	R19.5	233	30	36.7	4	86	
Supercritical 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
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
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	
PBMRlater 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	

It should be noted that lead times are construction lead times, and do not include time required for pre-feasibility and EIA process. Lead times including these processes may be longer, and high global demand for power plants may affect timing of actual implementation. Variable O&M costs as inputs to the Markal model do not explicitly include fuel costs, but costs attached to fuels upstream are taken into account by the model. 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).

Note that 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, be it from hydro-electric, gas- or coal-fired stations.

Wind turbines will be made available 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 will be placed on the wind turbines to reflect the number of good sites available. The research team will report these upper bounds in a future report.[4]

The research team will also further specify the kind of biomass co-generation used, which draws on waste products such as bagasse, wood chips, etc.

The capital cost and capacity factors for solar thermal plants (the 'power tower' as well as the trough) are within the quite wide range of capital costs reflected in the literature on solar thermal plants (World Bank 2006, 1999; NREL 1999; Sargent & Lundy 2003; Philibert 2005; De Vries *et al.* 2007; UNEP 2006; IEA & OECD 2006; IEA 2003; EDRC 2003; Banks & Schäffler 2005; Winkler 2006; DME 2004). The values reflected in Table 4 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 noted that it agreed to proceed with these numbers with caution, as the plant had not yet been built.[5]

Following queries from stakeholders, it is noted that CCGT costs do not include costs of re-gasification plant; but that such costs are included within in fuel costs, considered upstream in the modeling.

The exchange rate is relevant for imported capital equipment. In the modeling, the investment costs of power plants will be first taken in dollars, then converted by the exchange rate of R7.50 in 2003, increasing at 2% per year (as decided by SBT3).

Several stakeholders suggested that imported coal-fired electricity from Botswana needed to be considered. Available information suggests that two phases of approximately 2230 MW each will be developed, with the first phase starting in 2011. The value of the project is reported to be greater than $4 billion, the life of mine: 40 years and production of 12 million tons of coal per year. A significant part of the power (70%) will be sold to Eskom. What is not known is the price at which electricity will be sold (AEJ 2006b, 2006a; CIC 2006). In the absence of cost information, we assume that the levelised cost (c/kWh) of Mmamabula would be the same as a new coal-fired power station in South Africa. This would at least enable more accurate accounting of emissions within SA and attributable to imports. When information about the actual price becomes public, this could be adjusted.

The efficiency of supercritical coal-fired stations has been queried by several stakeholders. It was given as 40%, which the international literature indicates is possible. There is a range of efficiencies reported, from 36 – 42% (NEA *et al.* 2005). There is also evidence that in developing countries, efficiency may be lower than international values (Chikkatur & Sagar 2006). Given these various factors, our approach is to reduce efficiency of supercritical to 38% for the first new stations built, but to include more efficient stations (at 40%) from 2030 onwards.

Ultra-supercritical coal is not reflected in the table, as complete information across all the parameters required has not been found by the team, nor provided by stakeholders. The research team will consider inclusion, if further data becomes available. Further information on representing industrial co-generation in generic form in the modeling is being sought by the research team.

The following sections briefly describes the power generation technologies considered in this study. These technologies are currently available or are likely to become commercial available within the projected time period. Further detail describing the various technologies are provided in the Appendix.

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[4] This approach was agreed in a discussion of the small working group on 26 January 2007.

[5] This approach was agreed in a discussion of the small working group on 26 January 2007.

2.2.1.3 *Refineries*

All existing refineries are included in the model as a single unit of refining capacity, as are the synfuel plants. New crude oil refineries all have a capacity of 300 000 bbl/day. A new coal-to-liquid (CTL) plant is also included as an option, with 80 000 bbl-equivalent / day.

The new bio-ethanol plant under construction in Bothaville in the Free State is also included explicitly in the model. By the end of 2007 it is expected to be producing 473 000 litres of alcohol per day from 1126 tons of maize daily (25 Degrees 2006). Plans are in place for another seven such plants to be constructed in the Free State, North West and Mpumalanga.

Table 5: 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

Refineries can be set up to produce outputs in different ratios. The outputs for different refineries are reported in Table 6 by energy output.

Table 6: 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 / alchohols	8.2%	Fuel alchohols	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 to existing ones, as demand for fuels shifts.

Table 7: 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%

2.2.2 Non-energy emissions in waste, agriculture and land use

There area number of the non-energy sectors that are covered in this project. Each sector includes a number of activities as listed below.

- waste (solid, waste water treatment);
- agriculture (enteric fermentation, manure management, reduced tillage, burning of sugar cane residues);
- land use (wild fire, savanna thickening, afforestation);

This section deals with the latter three areas (waste, agriculture and land use), while the methodology for industrial process emissions is described in section 2.2.3.

The non-energy sector consists of a number of very diverse activities. The goal is to create a a suite of predictive models for emissions from this 'sector' that are robust and sufficiently flexible to allow a variety of processes and activities. The analysis of non-energy emissions is therefore could not be conducted through a single model, but in a series of spreadsheets. To ensure meaningful results from these models, the input data needs to be reliable and consistent across sectors. The output from the models has to be structured in the same format as the outputs from the energy sector model, to allow for comparison across all sectors.

Each activity within the sector has a completely different set of input parameters and is modelled using different set of equations. Each of these spreadsheet models, together with important data, assumptions and methodology are described in the sections below. More details on methodologies and explanations on data sources and assumptions made are provided in appendices.

2.2.2.1 Selection of mitigation options

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. The key general sources were:

- the previous South African greenhouse gas inventory and the associated country studies;
- Technology Needs Assessment for South Africa with respect to Climate change;
- IPCC guidelines.

The potential for mitigation in agriculture is explained and the international experience is summarised in Appendix 1. It is based on the Pew Centre on Global Climate Change publication entitled 'Agriculture's role in Greenhouse gas mitigation' (Paustian et al., 2006). The US experience described in this publication can be used as a point of reference for the role that agriculture can play in GHG mitigation in South Africa. More information will soon become available when IPCC 4th Assessment report by Working Group3 (IPCC, 2007 chapter 8: Agriculture) will be published. Some information from this Chapter (contributed by B Scholes, one of the co-authors) is used below.

The representatives of each sector which form a part of the LTMS stakeholder group, as well as other sector representatives, were consulted on the selection of mitigation options and on recent data that could be incorporated into the models.

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

It is important to note that most of the mitigation options considered below are based on reduction of CH_4 emissions. Since CH_4 has much shorter lifetime in the atmosphere (circa 12 years compared to 120 years for CO_2), and its 100-year global warming potential is 21 times higher on a mass basis than for CO_2 (Reference), it is an excellent candidate for mitigation, since stabilisation in 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 was based on the relative importance of the sector in terms of mitigation potential and relative size of the error resulting from the uncertainty associated with the existing calculations. This is tabulated below (Table 8).

Table 8: Uncertainty associated with sector emissions and accuracy of existing models (based on the total national emissions for 1990 of 347346 Gg $CO_{2\ eq}$

Source: DEAT: National Communication report, 2000

Sector	***1990 emis-sions (Mt CO_2 eq)***	***% of total (%)***	***2003 emissions***	***Average (2003-2050)***	***Mitigation potential (%)***	***Mitigation potential (2003-2050) (Mt CO_2 eq)***	***Uncer-tainty %***	***Error (Mt CO_2 e)q***	***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 savannah 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

From Table 8 it is clear that there is large potential for reducing emissions through:

1. enhancing sinks by fire control and savannah thickening;
2. solid waste management; and
3. enteric fermentation.

It is also important to note that 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 (so the error will be even less if compared to total emissions in the later years)

Although existing models were used were possible, some models and calculations were updated in cases when new information became available to allow for more accurate modelling.

Where data up to 2005 are available, the mitigation options are assumed to start from 2006, while for the rest of the options the mitigation implementation commencement year is assumed to be 2004 (if there are no technological barriers that force a later commencement).

Some mitigation options that are applicable in other countries, but not planned for South Africa, were excluded. For example waste incineration will only be considered for biomass waste, as incineration of domestic waste is not recommended by South African studies and strategies. Therefore, incineration of domestic waste is not considered.

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 ha is already relatively low and therefore the mitigation potential is limited.

2.2.3 Industrial process emissions (non-energy)

Industrial process emissions were modelled using a spreadsheet extrapolation from the base year in each case (see below) and were considered for the following industries:

- mineral products: cement production; lime production and dolomite use;
- chemicals: ammonia production; nitric acid production; carbide production; balance of the chemical sector;
- metals: iron and steel; ferro-alloys;
- mine emissions: coal mining;
- synfuels specific emissions: methane emissions; concentrated CO_2 streams; expanded coal-to-liquids production.

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, 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. In addition to this, some figures in the Inventory for 1990 were found to be inaccurate or absent, and were re-assessed. Table 9 portrays industrial process emissions and the relevant base year:

The 2003 emissions were then extrapolated on the same basis until 2050, using the same growth assumptions as the MARKAL model used for the energy sector: in other words, except for a few (pre 2009) short-term variations described in Table 9 all industries except coal and synfuels were assumed to grow at the same rate as the GDP rate used in the MARKAL model (GDP-e). The coal and synfuels industries were assumed 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 were assumed to remain constant with the following exceptions:

- Synfuels: new CTL plants were assumed to have CH_4 capture, and thus it was assumed that there would be no CH_4 emissions.
- Aluminium: it was assumed that for new production capacity (built after 2003), emissions of PFCs were significantly reduced, resulting in the total emissions factor dropping from the 2003 value of

Mitigation options were selected as the outcome of local consultation and a survey of local and international literature, including the following general studies:

- the previous GHG inventory and the associated country studies
- Technology Needs Assessment for South Africa with respect to Climate change
- IPCC guidelines.

Mitigation options were limited to six sectors: synfuels, coal mining, aluminium, cement, iron and steel and ferro-alloys. These were modelled using a spreadsheet as follows:

- Synfuels: two mitigation options were modelled: 1) capture the CH_4 emissions from the existing CTL plants; and 2) capture and store some of the CO_2 from potential new CTL plants (in the MARLAK model), up to a limit of 20 Mt CO_2 per year.
- Coal mining: reduce CH_4 emissions by 25% or 50%.

- Aluminium: reduce PFC emissions from existing plants.
- Cement: reduce clinker content.

Initial data has been gathered for modeling mitigation in iron and steel and ferro-alloys, but no results are available yet as key parameters still need to be identified.

Table 9: Industrial process emissions data

Industry	***Invent-ory year***	***Base year***	***Inventory year production – tons of product***	***Base year production – tons of product***	***Inventory year emissions – Mt CO_2eq***	***Base year emissions – Mt CO_2eq***	***Inventory year emissions factor – kg CO_2eq per ton product***	***Base year emissions factor - kg CO_2eq 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	2450	2450	Markal elasticity
Nitric acid production	1990	-	274 659	-	-	1.595	-	-	Markal elasticity
Carbide production	1990	2006	269 000	70 000	0.293	0.076	1090	1090	Markal elasticity
Iron and steel production	1990	2003	6 256 961	7 800 000	10.011	12.494	1600	1600	Markal elasticity
Ferro-alloy production	1990	2004	1 796 700	3 931 000	2.698	5.618	1501	1429	Markal elasticity
Aluminium production	1990	2004	175 500	865 000	0.761	2.01	2320	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 concen-trated co$_2$	1990	2003	-	-	23	23	-	-	MARKAL output
Synfuels point-source methane	1990	2003	-	-	3.738	3.738	-	-	MARKAL output

More detailed information on sources of data in Table 9 can be found in the Appendices.

2.2.4 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 *et al.* 1998b). 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, 2007). Further references to the literature on mitigation costs methodology include OECD (2000), Sims (2003) and earlier works listed in Clark & Spalding-Fecher (1999).

The approach can be summarised [6] as follows:

- The life cycle costs of the mitigation options and baseline should be calculated by discounting all of the costs of these options to a present value.
- These life cycle costs should then be levelised, so they are expressed in Rands per year.

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

- The cost effectiveness analysis should be based on the difference in the levelised life cycle costs of the mitigation option and the baseline option (levelised annual cost), divided by the average annual reduction in emissions.
- The cost-effectiveness analysis should exclude taxes and subsidies, external costs, depreciation and interest payments but include private costs or costs which can easily be quantified. Implementation costs should be included.

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

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

$$MC = LIC / ES,$$

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

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

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

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

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

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

2.2.5 Costs as share of GDP or system costs

At SBT4, the approach of expressing mitigation costs as a share of GDP was raised. There is a tradition of expressing mitigation costs in this way (see, for example, Nordhaus 1993; Azar & Schneider 2002; Halsnaes *et al.* 1998a), and generally have found this share to be higher in developing than developed countries. The share of GDP has 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 500-550ppm CO2e 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 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 impacts study does not provide a comprehensive monetization of the damage costs of climate change, it outlines that there would be some costs (see 1.4.10). The 1% of GDP level can be used as an externally-given threshold to assess whether mitigation costs at an acceptable level. 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 for calculating 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 / t CO_2-eq reported in the energy and non-energy modeling. The approach taken to calculating the share of GDP starts with the difference in total energy system costs, i.e. 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 – we take the average (mean) of the shares. The averaged share of GDP is what is reported, in percentages.

Using a similar methodology, the aggregate mitigation costs can be 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 will be higher.

2.3 Methodology for economy-wide modelling

2.3.1 Overview

The study investigates the economy-wide implications of climate change mitigation scenarios, focusing on changes in production and GDP (value added), employment and income distribution. The focus for the economic analysis is mainly on the production/supply side of the economy, i.e., either mitigation actions associated with the supply/generation of energy (liquid fuels, electricity), or energy use by productive activities. Residential energy savings, for example, are not considered, nor are non-energy emissions given modelling difficulties and/or small economic impacts. While short-run effects are briefly considered in the introduction, the focus is primarily on the long run structural effects, and, in particular, the following mitigations actions:

Energy efficiency:

- 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.

Structural changes in energy output mix

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

2.3.2 Energy Efficiency Scenarios (CGE model)

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 consumer 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 **simulationssimulations** implement various percentage reductions in energy use per unit of input, and compare outcome in a comparative static framework.

2.3.3 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 process. In the energy context this implies a relative increase in production capacity towards cleaner processes, e.g. 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 followingfollowing 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 is 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 Van Seventer and Davies, 2006). This is not desirable, hence we consider *relative* changes in production capacity within a sector. This approach allows us to keep the demand side constant; thus we don't have to deal with 'dynamic' issues such as labour force growth, population growth, capital accumulation rules and so on.

The research team discussed the advantages and disadvantages of using computable general equilibrium (CGE) versus fixed-price multiplier models. The team decided in this analysisanalysis to primarily use the IO/SAM multiplier model, for the following reasons:

- Intuitive nature of IO/SAM models as opposed to more complex CGE models where results are often determined by choices around model closures and elasticities, which may seem a bit foreign to people from a non-economics background.
- Results on changes in prices of petroleum and electricity commodities resulting from structural change is fairly dependent on the quality of the disaggregation in these sectors. Initial results from a CGE model show that price changes are likely to be small anyway.
- Using a CGE model for this analysis remains an option.

The **simulationssimulations** implement structural change scenarios and evaluate implications as far as intermediate input demand, production, employment and household incomes are concerned.

2.4 Drivers

The drivers in this section were discussed at SBT3 and revised based on a) the comments made at SBT3, b) further valuable inputs from several of you after the meeting, and c) a small working group discussion specifically on Table 2, dealing with power station costs. The working group eventually reached sufficient consensus on a set of numbers, on the basis of which the research teams now proceeded with their analysis of mitigation actions.

2.4.1 Gross domestic product

2.4.1.1 GDP projections

Together with population, GDP is one of the biggest drivers of energy use. As people become more affluent, their energy consumption changes as they move to cleaner, more convenient fuels (usually electricity), acquire more appliances and demand more energy. In long-term modelling of energy and greenouse gas (GHG) emissions, per capita income is often the major development indicator.

The task of projecting GDP growth is difficult and decisions on growth rates are often politically bias as governments would like to project a continuously high GDP growth when, in fact, this is 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: a single percentage growth. If one examines other developed regions of the world, it is easy to see that GDP growth increases, reaches a peak and then declines.

The IPCC describes this pattern in five major stages of economic development (IPCC 2000):

- First, the pre-industrial economy, in which most resources must be devoted to agriculture because of the low level of productivity.
- Second, the phase of capacity-building that leads to an economic acceleration.

- Third, the acceleration itself (about two decades).
- Fourth, industrialization and catch-up to the 'productivity frontiers' prevailing in the industrialized countries (about six decades).
- Fifth, the period of mass-consumerism and the welfare state.

South Africa is unique in that its apartheid history created a huge disparity between different ethnic groups and the areas in which they live so that today parts of the country represent developed nations while large parts of the country fall into what would be classified as 'developing'. South African could be described as being an accelerating economy (stage 3).

Another factor when developing a GDP growth projection for South Africa is that the impact of HIV/AIDS could play a significant role in the GDP of the country. If we assume that the population will stabilize and decrease over time, then we cannot believe that the GDP will follow an exponential growth. GDP will, to some extent, follow population trends.

Work was done on long-term GDP growth projections for energy modelling by Øvyind Vessia (Vessia 2006) at the Energy Research Centre at UCT. He 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 is the GDP growth pattern used for this study. The assumptions made are somewhat weak but serve as a first approximation for moving away from modelling GDP as a simple exponential growth trend.

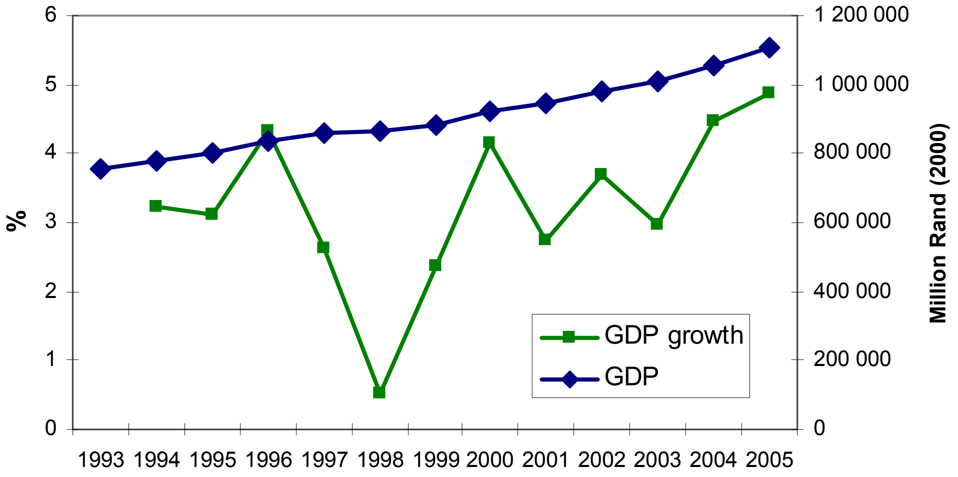

Figure 3: Annual GDP and growth rate for South Africa 1993 – 2005
Source: StatsSA 2006

Over the past 12 years, GDP growth in South Africa has fluctuated between 0.5% and 5% but has shown as positive trend as illustrated in Figure 3. 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). Figure 4 below shows this trend and the GDP growth as well as Vessia's projection of GDP growth to 2060. The current growth trend extends to 2015 and 2016 in which the peak growth at 5.24% is reached, after which growth decreases to a more stable lower level of approximately 2% annual growth.

The literature on GDP growth rates has been assessed *inter alia* by the IPCC (IPCC 2000). The world has witnessed high periodic economic growth in many countries. A per capita GDP growth rate of 3.5% per annum were, for instance, achieved in Western Europe between 1950 and 1980. Similarly, high per capita GDP growth rates were achieved in the developing economies of Asia. Per capita GDP growth rates of individual countries have even been higher – 8 % per annum in Japan over the period 1950-1973, 7 % in Korea between 1965 and 1992, and 6.5 % per year in China since 1980 (IPCC 2000). Based on such analysis, Vessia (2006) suggested that South Africa might be considered to be in and acceleration phase (stage 5). This would be consistent with AsgiSA targets of economic growth increasing from recently relatively low values around 2.5%. In the long-term, GDP growth rates might settle around 3%, consistent with the IPCC's recommendation for discount rates of 3% to be applied for long-term, inter-generational studies (IPCC 2001: 467).

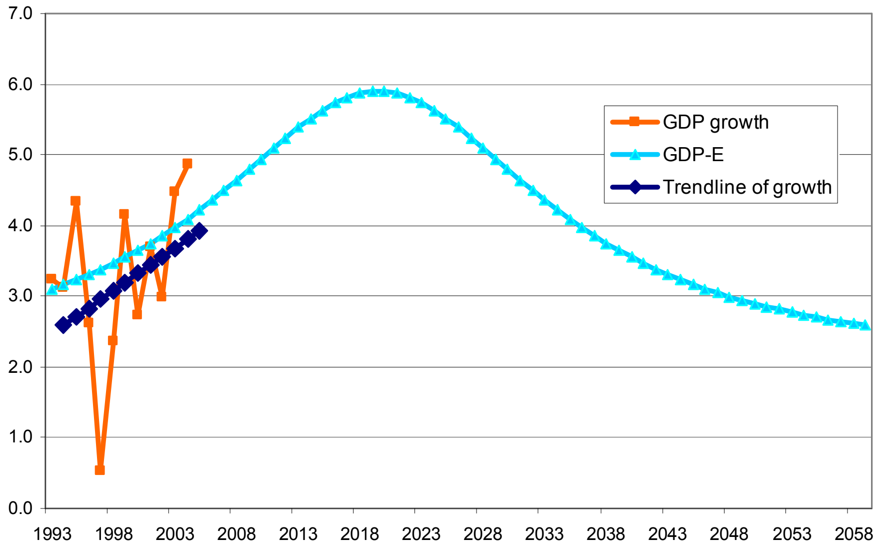

Figure 4: South Africa's GDP growth, the trend line and projected GDP-E growth

Hence the GDP growth projections in Figure 4 are adjusted to peak at 6%.[7] In the longer-term future (from 2030 to 2050), the GDP growth rate starts flattening out around 3%. The growth rate in the initial years lies slightly above the trend-line, but note that the actual data points varied substantially between 1993 – 2005.

2.4.1.2 GDP composition

A meeting with economists was held on 12 July 2007 to discuss macro-economic issues and long-term mitigation. Minutes of the meeting were circulated to SBT members, and documentation from the meeting, including a revised document on sectoral growth trends, was placed on the LTMS web-site. The following information summarises the key implications for modeling in the LTMS process.

The sectoral growth document focused on indices used in modelling the future energy system as a basis for the development of long-term mitigation scenarios. 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. Understanding sectoral growth trends better would have two outcomes for energy modelling: 1) a more realistic 'business as usual' case would result, and 2) policies could be modelled which would shift the GDP to a less energy-intensive basis. These policies promise to be amongst 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 would have on the energy system, and the broader economy.

For the purposes of the energy model, the energy system has been divided into five areas: industry, commerce, transport, residential and agriculture. 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. The most significant of these are described in more detail below, and form the basis of the discussion to follow. It is thus vital for these growth rates to be as plausible and accurate as possible, since these play a large part in determining the plausibility of the energy model as a whole.

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

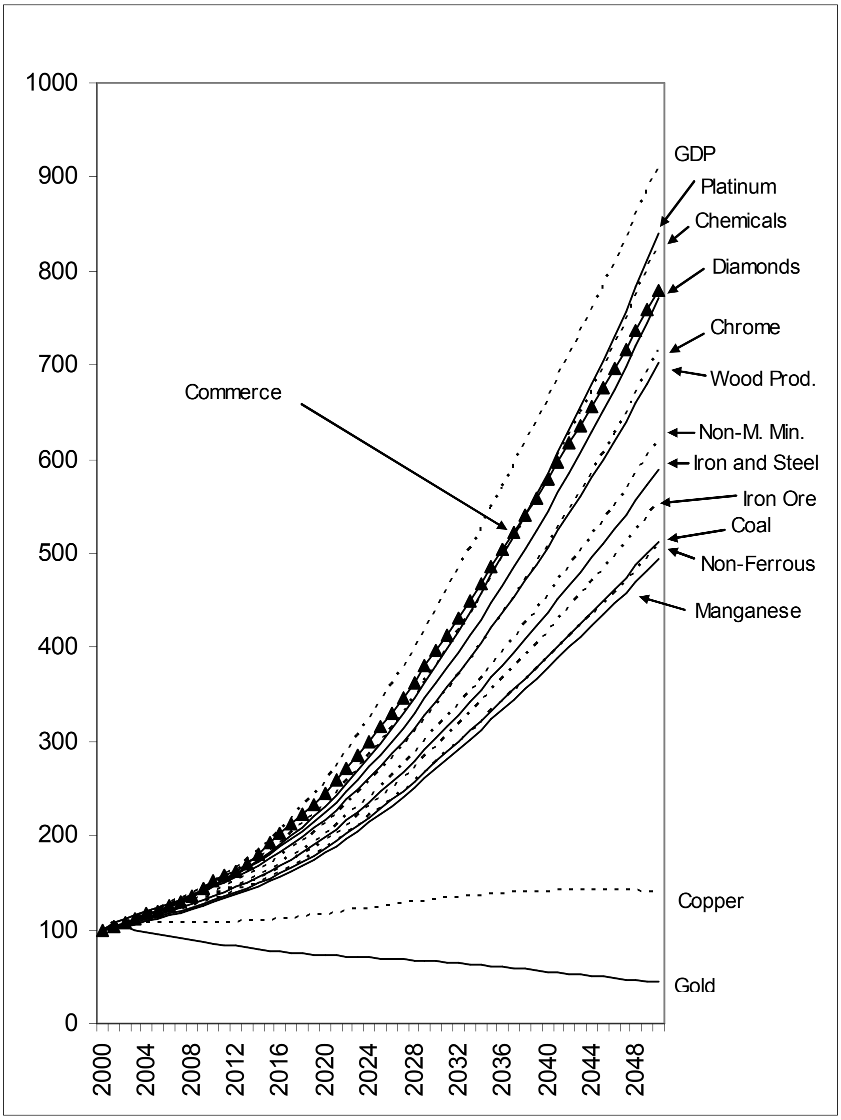

Figure 5: Growth in GDP by industry and commercial sector, old projections

The projections of sectoral growth were discussed with economists in the meeting of 12 July 2007. This served to check expectations as to how different sectors might grow in future. There was agreement that the structure of the economy was likely to change over time. Some information was provided for specific sectors, notably mining. Figure 6 shows the revised projections.

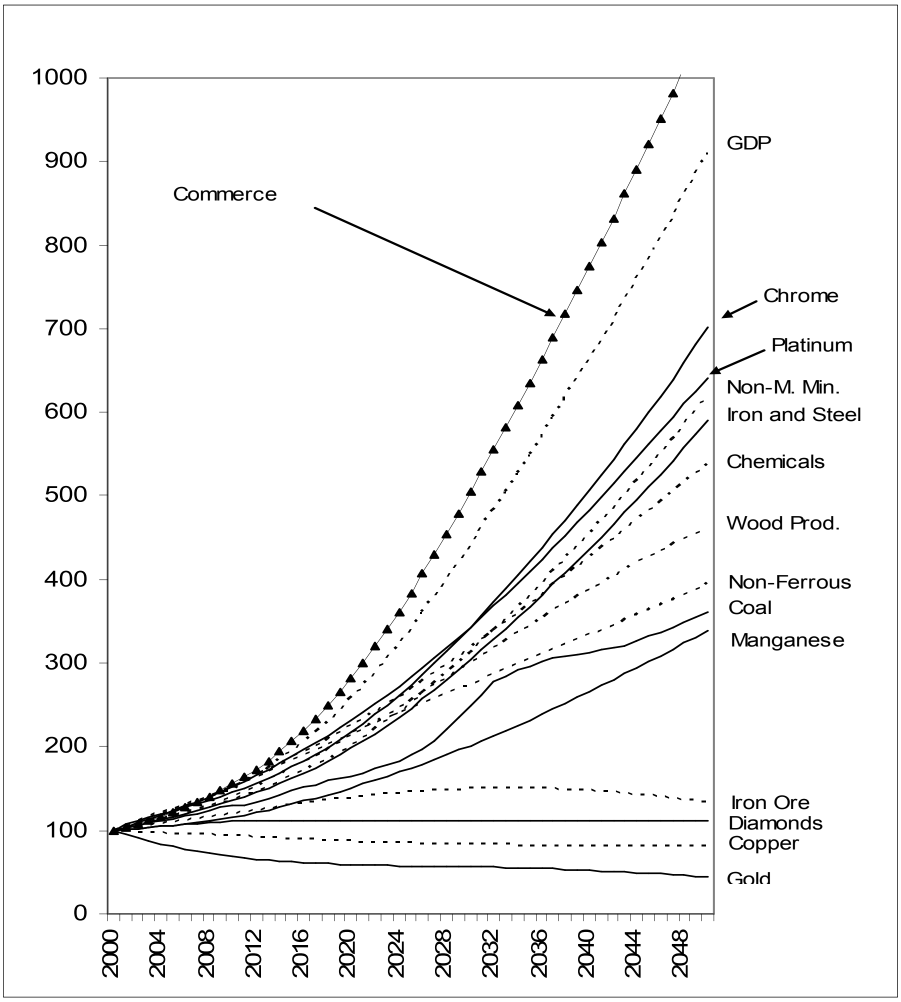

Figure 6: Sectoral growth projections, revised

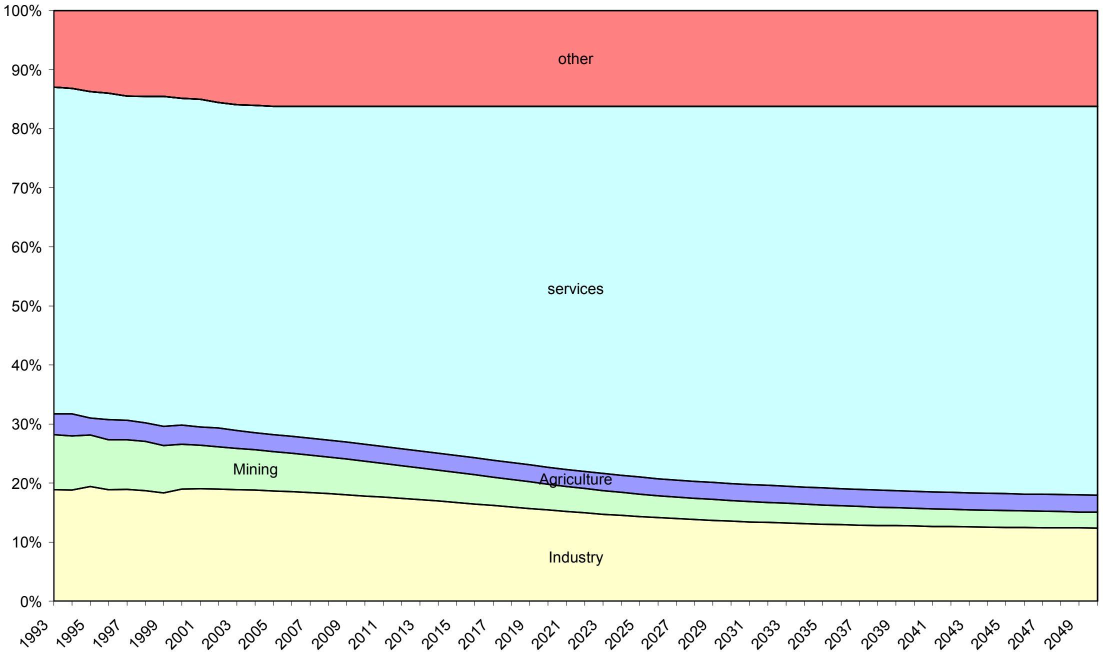

Figure 7: Composition of GDP, all sectors

2.4.2 Population projections

Population projections are a topic of much debate in South Africa given the high rate of HIV infection and how this will impact the growth of the population. Many believe that the population will level off and even decline in the future. No model can perfectly simulate this population growth as there are too many unknown variables. Nevertheless, a study by Professor Dorrington of the University of Cape Town Commerce Faculty for the Actuarial Society of South Africa is well respected for its population projections with the influence of HIV/AIDS (ASSA 2002). This is the model used for this study. Figure 8 below shows the simulated population growth over the study period.

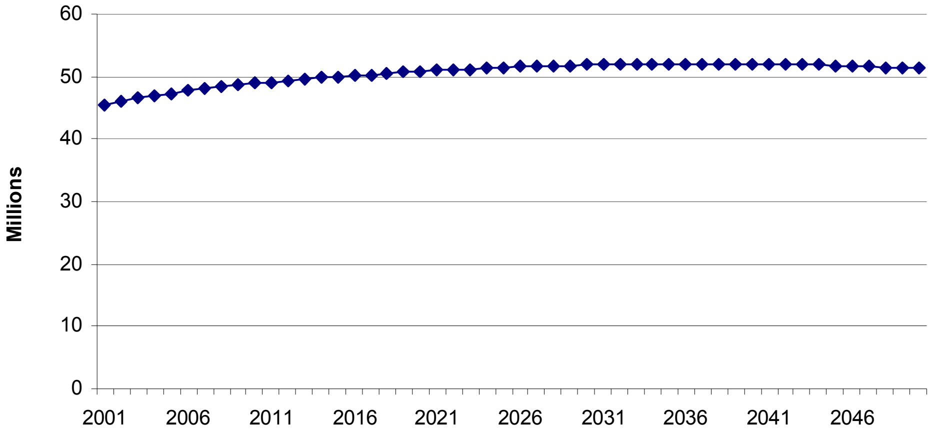

Figure 8: Population projection from ASSA model: 2001 – 2050

2.4.3 Discount rate

The discount rate is a critical factor influencing any analysis of economic effects over time. 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.

As noted at SBT3, 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 1700 professional economists and found that (a) economists believe that lower rates should be applied to problems with long time horizons, such as that 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 5 years hence) to the far distant future (beyond 300 years).

Good practice is to consider more than one rate, to provide policymakers 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 this study, sensitivity analysis will be conducted on discount rates at different levels, e.g. 15%, 10%, 3% and 0%.

2.4.4 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 (IEA & OECD 2000; Repetto & Austin 1997; Fisher & Grubb 1997; Energy Innovations 1997; IEA & OECD 2006) – the extent to which technologies get cheaper over time.

A range of technology learning rates were proposed at SBT2. After some discussion, it was decided to establish a virtual working group to consider this issue. ERC produced a discussion document, a tele-conference was held on 18 October.[8] Good progress was made at the meeting and further input received from some stakeholders. ERC circulated a revised document to participants and others who had indicated interest at the end of October. A further round of comments was invited, after which the document was produced.

The two central explanatory factors why new technologies get cheaper over time are i) learning-by-doing and ii) economies of scale. Further background, including the mathematical approaches used to represent learning, are explained more fully in the SBT3 document. Empirical data on learning for energy technologies has been gathered (IEA & OECD 2000; World Bank 1999; Laitner 2002; NREL 1999; Papineau 2006; Nemet 2006; Junginger *et al.* 2004). Learning curves show the decline in costs (c/kWh for electricity generation technologies) as cumulative electricity production doubles.

Technologies will grow until they reach a maximum global capacity. Using these maximum global potentials, the growth of technologies can be represented in the form of a logistic equation, i.e. one that does not increase exponentially forever, but slows as it approaches an upper limit and eventually flattens out (see Appendix 1 of SBT3 document). If global cumulative capacity approaches an upper limit, the rate of growth in installed capacity will slow, and consequently learning would slow accordingly. The SBT agreed that where the research teams could not find maximum global potentials in the literature, they would assume an estimate. These potentials are reported in the third column of Table 10, with a more detailed derivation in the Appendix 1 of the SBT3 document. In addition, there is information on the rate of the doubling based on the historical growth rates. These doubling times can be used to cross-check doubling resulting from the logistic equation.

Table 10 shows the learning rates for new electricity generating technologies, based on the process undertaken by the working group as outlined above. Appendix 1 of the SBT3 document compared learning ratios from studies, with the last column reporting the values for this study, which were chosen as being within the range cited in the peer-reviewed literature.

Table 10: 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%
Supercritical 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 Appendix 1 of the SBT3 document for all the values.

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[8] Participants were Mandy Rhambaros (Eskom), Richard Worthington (SECCP), Jason Schäffler (Nano Energy), Mary Haw, Harald Winkler (ERC).

It will be noted that gaps exist for some new technologies. Information from stakeholder would be welcome, based on peer-review literature and / or rates used in official plans developed with stakeholder participation (e.g. IEP, NIRP, etc).

Carbon capture and storage (CCS) costs can 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 not listed above. The costs of CCS are added to the costs of power plants. Estimates of future costs as assessed by the IPCC from the international literature (IPCC 2005) will be 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 primarily national (although China is also developing a PBMR-like reactor). The reference plan for NIRP 2 indicated that the first greenfield PBMR (base) would 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 R 18 707 / per installed kW. Costs for the later 'series' multi-module are given at R 10 761 / kW (NER 2004: 28, Table 8). We further assume that the 32 modules would be built over a period of 12 years, i.e. completed by 2025.

The SBT adopted the approach to technology learning, the rates in Table 10 and the above approach to PBMR costs, on the basis of the work by the working group (see also Figure 5 in Appendix 1 of the SBT3 document). 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.

2.4.5 Exchange rate forecasting

South Africa's exchange rate has been volatile in the recent past. Appendix 4 of the SBT3 document showed 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). South Africa follows a flexible exchange rate regime, which allows exchange rates to be determined by the supply and demand for the currency.

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 can therefore 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 we are also unlikely to see the inflation rate dropping to lower levels comparable to that 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. An annual depreciation rate of around 2 to 3% per annum is probably an accurate prediction for the long term future (see Appendix 4 of the SBT3 document for a more detailed discussion).

Based on the literature reviewed by the macro-economic team, the exchange rate will increase at 2% (and following Rod Crompton's suggestion at SBT2, but no need to average). Exchange rate will only apply to imported capital equipment; currently, this is being applied for power plants, refineries and imported fuels, which are quoted in US dollars. It could be applied to major industrial equipment as well, if data were made available by stakeholders, but the intention is not to apply these to small appliances.

The strength or weakness of the South African rand compared to international currencies is another factor that can 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 can 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 assumed exchange rate of R7.50 to the US dollar in 2003 was agreed upon. To follow recent trends of increased exchange rates, a 2% increase per year is assumed (Pauw 2006). Table 11 shows the projected exchange rate of the South African rand to the US dollar from 2003 to 2050.

Table 11: Projected rand-dollar exchange rate over the study period

2003	R 7.50
2005	R 7.80
2010	R 8.62
2015	R 9.51
2020	R 10.50
2025	R 11.59
2030	R 12.80
2035	R 14.13
2040	R 15.61
2045	R 17.23
2050	R 19.02

The energy model is structured in such a way that sensitivity analyses can be run on exchange rate values.

2.4.6 Future energy prices

Predicting future fuel prices is virtually impossible and different theories come up with very different results. The only thing that is certain is that whatever prediction one makes, it will almost definitely not be the real price in future. Yet to model mitigation actions and scenarios, some assumptions must be made.

Prices are reported in R / GJ in Appendix 3 of the SBT3 document.

2.4.6.1 Oil prices

Liquid fuels constitute the largest end use of energy in South Africa. Predicting future prices of these fuels is a key parameter. Background to oil, gas and coal prices are described more fully in Appendix 5 of the SBT3 document. Projections for the crude oil price have 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 2004-5. Even though the oil price for 2030 is lower than current levels, all major projections suggest these levels.

The possibility of a second synthetic fuel plant will be included in the modeling. It can be included either in Current development plans or Growth without constraints.

→ For the reference case, we project 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.

2.4.6.2 Gas prices

Prices 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, we assume that the increase continues at the same rate as 2003-2030.

2.4.6.3 Coal prices

As agreed at SBT2, the domestic coal price for electricity generation is higher at R 6 / GJ, than in previous studies (about R 3 / GJ). Domestic coal prices are expected to increase, as it is believed that as resources become more difficult to extract. Hence this assumes a higher coal price for coal than previous work. Beyond that, coal may increase further in prices, according to Ernst Venter of Kumba, as it is likely that during the next few decades, coal could be in much shorter supply.[9]

Prices rise from around R 3 / GJ in 2003 and then rise to R6 per GJ, in 2030 after which they increase further.

2.4.7 Emission factors

The study generally uses IPCC default emission factors. In the energy model, emission factors are placed on the primary energy carriers at the point where the fuel is combusted. For example emissions from petrol are placed on the petrol going into a vehicle and not on the crude oil going into a refinery. Excess emissions from the refining process itself, are placed on the refinery. Coal being burnt in power stations has emissions factors associated with it, but electricity does not have emission factors.

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 t CO_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). Following IPCC methodology, local emission factors or adjustments to defaults based on local conditions were made.

For carbon dioxide from other bituminous coal, 26.25 tC/TJ was 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 19.59MJ/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.

At the time of the study, biofuels do not have emissions associated with them in the model since they are regarded as carbon neutral. Taking into account up- and down-stream emissions, biofuel production may show in some cases that biofuels have substantial emissions (Von Blottnitz & Curran in press). This is supported by American studies for ethanol on maize that show a positive-carbon balanc

2.5 Constraints

2.5.1 Constraints in energy modeling

At SBT4, stakeholders requested further information on constraints, noting that constraints were of various kinds. References was made to a number of different *kinds* of constraints – physical constraints, constraints on resource availability (e.g. coal, uranium, helium, water, land and others). The energy modeling team noted that even in ‘Growth without Constraints’, 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 in energy modeling. The constraints included are resource constraints, ‘build’ constraints and so-called ‘activity ratios’.

Resource constraints are applied where there is a limit on the availability of a resource. In Markal, these are typically applied as upper, fixed or lower bounds on technologies using a resource (BOUND(BD) in Markalese). The bounds are shown in Table 12.

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

Table 12: Upper, fixed and lower bounds on technologies using energy resources

Unit: GW (total capacity that can be built)	*Type of bound*	*2003*	*2005*	*2015*	*2025*	*2035*	*2050*
Bagasse co-gen station new 1	UP	0.1130	0.1130	0.1130	0.1130	0.1130	0.1130
New CCGT	UP	3.8700	3.8700	3.8700	3.8700	3.8700	3.8700
New FBC station	UP	11.1840	11.1840	11.1840	11.1840	11.1840	11.1840
New OCGT natural gas	UP	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Interutible supply	UP	1.5100	1.5100	0.3840	0.3840	0.3840	0.3840
Landfill gas electricity generation large installations	UP	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Landfill gas electricity generation medium installations	UP	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270
Landfill gas electricity generation micro installations	UP	0.0230	0.0230	0.0230	0.0230	0.0230	0.0230
Landfill gas electricity generation small installations	UP	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200
New PBMR station	UP	1.9800	1.9800	1.9800	1.9800	1.9800	1.9800
New PF station with FGD	UP	40.0000	40.0000	40.0000	40.0000	40.0000	40.0000
Camden PF station	UP	1.5200	1.5200	1.5200	1.5200	1.5200	0.0000
Grootvlei PF station	UP	1.1280	1.1280	1.1280	1.1280	1.1280	0.0000
Komati A PF station	UP	0.4350	0.4350	0.4350	0.4350	0.4350	0.0000
Komati B PF station	UP	0.4560	0.4560	0.4560	0.4560	0.4560	0.0000
New Braamhoek pumped storage plant	UP	1.3320	1.3320	1.3320	1.3320	1.3320	1.3320
New generic pumped storage plant	UP	0.9990	0.9990	0.9990	0.9990	0.9990	0.9990
New PWR station	UP	15.0000	15.0000	15.0000	15.0000	15.0000	15.0000
Wind turbine 20% load factor	UP	0.0000	0.0000	1.9250	5.7750	7.7000	7.7000
Wind turbine 25% load factor	UP	0.0033	0.0033	1.9275	5.7758	7.7000	7.7000
New Integrated Gasification Combined Cycle	UP						
New CCGT at Coega	UP	3.6000	3.6000	3.6000	3.6000	3.6000	3.6000
New CCGT at New Castle, KZN	UP	0.0150	0.0150	0.0150	0.0150	0.0150	0.0150
New Super Critical coal with FGD	UP	40.0000	40.0000	40.0000	40.0000	40.0000	40.0000
OCGT in Atlantis - under construction	FX	0.0000	0.0000	0.6160	0.6160	0.6160	0.6160
OCGT in Mossel Bay - under construction	FX	0.0000	0.0000	0.4530	0.4530	0.4530	0.4530

Build constraints might apply even if the energy resource is available, technology might not be able to be built. 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 13 shows the constraints for building of power stations applied in GWC.

Table 13: Build constraints (IBOUND(BD)) on power stations

Unit: GW (capacity built /yr)		*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

There is a build bound on new CTL plants in GWC, of 26 PJ per year.

The year in which new technologies can start can be thought of as a constraint as well. Starting dates for power plants are entered in the energy model, based on the lead times agreed as part of the table of characteristics of new electricity generation technologies (Table 8 of the appendix). The earliest starting dates for refineries are showing in the following list; the technology may come in later, so years shown are the earliest possible:

- 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 bio-diesel refinery; 2007;
- new bioethanol refinery; 2008;
- new small bio-diesel refinery; 2007;
- Sasol CTL - new; 2014.

A range of other factors are ‘constrained’ in energy modeling. Markal itself solves for the least-cost solution subject to a number of built-in constraints, e.g. energy supply meeting demand, maintaining reserve margin, etc. 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 paramaters. For example, if the energy demand for lighting in residential households can be met by incandescents, CFLs, candles, and paraffin lights, the relevant RAT_ACT is 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) is used as a starting point. These ratios can be kept fixed (if there is no reason to expect that they would change). To allow fuel-switching in policy cases, RAT_ACTs are defined with upper and lower bounds, so that the shares can change over time. The set of RAT_ACTs is too large to reflect in a table here, but a complete dump from the Markal model is available on request.

2.5.2 Availability of water

2.5.2.1 Water constraints on new coal-to-liquid plants

Sasol currently has two plants receiving water from the Integrated Vaal River System. The Sasol Secunda Complex’s primary source of water is Grootdraai Dam, which will be supported through the Vaal River Eastern Sub-system Augmentation Project in 2008. The Sasol Sasolburg Complex is supplied from Vaal Dam, which is 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 14: Sasol's water requirements

Source: DWAF (2006)

	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

This projection by DWAF does not include any new plants from SASOL. According to Sasol the water requirement per new CTL of 80 000 bbl / d is approximately 40 million m^3 (Fraser 2007). The current allocation of 3000 million m^3 of water in the Vaal water system is fully allocated.

Under normal economic and population growth scenarios, the next augmentation to the Vaal water system from the Lesotho Highlands Transfer scheme is planned for around 2020. The feasibility study is due for completion by December 2007. This would be followed by a transfer scheme from the Thukela in 2035. It is envisaged that augmentation from the Umzimvubu would only be required in 2050. This will be a very costly scheme – estimated at two times that of the other two (van Rooyen 2007).

The system can accommodate 2 new CTLs by 2020 by implementing stringent DSM in the Vaal system. A major problem with this however, is that it will bring the system too close to its limits, leaving very little reserve margin. Given that a 12-15 year period from conception to commissioning is required, it is already unlikely that one of the augmentation schemes will be built before 2020 in time for additional Sasol plants (van Rooyen 2007).

In order to accommodate the additional 3 CTL's 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.

Table 15: The present value costs and capacity

Scheme	***Capacity***	***Estimated cost***
Lesotho Highlands	~460 million m^3 (DWAF 2006)	Study due in Dec 07. Possibly same magnitude as Thukela.
Thukela (KZN)	450 million m^3 (DWAF 2001)	R 5 billion (1998) (DWAF 2001)
Umzimvubu (E-Cape)	630-1260 million m^3 (a portion of this would be needed for agriculture in Transkei) (van Rooyen 2007)	¬ R17 - 32billion (2006) (Rademeyer 2007)

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

- desalination from Richard's Bay, pumped up to Vaal River;
- reallocation of water use, although this is unlikely to happen before the augmentation of the Lesotho Highlands or Thukela options since the Agricultural lobby is unlikely to give up its allocation;
- use of return flows in the Vaal system is already taking place.

DWAF have recently completed the first stage reconciliation strategy for the Vaal River system and are currently working on the second phase study which will incorporate updated water requirements from the bulk users, Eskom and Sasol.

2.5.2.2 *Water for coal power stations*

Eskom currently operates 12 coal fired electrical power stations, which receive water from the Integrated Vaal River System. Some of these stations were decommissioned and are now being de-mothballed to increase 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 Vaal Dam, and current planning is that the third will be located close to the existing Kendal Power Station and receive water from the Eastern Vaal River Sub-system (a component of the Integrated Vaal River System). The table below provides a summary of the water requirements and lists all the power stations, 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 would have a less significant impact if they are dry cooled, i.e. 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 16: Eskom's water requirements

Source: DWAF (2006)

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
Kendel		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

3. Description of mitigation actions

Mitigation actions were considered by SBT3 in three categories – energy supply, energy use and non-energy emissions. Each of these includes sub-sectors. Energy modeling considered energy supply (notably electricity generation and liquid fuels), as well as energy use in major economic sectors – industry, transport, commercial, residential and agricultural sectors. The CSIR considered non-energy emissions in agriculture, waste and land use, land use change and forestry (LULUCF). Industrial process emissions were considered by Gerrit Kornelius of AirShed, focusing on synfuels production, coal mining, iron and steel, ferro-alloy production, alumium and cement.

The notion of 'wedges' was developed by Pacala and Socolow (2004){, 2004 #2121} to show that a range of existing technologies could deliver 1 GtC in emission reductions over the next 25 years. The challenge was to scale up technologies, provide policy guidance and channel investment. Wedges in the LTMS context mean emission reductions over time. If the reduction increase over time, the graphs have the shape of a wedge. Mitigation actions and the resultant wedges are used somewhat interchangeably in this report.

Table 18 provides a brief description of the mitigation actions modelled, including key model parameters, time-frames, goals (e.g. penetration rates, extent of action) for the reference and mitigation cases. Below, we describe in more detail the parameters for each mitigation action. Results for the modelling are described in detail in sections 4.2.15 to 4.2.20.

3.1.1 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 scenario these technologies are introduced in 2008, i.e in the first year that government is expecting to implement awareness campaigns under the energy strategy. The exception is efficient lighting options such as CFL's which are introduced prior to 2008. This is done because attempts to improve lighting efficiency through the use of CFL's 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.

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 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 and 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 are 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 is 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 (VSD's) 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).

It is assumed that variable speed drives can improve the efficiency of HVAC systems by 15% and that 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 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 5 years is assumed for these measures.

Heat pumps and central air conditioners are allowed to meet a greater portion of demand after 2008. The portion of demand that 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 met their cooling needs.

Thermal design

It is assumed that 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. The savings are introduced into new buildings from 2008 onwards.

Efficient lighting

Retrofits and a move towards CFL's 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%.

It is assumed that lighting demand in existing buildings can 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 periods for the lighting retrofit is 4 years, ballasts are replaced with electronic ballasts as they fail at no additional cost.

CFL's are allowed to replace 3.3% of demand for incandescent lighting in 2015 and 6% of demand for incandescent lighting by 2030.

In new buildings it is assumed that improved design will 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 is assumed to reduce 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. It is assumed that 25% of appliance demand can increase 15% in efficiency and a further 25% can achieve a 30% increase in efficiency. These measures are assumed to have a one year payback.

3.1.2 Energy efficiency in the Industrial sector

The industrial sector is a sector which promises great opportunities for improving energy efficiency. In this sector improvements in energy efficiency 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 2008 and continue to improve until 2030. They are assumed to be 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 below, in all cases the savings suggested are the average savings that could be achieved across all types of industries 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 a 20% improvement in steam system efficiency could be achieved. An average payback period of 1.4 years is assumed for the basket of measures.

Compressed air savings

Compressed air savings can be realised at the compressors as well as the ducting system. Fixing leaks in compressed air pipes and 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. We estimate the payback period for compressed air savings to be 11 months and that a saving of 20% is achievable.

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 are 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 6 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 7 years

Industrial measures are allowed a penetration rate of between 2% and 7% each year, ie 2-7% of demand is assumed to improve in efficiency each year. This penetration rate is based on anticipated success of audits and awareness campaigns, but it should be noted that without significant effort on the part of government it is likely that this penetration rate will be achieved (Howells et al, 2003).

3.1.3 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 measures taken in the residential case to achieve the savings.

Basa Njengo Magogo

An improved method of using coal braziers known as the ‘Basa Njengo Magogo’ method shows an increase in efficiency of 37.5%. This method of cooking which is simple and requires no additional or alternative appliances is part of a DME 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 as the fire is lit from the top of the Briazier and burns slowly down, in the traditional method of cooking the fire is lit at the bottom of the stove. 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), it is assumed that the Basa Njenga Magogo method is used in up to 3% of households in 2015 and 7% in 2030. In the reference case it is assumed that in Urban Low-income Electrified and Non-electrified households up to 20% of coal braziers shift to the Basa Njenga Magogo method by 2015 and 40% by 2030 for space heating and cooking. These upper bounds on penetration rates are based on assumptions about the effectiveness of government programs to reach households and convince them to shift to the new method.

Solar water heaters

Solar water heaters (SWHs) are gaining popularity with cities such as Cape Town considering policies to make Solar water heaters on new homes a by-law. In the residential reference case, we allow high penetration rates of Solar water heaters, Table 17 shows the assumed penetration rates of solar water heaters into new houses. A much lower rate is assumed for old houses.

Table 17: Assumed rates of adoption of solar water heaters by household type

	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%
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 water heating technology to be implemented in this scenario. We assume a high penetration rate of approximately 65% of electric geysers are 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 it greatly affects the thermal comfort and space heating requirements of the building. In this scenario we assume a high penetration of thermal efficiency in new buildings and a smaller penetration rate for old buildings where limited retrofit is possible and more costly. In new houses it is assumed 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 replacement to paraffin for use in low-income houses for cooking and lighting. Advantages are mainly in safety (if knocked over, gel fuel stoves will not cause wide-spread fires as paraffin stoves do) and in 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, 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.

Given the algorithms used by the model, gel fuel stoves would prove to be very unfavourable in a least-cost optimising scenario. In reality, it seems that gel fuel may have advantages over paraffin that the model cannot take into account: the safety aspect mentioned above and reduced evaporation rate. In the base case there is little to no penetration of gel fuel into the residential fuel mix, however in the reference case, the bounds on 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 base case, a very low penetration rate of CFLs is assumed: 5.3% in urban areas and 1.9% in rural areas. In the reference case this is increased dramatically to 40% by 2015 in urban areas and up to 35% in rural areas. The upper bound on penetration 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.

3.1.4 Energy efficiency in transport

The overall target for final energy demand reduction in the transport sector by 2015 is 9%. In order to reach this goal a number of stringent policies or measures are introduced. The transport sector energy efficiency case is modelled with less freedom than the other efficiency cases. It is not believed that customers will choose more efficient vehicles without the introduction of policy or that the purchase or use of transport modes amongst the higher income groups is done with consideration to the cost.

In the base case, all new private passenger vehicles and light commercial vehicles increase in efficiency by 0.4% per annum. In the scenario this efficiency improvement is increased to 0.9% per annum, based on savings which have been achieved in the United Kingdom (An & Sauer 2004). 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 recapitalization plan is also included in this scenario. In the base case we have 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 19-35 passengers compared with the mini buses that seat 18 passengers or less and are designed for longer distances. In the scenario, 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 does demonstrate 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 make up 15-30% of private passenger-kilometres by 2030.

Hybrid vehicles are included as an option for improved vehicle efficiency. Hybrid vehicles can make up 2% of passenger km by 2030. SUV use decreases compared to the base case where it is assumed to increase up to 2%. In the scenario the use of SUV's is capped at 1% of private passenger-kilometres.

In addition, the use of public transport is allowed to increase. In the base case public transport is 51.2% of demand, in the scenario case public transport is allowed to grow by 25% above this.

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

In this scenario the biofuels blends are increased to determine the effect this has on the cost and fuel mix of the country. 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. 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. It should be noted however that 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, 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.

3.1.5 Renewable electricity

In this scenario we apply a minimum penetration of renewable technologies for electricity generation. The 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.

3.1.6 Nuclear

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

3.1.7 Tax on CO_2

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 CO_2 emissions from the energy. See results section 4.3.1 below for details.

3.1.8 Mitigation actions in the non-energy sectors

1. Reduction of enteric fermentation by smaller, more productive herd through move from rangelands to feedlots with improved feed. This scenario represents S3 scenario.
2. Improvement of manure management by disposal as dry spread instead of lagoons (80% of manure from dairy and feedlot will be disposed as dry spread).
3. Aggressive adoption of no tillage practice (on 80% of lands). This scenario represents S5 scenario.
4. Less aggressive adoption of no tillage practice (40% for wheat and 20% for maize). This scenario represents S1 scenario.
5. Aggressive adoption of waste management (20% waste minimisation, 15% composting, 35% of LFG capture and use and 20% of LFG flaring). This scenario represents S5 scenario.

6. Less aggressive adoption of waste management (5% waste minimisation, 10% composting, 25% of LFG capture and use and 10% of LFG flaring). This scenario represents S1 scenario.
7. Limited carbon capture and storage (CCS) on new CTL plants (a limit of 20 Mt per year).
8. Methane capture from existing CTL plants.
9. Coal mine methane capture (25% and 50%).
10. PFC capture from existing aluminium plants.
11. Reduction in the clinker content of cement.

Each mitigation action is described in more detail in sections 4.2.15 to 4.2.20.

Table 18: Specification of mitigation actions modelled

Mitigation action	***Model parameters***	***Time-scale***	***Ref. goaf***	***Mit. goal***	***Quantity***	***Remaining comment/ qualifications***
Energy supply[10]						
Renewable electricity action	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	2030		27% (remains at least 27% to end of period)	Total electricity dispatched	Linear extrapolation of 15% by 2020 gives 27% by 2030
Nuclear energy action	27% of electricity dispatched by 2030 is from nuclear, either PBMRs or conventional nuclear PWRs – model optimised for cost etc	2030		27%	Total electricity dispatched	27% in 2030 to be comparable to renewable and clean coal
Cleaner coal for electricity action.	27% of electricity dispatched by supercritical coal and /or IGCC coal technologies by 2030; first plant could be commissioned by 2015	2030		27%	Total electricity dispatched	27% in 2030 to be comparable to renewable and nuclear
Limited CCS action	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	
Carbon/GHG emissions tax	R100 (2003 Rands) per ton of CO_2 from electric power plants, introduced from 2008					
Transport[11]						
Improve energy efficiency of private cars and light commercial vehicles	Vehicle efficiency improves by 0.9%-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	% improvement vehicle efficiency	
Hybrid vehicles	20% of private cars are hybrids by 2030 (ramped up from 0% in 2001	2015 2030		7% 20%	% of private cars which	

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[10] 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).

[11] 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.

Mitigation action	*Model parameters*	*Time-scale*	*Ref. goaf*	*Mit. goal*	*Quantity*	*Remaining comment/ qualifications*
	to 7% in 2015) Shares of petrol cars reduce to accommodate				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%	% passenger kms travelled on public transport	
Encourage vehicle downsizing (e.g. from SUVs)	SUVs limited to 2% of private passenger kms by 2030	2030	4%	2%	% of private passenger kms travelled in SUVs	
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%	% rich households with SWH %poor households with SWH	
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	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%).

Mitigation action	Model parameters	Time-scale	Ref. goaf	Mit. goal	Quantity	Remaining comment/ qualifications
	process control, using building energy management systems, improving building shell design, and introducing variable-speed drives.					Penetration rates for efficient boilers are as in base case: 2015: 51%, 2030:80%, 2050:100%
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	
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 savannah	50% reduction in fire episodes in savannah 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	
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 CH_4 emissions from	2010		0	CH_4	

Mitigation action	***Model parameters***	***Time-scale***	***Ref. goaf***	***Mit. goal***	***Quantity***	***Remaining comment/ qualifications***
capture from existing CCS plants	existing CTL plants from 2010				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	
Cement: clinker reduction	Reduce emissions factor from 715 to 650 kg CO_2/ton of production by reducing clinker content by 2010	2010		650	Emissions factor	

Table 19 provides descriptions of the new and extended wedges modelled for SBT5.

Table 19: Description of extended wedges

Mitigation action	Extended wedge modelled for SBT 5
Cleaner coal	The bound on commissioning of new IGCC capacity increases from 2.5GW/year in 2020 to a maximum 4.5 GW/year in 2030, where it remains until 2050, this allows an increased penetration of IGCC in this scenario. Coal is still restricted to supply a maximum of 80% of total electricity demand.
Renewable Electricity	The bound on commissioning of new Parabolic Trough and Solar Power tower plant is increased to 2.5GW/year. A target of 27% of electricity supplied by renewable generation technologies by 2030 and 50% by 2050 is imposed.
Nuclear electricity	A target of 27% of electricity supplied by renewable generation technologies by 2030 and 50% by 2050 is imposed. The bound on investment in new capacity for both PBMR and PWR were increased.
Renewable and nuclear	This scenario combines the scenarios above. i.e no fossil electricity by 2050
SWH subsidy	The cost of SWHs in the residential sector was reduced. The cost after subsidy in 2001 is 534.7 mil R/PJ/a which reduces further to 336.77 mil R/PJ/a in 2050.
RE electricity subsidy	-106 R/GJ subsidy on electricity from power tower, trough, PV, wind, hydro, bagasse, LFG
CO2 tax	An escalating CO_2 tax is imposed on all energy-related CO_2 emissions , including process emissions from Sasol plants. This scenario does not include further energy efficiency options or increased penetration of nuclear or renewable technologies.
Encouraging vehicle downsizing (limiting SUVs)	SUV penetration is limited to 1% of private passenger kilometre demand in 2050.
Transport modal shift in freight	50% of tonne kilometres are transported by freight. Only increase in freight tonne kilometres over the base case incur an additional infrastructure cost, the additional costs are assumed to be 7million (2003) rand per million additional tonne km of carrying capacity.
Transport passenger kilometre	75 percent of passenger kilometre is carried by public transport. Includes the cost of additional infrastructure in addition to existing carrying capacity. The additional costs are 10 million (2003) rand per million additional passenger km carrying capacity.
Hybrid vehicles	The use of hybrid vehicles are increased at the expense of petrol cars.
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.

4. Results for scenarios and mitigation actions

4.1 Envelope scenarios

4.1.1 Growth without Constraints (GWC)

This is the 'no-mitigation' scenario, in which there is growth without constraints (GWC). It would involve no change from current trends, not even implementing existing policy. This scenario is important for the negotiations, as it could represent a 'maximum position'. By stating this higher-emission case, the substantial mitigation actions required to reach CDP would receive more acknowledgement.

Figure 9 shows upfront the result that emissions under GWC increase dramatically, increasing more than four-fold. Most of the GHG emissions continue to be associated with energy supply and use, with non-energy emissions (industrial processes, waste, agriculture and LULUCF) contributing roughly a fifth. GDP growth drives much of this increase, with more detailed reasons elaborated in the text below.

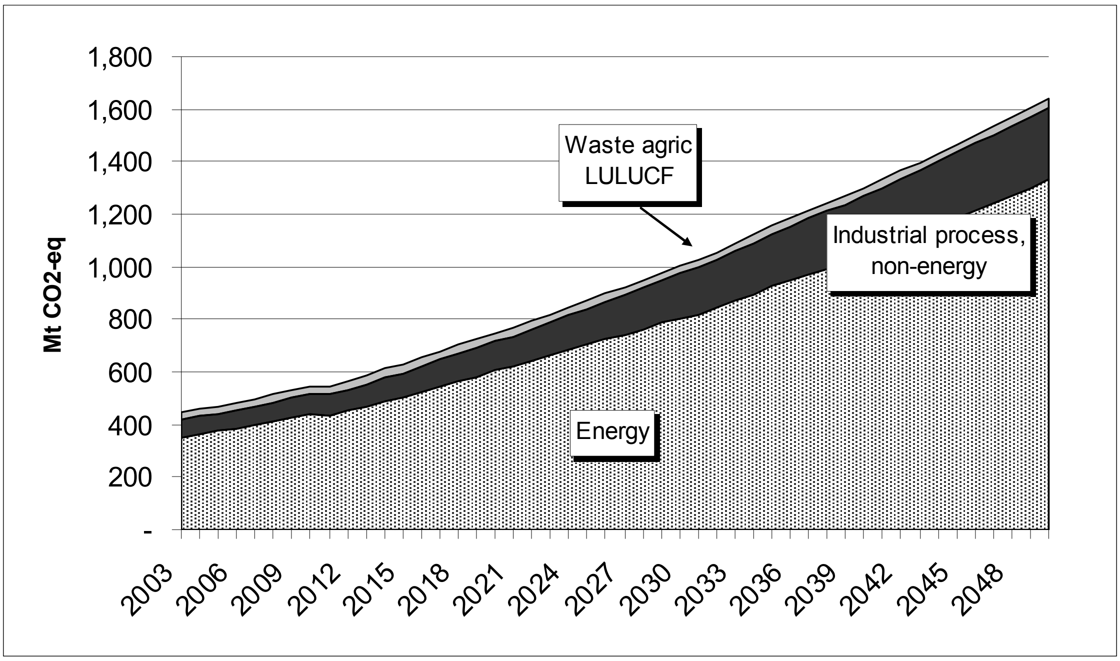


Figure 9: Energy and non-energy emissions under Growth without Constraints, Mt CO_2 –eq

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 10 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 & 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 has resulted in 63% of fuel use using electricity as a carrier 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.

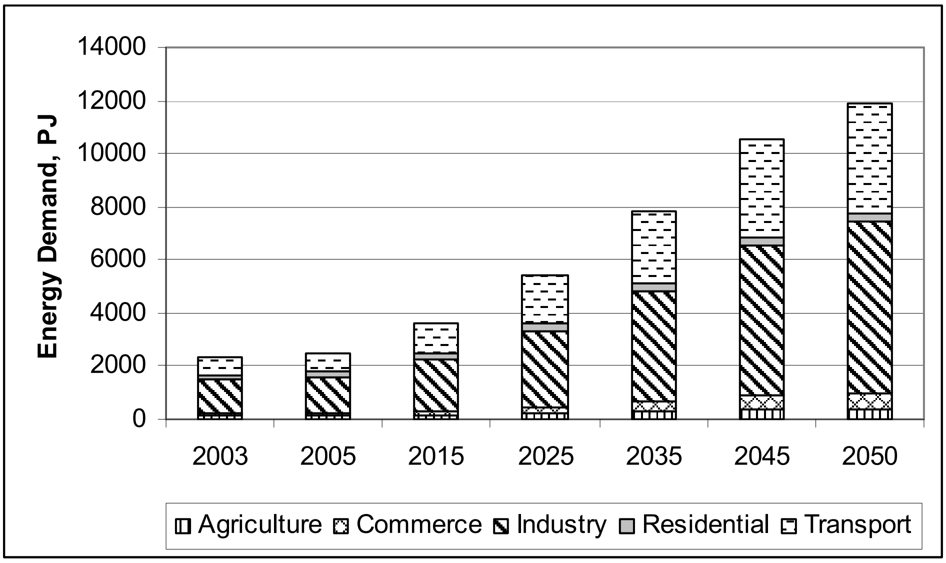


Figure 10: Fuel use by sector, all fuels (PJ)

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 pulverized fuel coal plants are all super-critical with a higher efficiency of 38% rising to 40% over time – no more sub-critical PF coal plants (34.5% efficiency) are built. IGCC plants are the predominant coal-fired technology, comprising 56% of capacity by 2050.

Figure 11 shows new supercritical coal start coming 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 shares of coal and nuclear continues close to 90% until around 2050. CCGT reaches 3% capacity during the period.

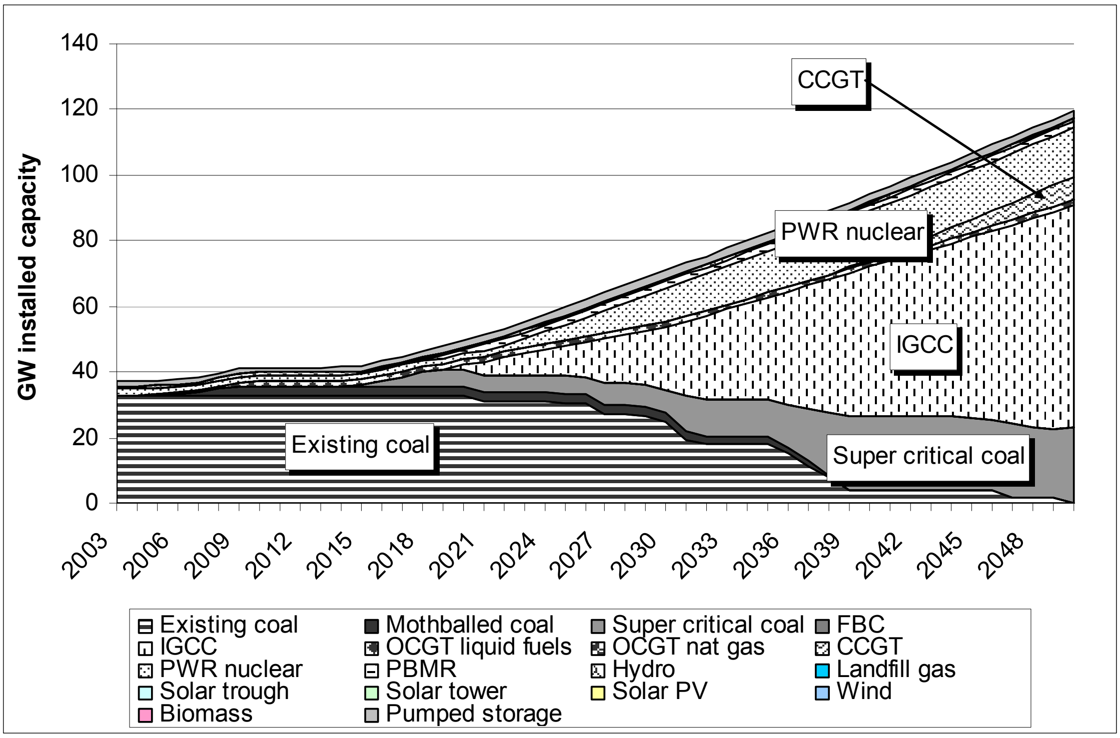


Figure 11: Electricity expansion plan in the GWC case, GW installed capacity 2003-2050

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 a percent of installed capacity, declining from 2.18% of installed capacity in 2003 to 0.74% in 2050 (see also Table 20), 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 20: 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
Super critical 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	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 CTL 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-termperature Fischer-Tropsch, with a product profile of 70% diesel, 25% naphtha (used for petrol) and 5% LPG.

At SBT4, Sasol indicated that only 'half' a new CTL (i.e. 80 000 bbl / day for Mafutha, compared to 160 000 bbl at Secunda) might be built, but agreed to discuss this with the Sasol strategy team. Harald Winkler met with the Sasol team at their request on 21 June 2007 to discuss this matter. A letter from Sasol was received on 27 June, reflecting Sasol's considerations in particular of coal and water constraints on CTL under 'Growth without carbon Constraints'. It concludes 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'. The letter was circulated to SBT members. The research team engaged further with DWAF on the availability of water, which emerged as a key constraint, with 'significant cost implications'. This issue is reflected, together with other constraints, in section 6.

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, we assume that a new CTL plant, with a capacity of 80 000 bbl / d (half of Secunda) could be built no faster than one every six years. Five new CTL 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.

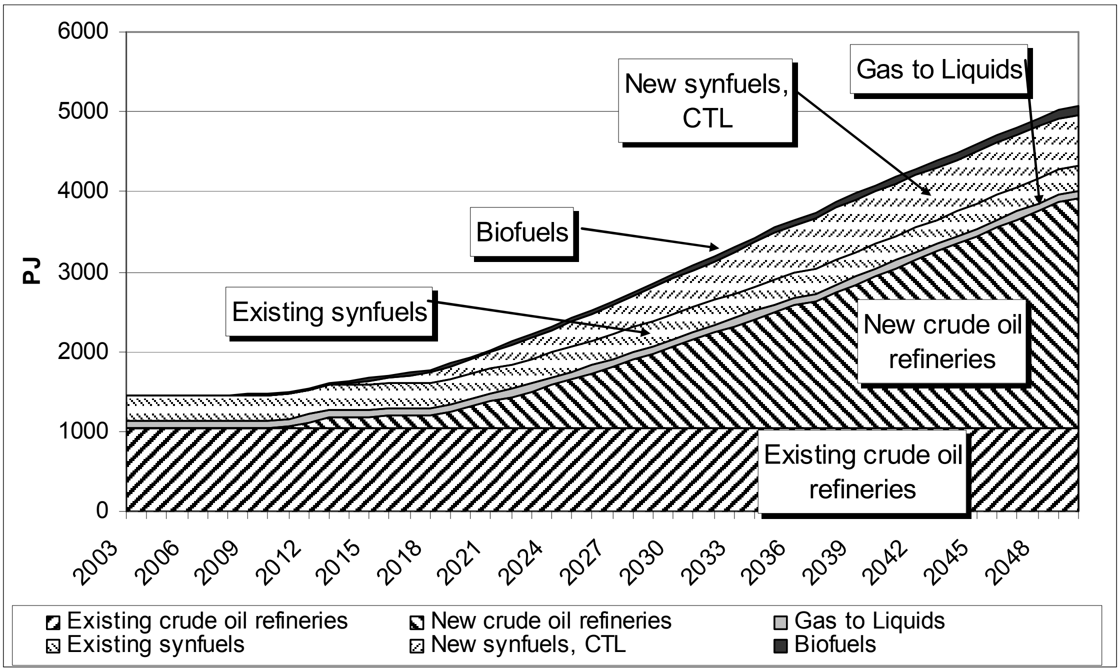


Figure 12: Growth of refinery capacity in the GWC case, 2003-2050

On current energy trends, greenhouse gas emissions will rise dramatically. 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. Without constraints, energy-related emissions grow at an average 2.9% annually. Energy GHG emissions reach 1 330 Mt CO_2eq in 2050, an increase of more than 978 Mt. Electricity generation accounts for 56% of energy-related CO2 emissions in 2003 declining to 41% in 2050. The declining share is due to emissions growth in liquid fuels and coal use in industry, with five new coal-to-liquid plants.

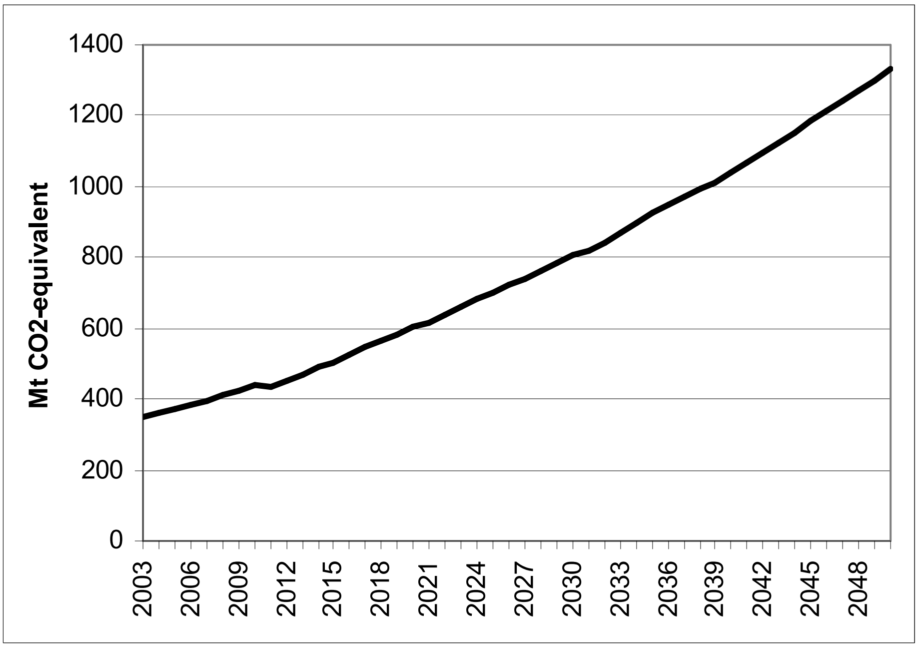


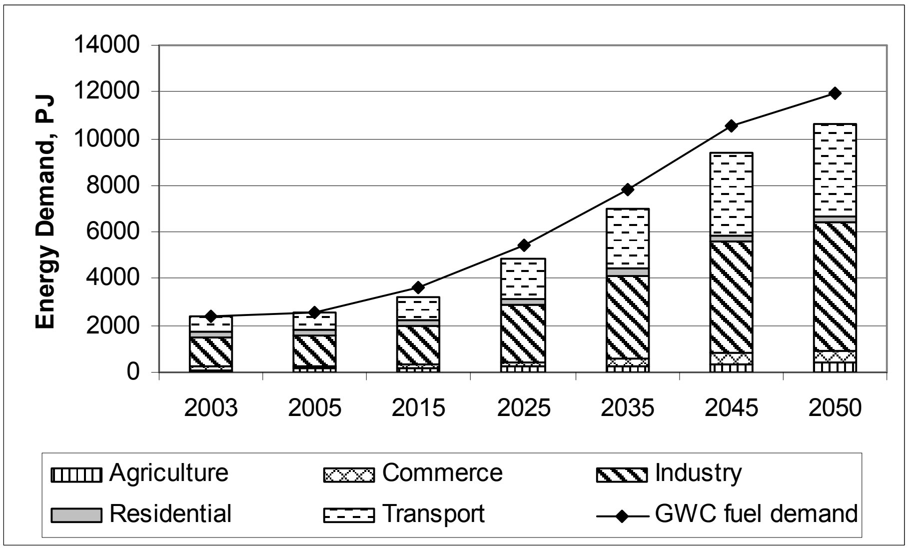
Figure 13: Projections of GHG emissions from energy supply and use in the GWC case, 2003-2050

4.1.2 Current development plans (CDP)

The Current Development Plans (CDP) scenario assumes that existing government policy is implemented. Notably, the energy efficiency target of reducing final energy demand by 15% below projected levels by 2015, and the renewable energy target of 10 000 GWh by 2013 are assumed to be reached. This was consistent with the base case for the Integrated Energy Planning (IEP) process and National Integrated Resource Plan (NIRP2). The SBT agreed that the CDM would be excluded from the base case, as it will have a negligible impact.

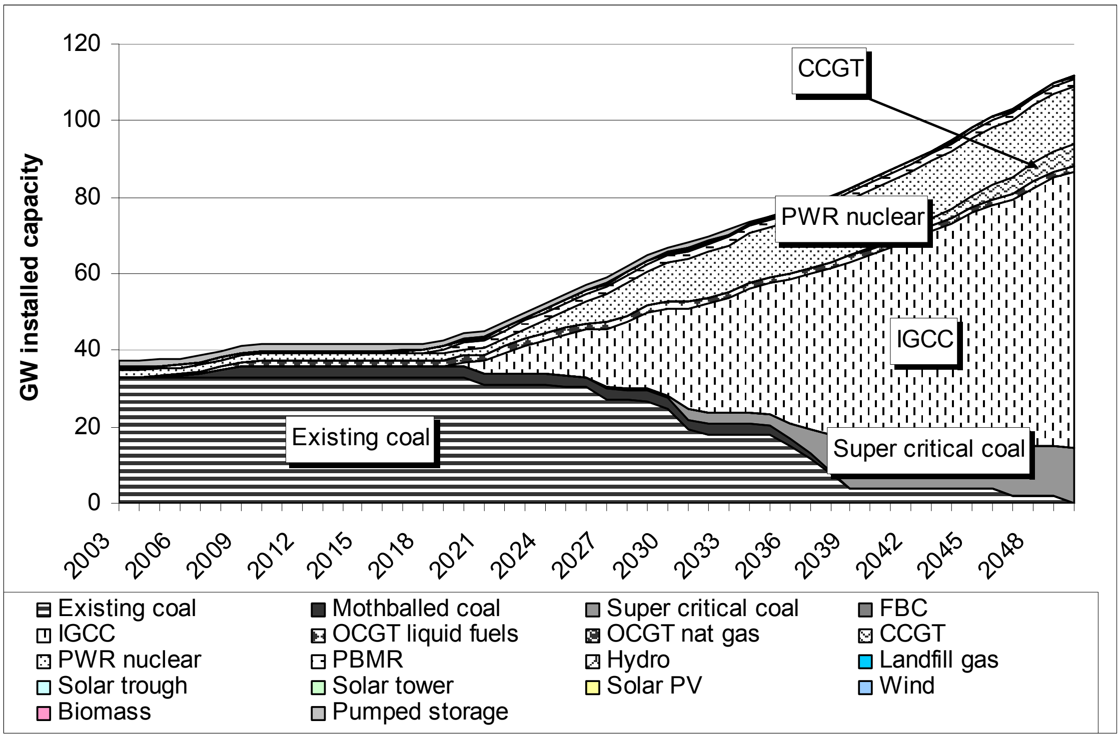
In the 'Current Development Plans' scenario, energy demand grows mainly in the industry and transport sectors. Figure 14shows that the growth in commercial, residential and agricultural fuel use are relatively small in comparison. The predominant fuels differ by sectors. In 2050, 59% of industrial fuel use comes from coal, with another third from electricity. The commercial sector uses electricity for 66% of its energy needs, with another fifth from coal. Fuel use in transport is dominated by petrol (55% in 2003, but 32% by 2050), diesel (31%; 31%) and jet fuel (12% increasing to 18%). In the residential sector, electricity use increases but more moderately than in GWC (63% to 68%).

Figure 14: Fuel use by sector, all fuels (PJ)



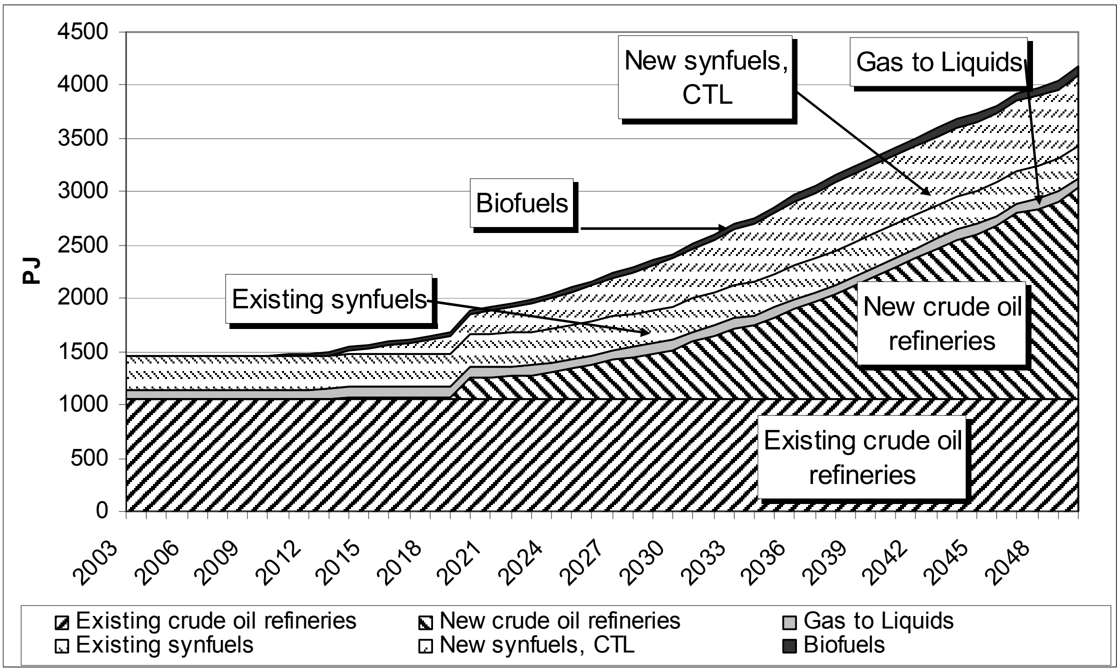
In 'Current Development Plans', electricity continues to be generated overwhelmingly from coal and to a lesser extent nuclear power. Electricity generating capacity in CDP is lower - while in GWC, capacity added is about three times the base year capacity, the CDP grid is around 10 GW smaller. The somewhat lower growth is due to reduced demand for electricity, as final energy demand is reduced by 15% in pursuit of the energy efficiency target. GWC sees less new coal stations coming in from the middle of the period, initially with fewer pulverized fuel stations, but increasingly also not building as much super-critical coal as in CDP. Conventional nuclear and CCGT power plants see less investment. As in GWC, there is no significant investment in renewables.

Figure 15: Electricity expansion plan in the CDP case, GW installed capacity 2003-2050



The capacity to produced petroleum products from refineries is dominated by crude oil and synfuel refineries in CDP. Demand for liquid fuels is considerable lower in CDP than in GWC, resulting in the commissioning of one less refinery.

Figure 16: Refinery capacity in the CDP case, 2003-2050

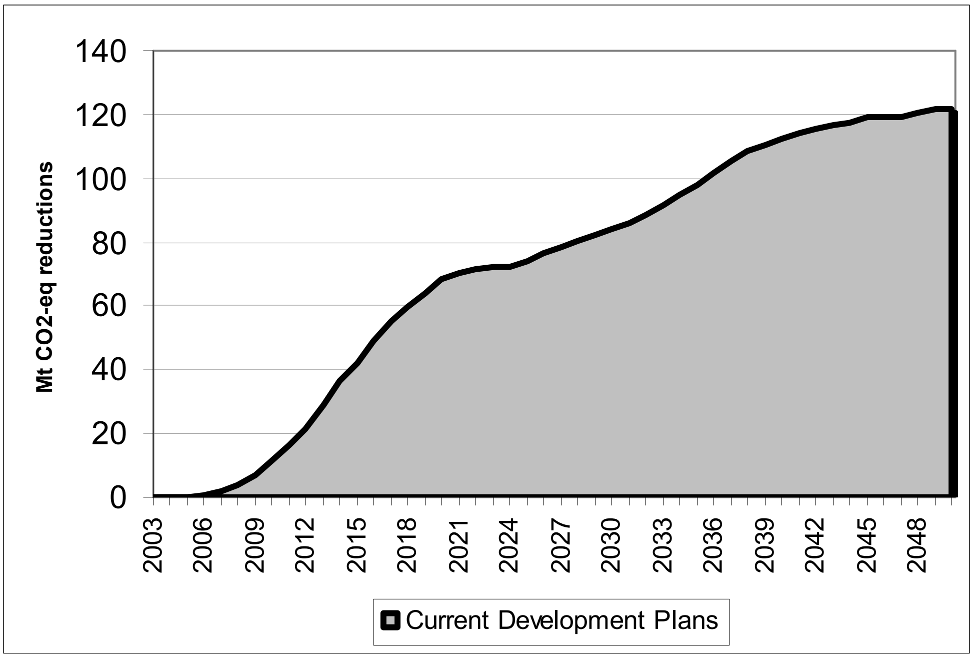


In CDP, GHG emission still rise dramatically. Nonetheless, CDP includes a significant effort in reducing emissions measured in millions of tons of CO_2 avoided compared to Growth without Constraints.

Figure 67Figure 17 below shows the emission reductions due to the mitigation actions already included in the CDP scenario, notably the energy efficiency targets being met. A total of 3 412 Mt of CO_2-eq are avoided during the period, at a saving of –R510 per ton.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	-77,364	-36,270	-20,836
Annual CO_2eq saving (Mt/yr)	71		
Cost effectiveness (R/t CO_2eq)	-1,088	-510	-293
Total CO2eq saving (Mt, 2003-2050)	3,412		
% increase on GWC costs	-11.39%		
% of GDP	-2.36%		

Figure 17: Emission reductions due to CDP relative to GWC



4.2 Results for mitigation actions

4.2.1 Mitigation actions: Commercial energy efficiency

The commercial energy efficiency interventions results 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 – replace incandescents. Consumption of non-renewable fuels in both cases is approx 1000 PJ lower than in GWC. The main savings are in water heating, followed by lighting and HVAC. The resultant 'wedge' of emission reductions in shown in Figure 19.

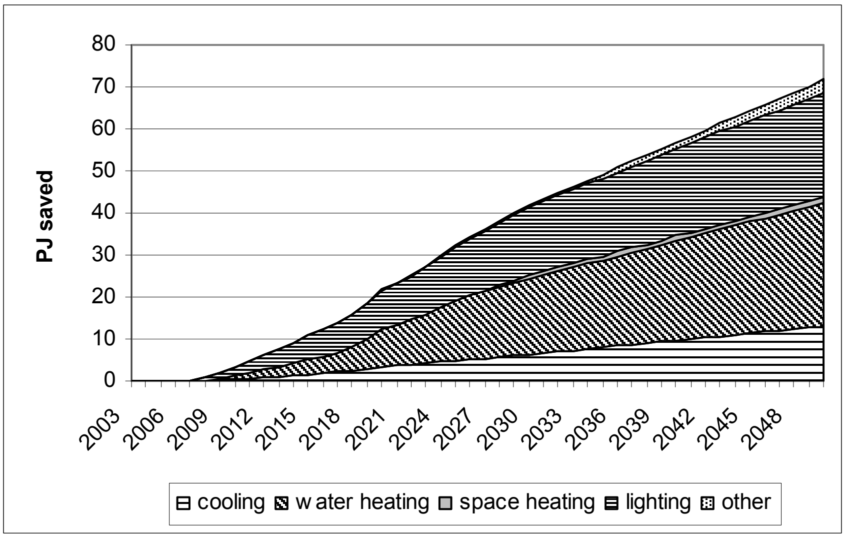


Figure 18: Fuel use comparison in the commercial sector

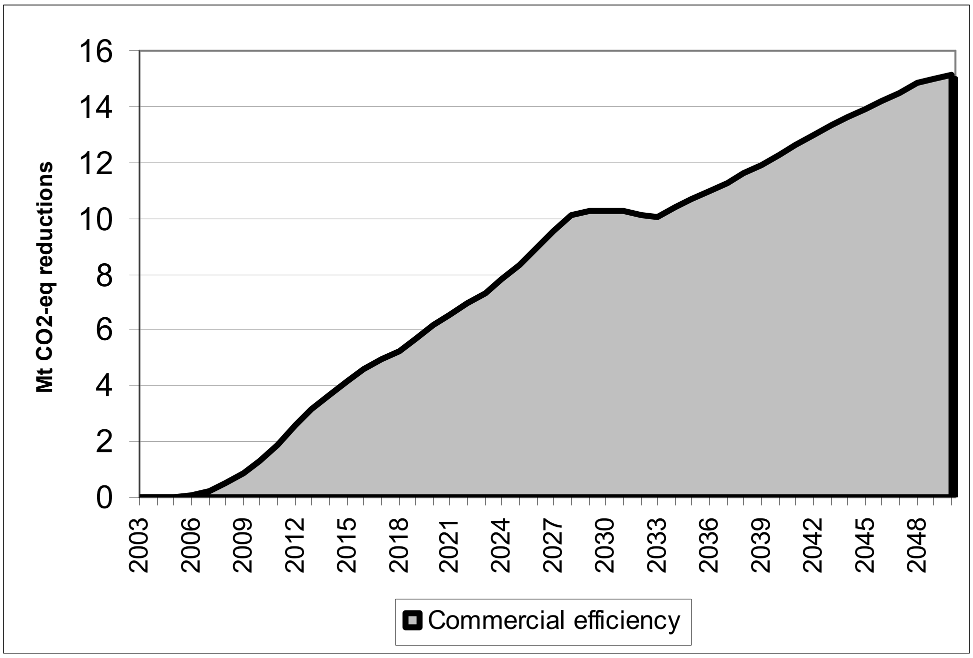


Figure 19: Emission reductions for commercial energy efficiency

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 / t CO_2-eq. Like other energy efficiency wedges, **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.**

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	-3,923	-1,611	-894
Annual CO_2eq saving (Mt/yr)	8		
Cost effectiveness (R/t CO_2eq)	-494	-203	-113
Total CO2eq saving (Mt, 2003-2050)	381		
% increase on GWC costs	-0.56%		
% of GDP	-0.12%		

4.2.2 Mitigation actions: Industrial energy efficiency

At SBT4, this wedge showed the largest cumulative reduction in emissions. Different views were expressed as to whether this was achievable or not. The auditing process included a meeting with industry stakeholders (21 June 2007).[12]

Table 21: 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%

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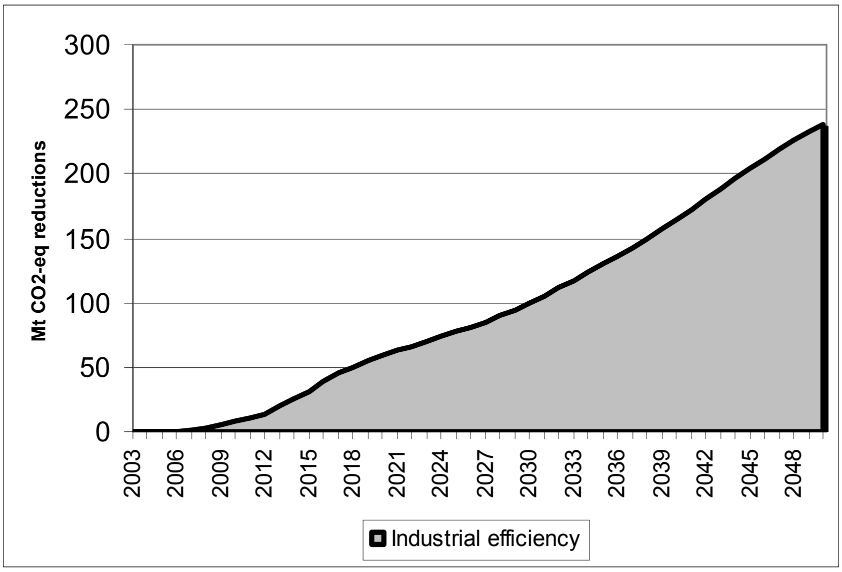
[12] The meeting was chaired by Ian Langridge, chair of the Energy Efficiency Technical Committee.

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 21 emerged from the discussions at the small meeting on industrial energy efficiency. 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 considering technology in a narrow sense, but further savings are possible when taking the broader system into account. The percentage are additive to give overall savings.

The industrial energy efficiency wedge was not doubled, compared to the wedge shown at SBT4. The industrial energy efficiency wedge has been re-run, based on the adjusted energy savings considered possible at various periods. The size of the industrial energy efficiency 'wedge' shown in Figure 21 is still large, although slightly smaller than that shown at SBT4, now at 4 805 Mt CO_2-eq.

Figure 20: Emission reductions for industrial energy efficiency



Industrial energy efficiency is also a net negative cost mitigation action, at -34 / t CO_2-eq. The range of interventions in industrial efficiency cover a range of more energy-intensive activities, leading to larger total reductions.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	-9,250	-3,235	-1,595
Annual CO_2eq saving (Mt/yr)	95		
Cost effectiveness (R/t CO_2eq)	-97	-34	-17
Total CO2eq saving (Mt, 2003-2050)	4,572		
% increase on GWC costs	-1.24%		
% of GDP	-0.26%		

4.2.3 Mitigation actions: Transport

It is important to note two important differences in modelling the transport sector, which differentiate it from others:

1) 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.
2) The basic units in the transport section are passenger-kilometres[13]; thus, energy consumption is measures in terms of how much energy is required per passenger-km. 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.

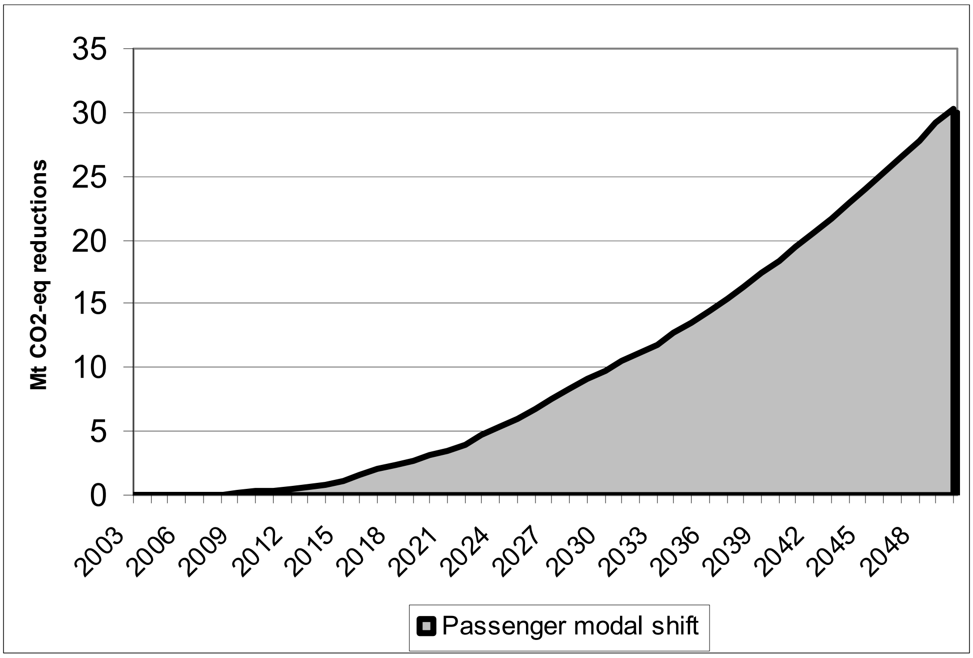
4.2.3.1 Modal shifts for passenger transport

A modal shift in passenger transport means that more passenger-kilometres are produced by the same energy use. The emission reduction are mostly due to reduced use of diesel and petrol (although electricity use increases at the same time).

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	-38,439	-11,048	-4,685
Annual CO_2eq saving (Mt/yr)	10		
Cost effectiveness (R/t CO_2eq)	-3,936	-1,131	-480
Total CO2eq saving (Mt, 2003-2050)	469		
% increase on GWC costs	-4.89%		
% of GDP	-1.05%		

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.

Figure 21: Emission reductions from modal shift in passenger transport, 2003-2050



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[13] This is a measure of transport services; thus one passenger-kilometer = transport required to move one passenger one km.

4.2.3.2 Electric vehicles

Capital costs are higher at R176 000 for an electric vehicle, composed to R100 000 for petrol and R115 000 for diesel cars, although these 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 one in 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, take-up of electric vehicles results in mitigation of 450 Mt CO_2-eq over the period, even with on a coal-dominated grid, at a relatively high cost of R607 per ton. As vehicle cost reduces, 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.

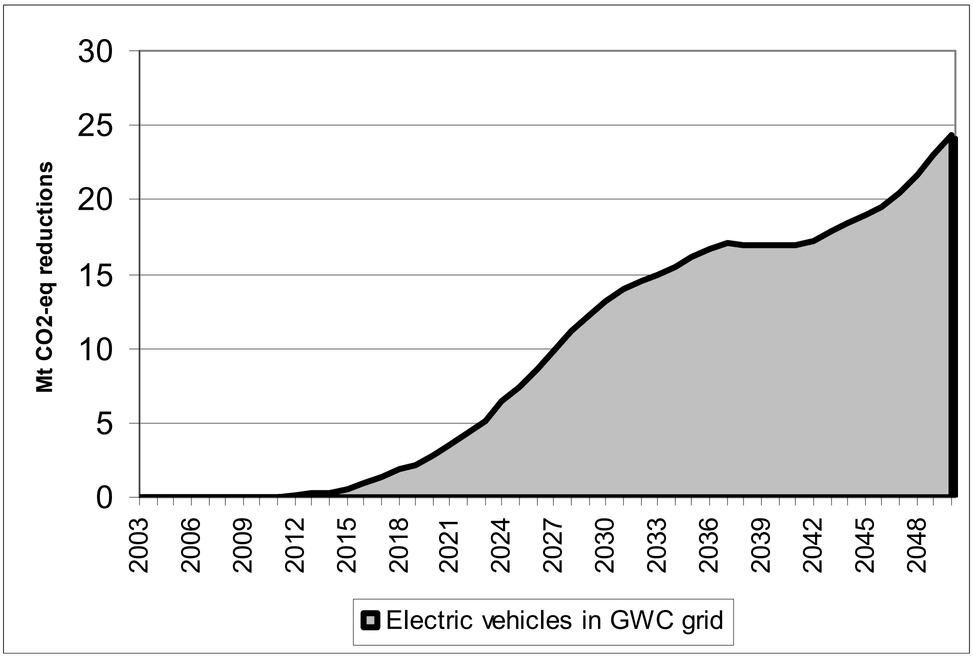
Discount rate	***3%***	***10%***	***15%***
Incremental Annual Cost (R millions)	17,218	5,689	2,708
Annual CO_2eq saving (Mt/yr)	9		
Cost effectiveness (R/t CO_2eq)	1,838	607	289
Total CO2eq saving (Mt, 2003-2050)	450		
% increase on GWC costs	2.27%		
% of GDP	0.48%		

If a grid dominated by nuclear and renewables is assumed, the CO_2 savings are somewhat higher, as portrayed in the table below:

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	37,826	13,338	6,539
Annual CO_2eq saving (Mt/yr)	130.32		
Cost effectiveness (R/t CO_2eq)	290	102	50
Total CO2eq saving (Mt, 2003-2050)	6,255		
% increase on GWC costs	5.07%		
% of GDP	1.08%		

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.

Figure 22: Emission reductions from electric vehicles on a GWC grid



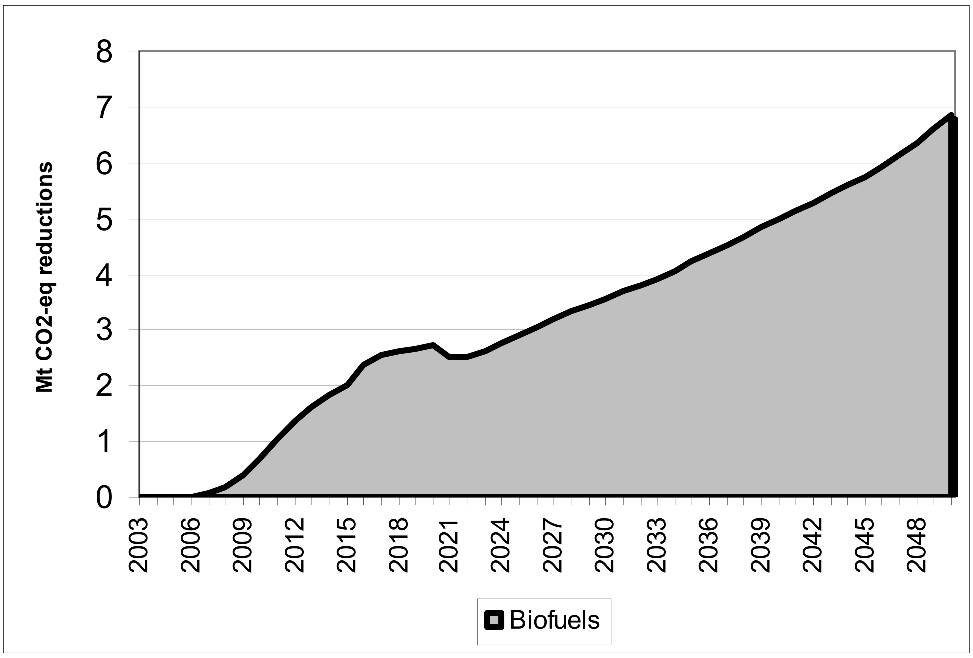
4.2.3.3 Biofuels

Biofuels forms part of a more general renewable energy option, but is here reported separately. In addition, as an economic instrument, a subsidy for biofuels has also been modelled.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	3,267	1,679	1,109
Annual CO_2eq saving (Mt/yr)	3		
Cost effectiveness (R/t CO_2eq)	1,019	524	346
Total CO2eq saving (Mt, 2003-2050)	154		
% increase on GWC costs	0.52%		
% of GDP	0.10%		

The biofuels 'wedge' in Figure 23 is on a scale of less than 10 Mt CO_2-eq per annum, with 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 R 524 / t CO_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.

Figure 23: Emission reductions from biofuels

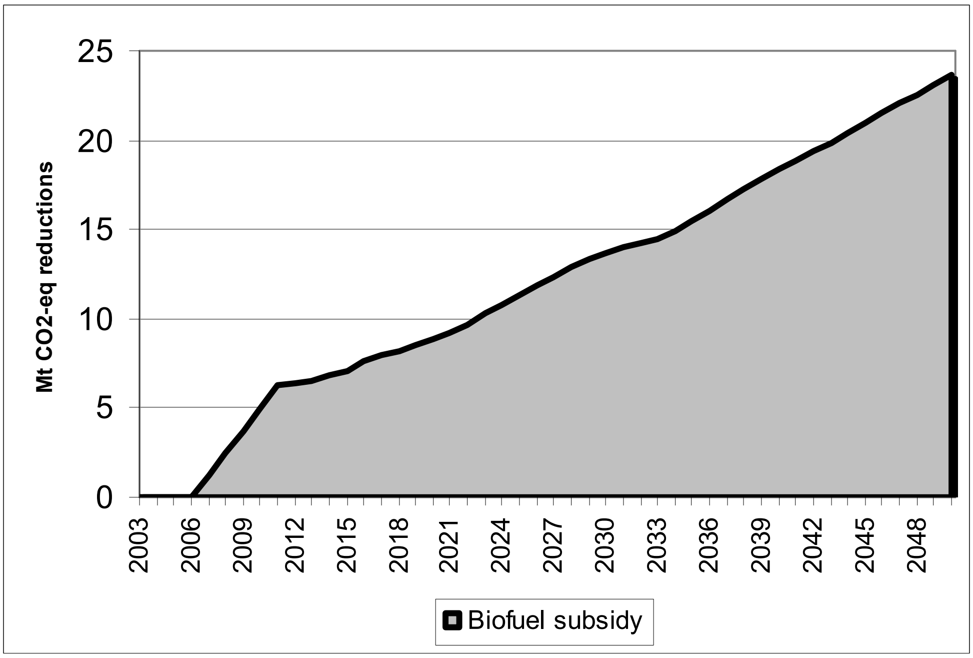


4.2.3.4 *Subsidy for biofuels*

A subsidy was applied to biofuels of R166 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.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	13,304	8,317	6,257
Annual CO_2eq saving (Mt/yr)	12		
Cost effectiveness (R/t CO_2eq)	1,115	697	524
Total CO2eq saving (Mt, 2003-2050)	573		
% increase on GWC costs	2.34%		
% of GDP	0.44%		

Figure 24: Emission reductions from biofuels subsidy



4.2.3.5 *Efficient light vehicles*

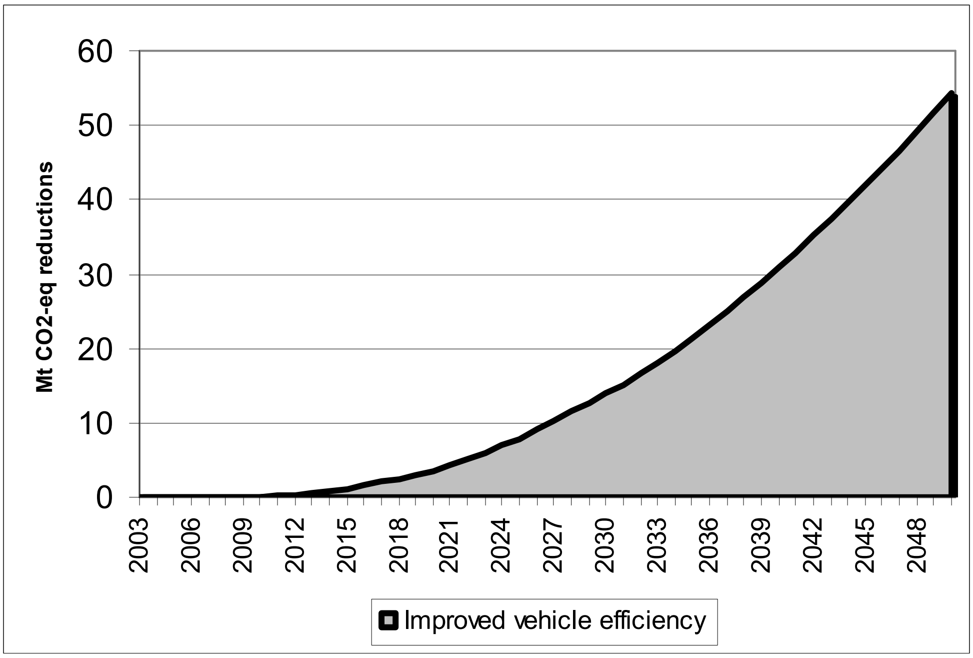
Vehicle efficiency increases 0.5% in GWC, whereas as in CDP, it increases by 0.4% between 2003 and 2007, and 0.9% thereafter. In case reported for SBT 5, vehicle efficiency improves beyond the CDP case, by 1.2% per year, saving a significant amount of petrol. There is a significant reduction in domestic fuel requirements (17%), significantly less refinery capacity is built domestically, and imports increase significantly to balance the domestic product profile.

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 saving 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 in Figure 25 is shown on a scale of up to 60 Mt CO_2-eq per year, although the annual average is 16 Mt. Between 2003 and 2050, some 758 Mt CO_2-eq can be avoided at a cost of –R269 / t CO_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.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	-14,942	-4,243	-1,779
Annual CO_2eq saving (Mt/yr)	16		
Cost effectiveness (R/t CO_2eq)	-946	-269	-113
Total CO2eq saving (Mt, 2003-2050)	758		
% increase on GWC costs	-1.90%		
% of GDP	-0.41%		

Figure 25: Emission reductions from vehicle efficiency

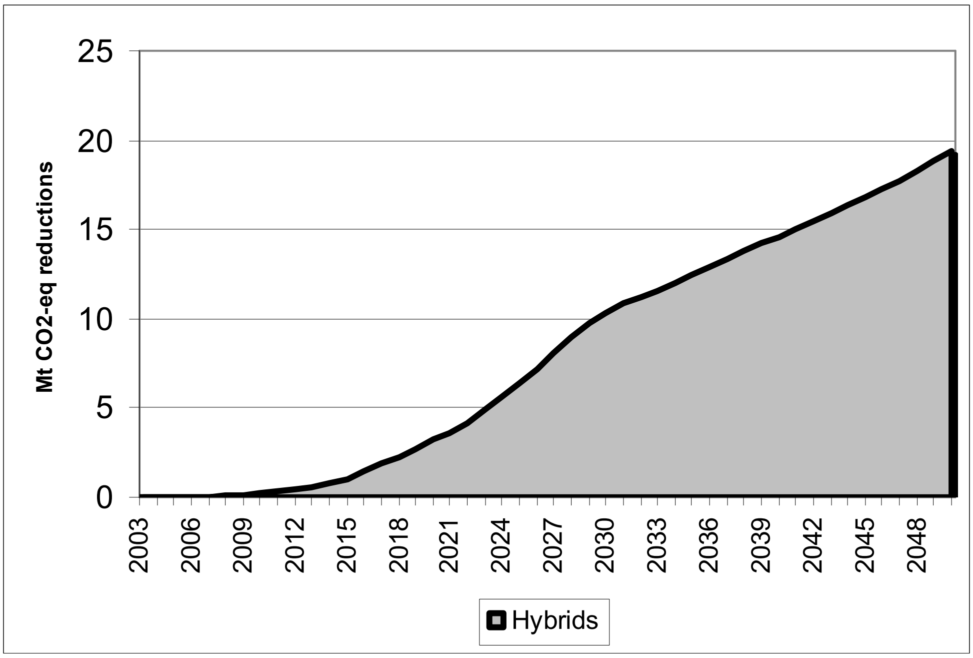


4.2.3.6 *Hybrid vehicles*

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 result in substantial emissions savings over the period of 381 Mt CO_2-eq, but at a high cost of R1 987 / t CO_2 at a 10% discount rate.** This is a significant cost for reductions that average only 8 Mt CO_2-eq per year.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	47,739	15,789	7,362
Annual CO_2eq saving (Mt/yr)	8		
Cost effectiveness (R/t CO_2eq)	6,009	1,987	927
Total CO2eq saving (Mt, 2003-2050)	381		
% increase on GWC costs	6.27%		
% of GDP	0.52%		

Figure 26: Emission reductions from deployment of hybrid vehicles



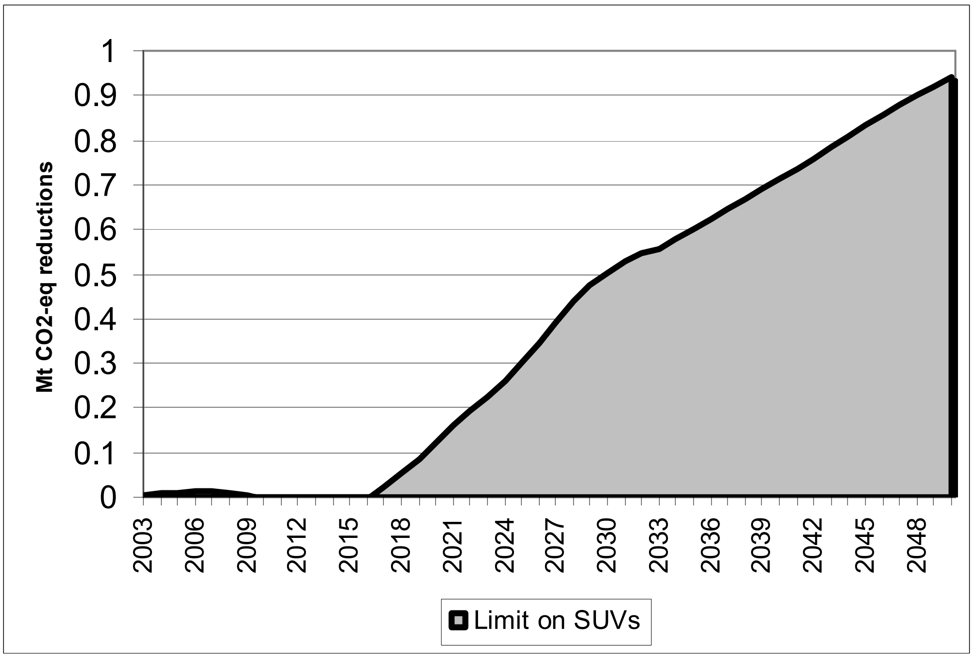
4.2.3.7 Downsizing/ limiting SUVs

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

A limit on vehicle size is implemented in that only 1% of private passenger-kilometers 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 (Figure 27). The highly negative costs are realistic, as they reflect a move to vehicles that have a lower capital cost and lower running costs.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	-5,450	-1,660	-700
Annual CO_2eq saving (Mt/yr)	0.4		
Cost effectiveness (R/t CO_2eq)	-14,457	-4,404	-1,856
Total CO2eq saving (Mt, 2003-2050)	18		
% increase on GWC costs	-0.70%		
% of GDP	-0.15%		

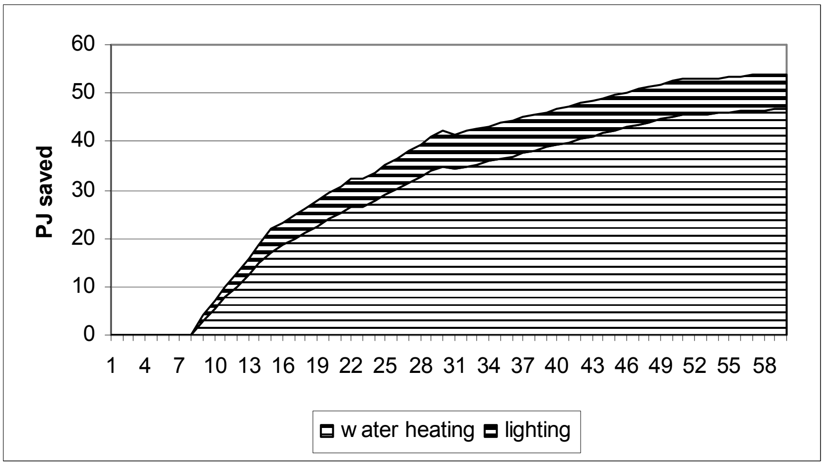
Figure 27: Emission reductions from limits on SUVs, 1%



4.2.4 Mitigation actions: 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 / t CO_2-eq. Most energy savings derive from water heating, with a smaller saving from lighting.

Figure 28: Savings through energy efficiency measures in the Residential sector



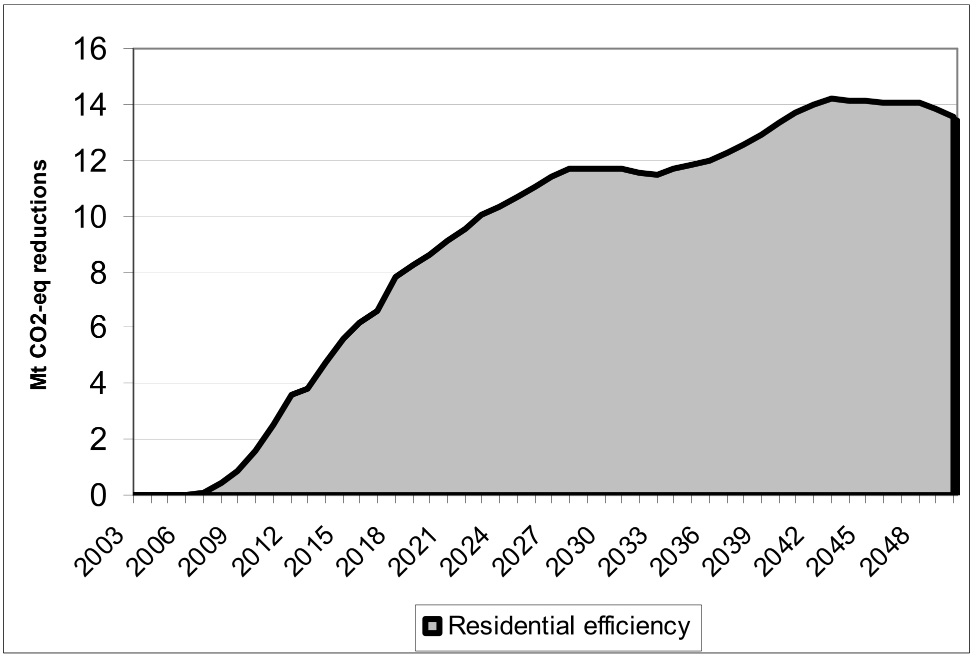
Residential energy efficiency (including SWH) is a good negative cost mitigation option. While individual interventions are small, across a large number of households they add up avoided emissions of over 400 Mt CO_2-eq over time. In addition, there are clear socio-economic benefits – increased service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

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	-3,601	-1,770	-1,072
Annual CO_2eq saving (Mt/yr)		9	
Cost effectiveness (R/t CO_2eq)	-402	-198	-120

Total CO2eq saving (Mt, 2003-2050)	430
% increase on GWC costs	-0.55%
% of GDP	-0.11%

The total emission Emphasise that these interventions (CFLs, insulation, SWH, other efficiency) have great local sustainable development benefits.

Figure 29: Emission reductions from residential energy efficiency



4.2.5 Mitigation actions: Renewable electricity

4.2.5.1 Renewable electricity to 27%

For this action, 15% of electricity dispatched must come from domestic renewable resources by 2020, from South African hydro, wind, solar thermal, landfill gas, PV, 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.

This scenario sees the introduction of solar power towers, parabolic trough, wind. The extent to which each is introduced can be seen in Figure 30. The solar power tower comes into the mix from 2014 and reaches its limit of 30 GW in 2045. The 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 30: Electricity generating capacity for renewables with learning

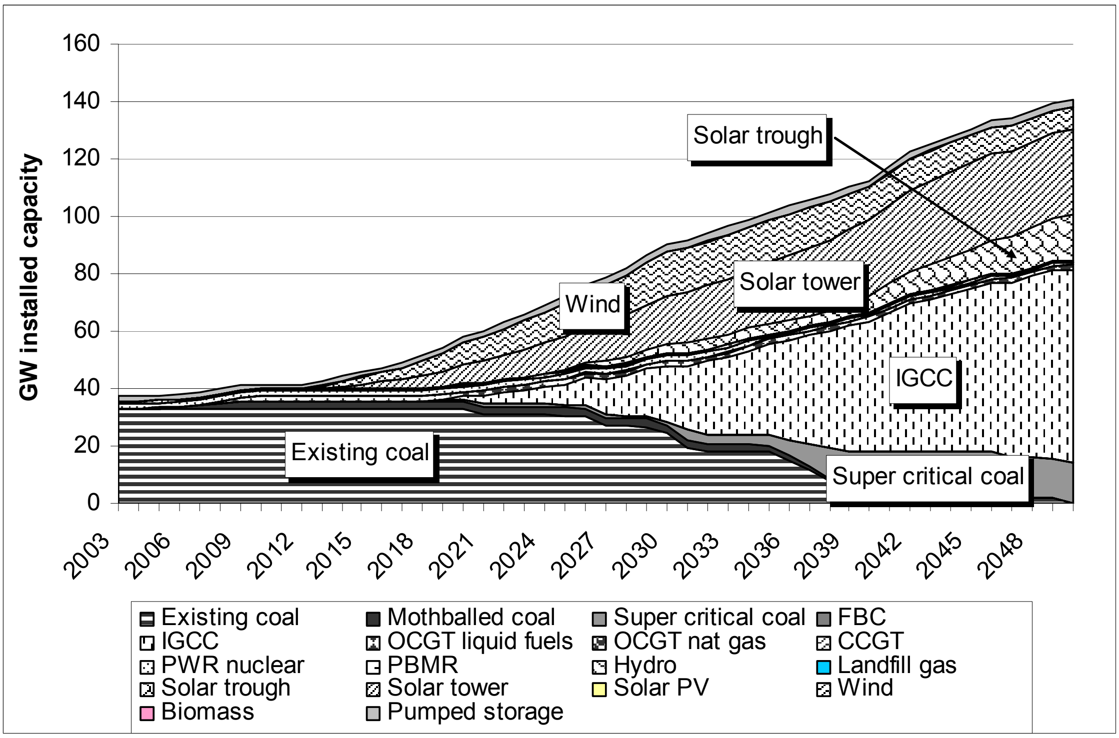


Figure 30 shows installed capacity (GW), not electricity generated (kWh). Since renewable energy technologies generally have lower availability factors (with the exception of the power tower at 60%), more capacity needs to be built for the same electricity output than for a high-availability plant; thus the size of the grid in this case is 140 GW, 20 GW larger than in GWC.

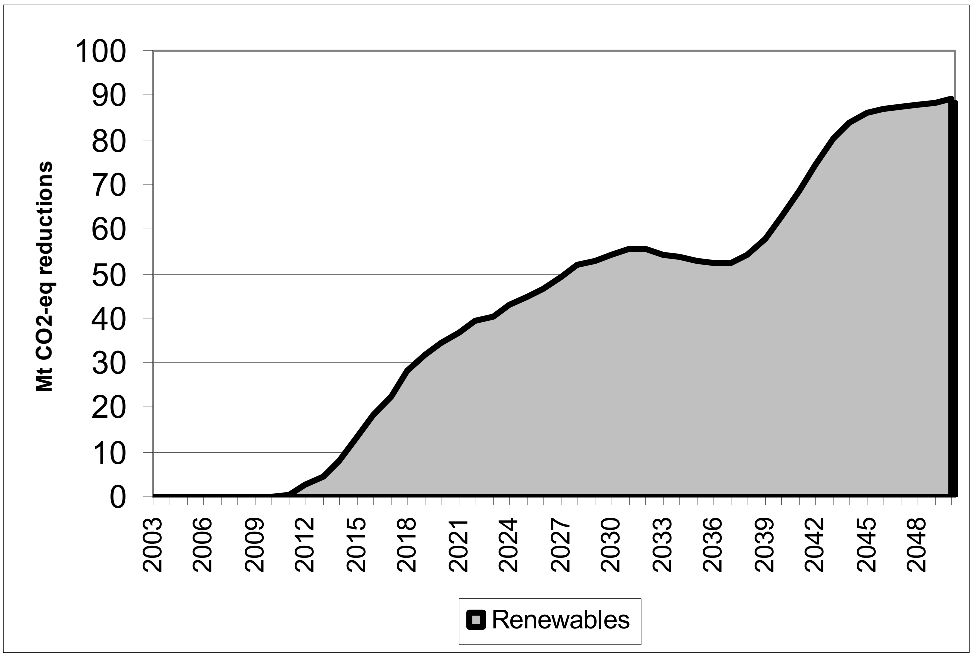
Table 22: Electricity generating capacity by generation type (GW): Renewable energy scenario

	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
Super critical coal	0	0	0	0.85	3.58	14.3	13.89
FBC	0	0	0	0	0	0	0
IGCC	0.0	0.0	0.0	7.3	32.0	56.4	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	0.09	0.7	0.89	0.8
PWR nuclear	1.8	1.8	1.8	1.8	0	0	0
PBMR	0	0	0	0	0	0	0
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	0.66	3.57	10.76	15.76
Solar tower	0	0	1.53	11.53	21.53	30	30
Solar PV	0	0	0	0	0	0	0
Wind	0	0	2.78	11.56	14.55	9.62	7.7
Biomass	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Pumped storage	1.58	1.58	1.67	2.28	2.73	2.33	2.33
Total	37	38	46	72	101	131	140

The table below shows that the emission reductions in Figure 31 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.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	4,177	2,165	1,241
Annual CO_2eq saving (Mt/yr)		42	
Cost effectiveness (R/t CO_2eq)	100	52	30
Total CO2eq saving (Mt, 2003-2050)		2,010	
% increase on GWC costs		0.63%	
% of GDP		0.13%	

Figure 31: Emission reductions from renewables

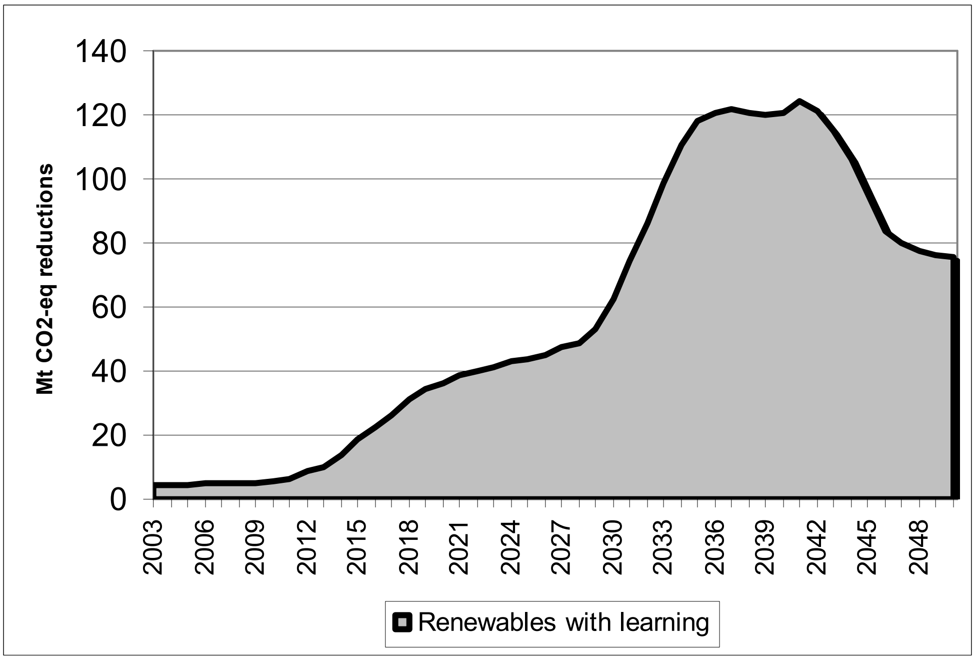


If technology learning is assumed for both GWC and the renewable case, the mitigation costs decline significantly, becoming negative at –R143 / t CO_2-eq. The total emission reductions are also increased to 2 757 Mt CO_2-eq over the period.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	-11,087	-8,208	-7,557
Annual CO_2eq saving (Mt/yr)		57	
Cost effectiveness (R/t CO_2eq)	-193	-143	-132
Total CO2eq saving (Mt, 2003-2050)		2,757	
% increase on GWC costs		-2.13%	
% of GDP		-0.38%	

Emission reductions increase with learning, even when compared to the base case with learning (see Figure 32). **Annual emission reductions are 15 Mt CO_2-eq higher if technology learning is assumed.**

Figure 32: Emission reductions from renewables with learning, compared to GWC with learning



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.

4.2.5.2 Extended wedge: Renewable electricity to 50%

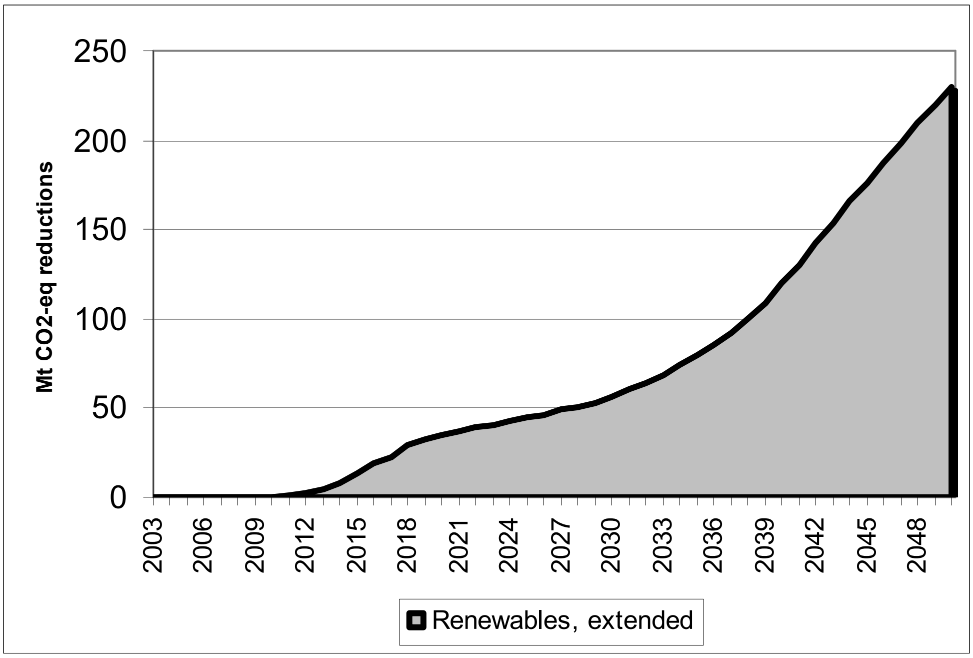
In this case, renewables are extended to 50% by 2050. Total emission reductions increase to 3 285 Mt CO_2-eq, but at a higher mitigation costs of R92 / t CO_2-eq.

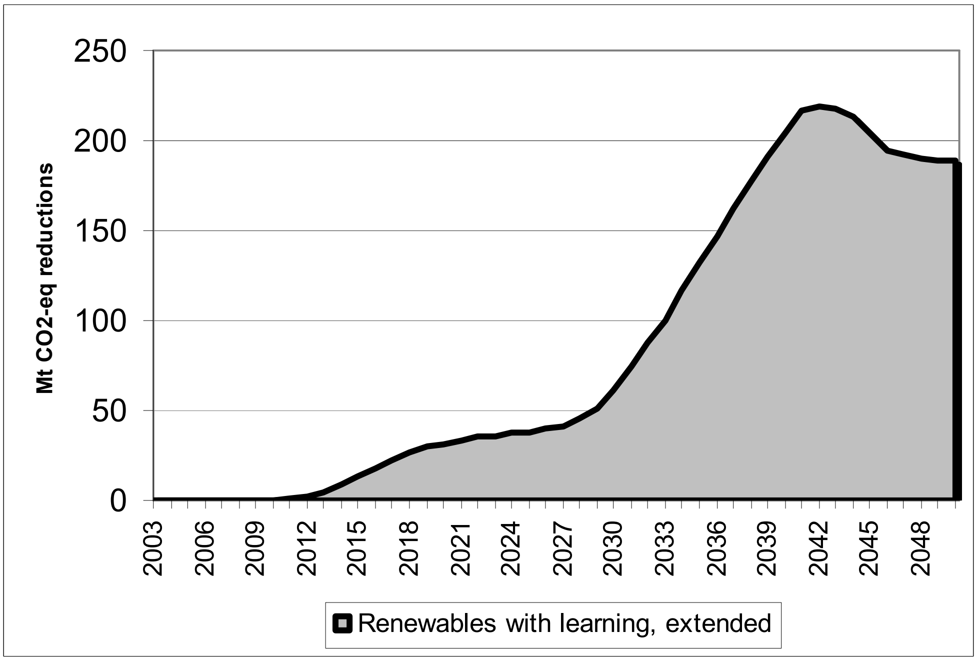
Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	20,276	6,310	2,872
Annual CO_2eq saving (Mt/yr)	68		
Cost effectiveness (R/t CO_2eq)	296	92	42
Total CO2eq saving (Mt, 2003-2050)	3,285		
% increase on GWC costs	2.64%		
% of GDP	0.56%		

When taking learning into consideration, mitigation costs are R 3 / t CO_2-eq, with annual emissions reductions of 83 Mt CO_2-eq. A total of 3 990 Mt is mitigated over the period.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	527	278	79
Annual CO_2eq saving (Mt/yr)	83		
Cost effectiveness (R/t CO_2eq)	6	3	1
Total CO2eq saving (Mt, 2003-2050)	3,990		
% increase on GWC costs	0.07%		
% of GDP	0.02%		

Figure 33: Emission reductions from extended renewables, with and without learning





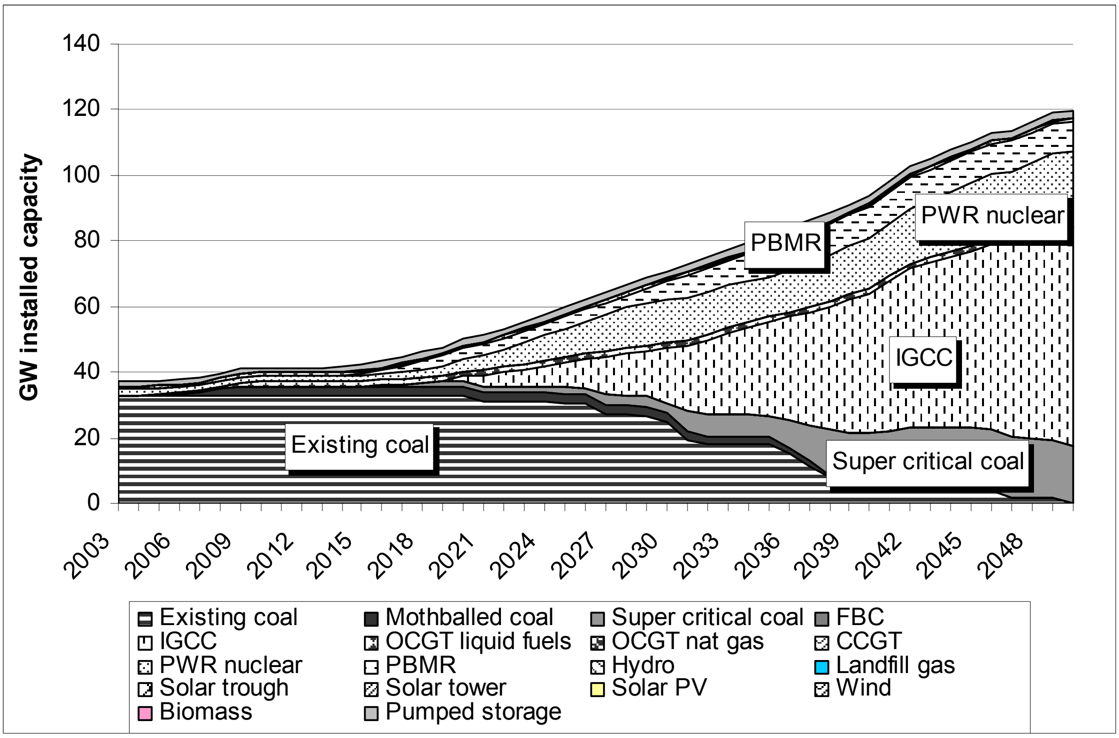
For the mitigation costs of renewable energy technologies, assumptions about learning are clearly important.

4.2.6 Mitigation actions: Nuclear power

4.2.6.1 Nuclear power to 27%

In this scenario, either the Pebble Bed Modular Reactor, 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 bounds on capacity are relaxed in the mitigation case (100 GW PWR max; 50 GW PBMR).

Figure 34: Electricity generating capacity for nuclear mitigation



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 an 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.

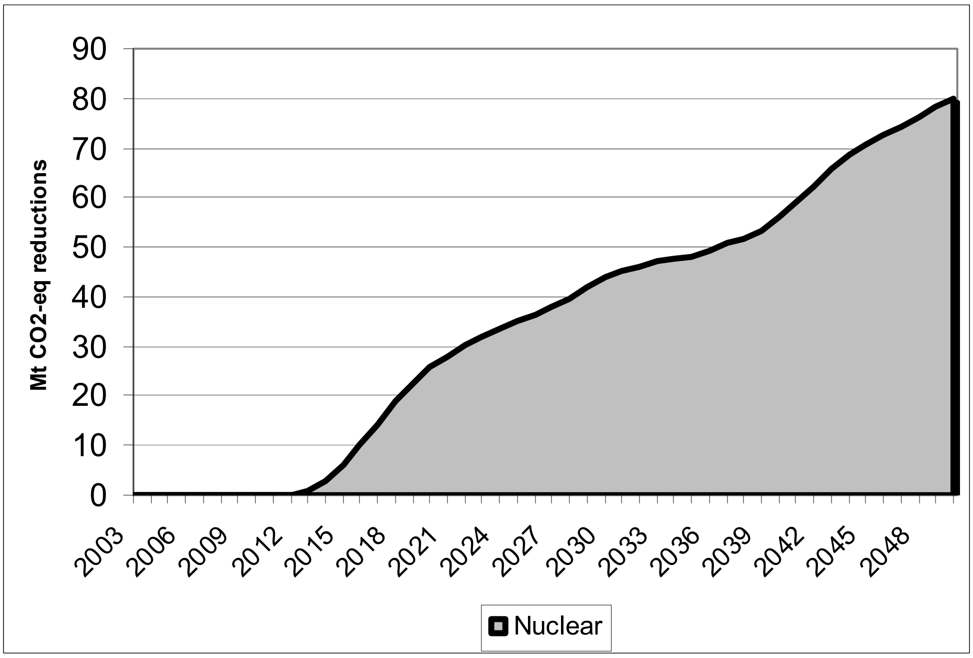
Table 23: Electricity generating capacity by generation type (GW): Nuclear scenario

	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
Super critical coal	0	0	0	1.93	6.47	19.06	17.33
FBC	0	0	0	0	0	0	0
IGCC	0.0	0.0	0.0	7.5	28.6	54.0	65.3
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	0	0
PWR nuclear	1.8	1.8	1.8	8.87	12.11	19.19	22.99
PBMR	0	0	0.48	3.4	9.38	9.38	9.38
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	1.58	1.58	1.77	2.17	2.46	2.33	2.33
Total	37	38	42	60	82	110	120

The total emission reductions from building nuclear power are 1 660 Mt CO_2-equivalent over the 48 years. The cost of saving is R 18 per t CO_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.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	1,537	611	309
Annual CO_2eq saving (Mt/yr)	35		
Cost effectiveness (R/t CO_2eq)	44	18	9
Total CO2eq saving (Mt, 2003-2050)	1,660		
% increase on GWC costs	0.21%		
% of GDP	0.05%		

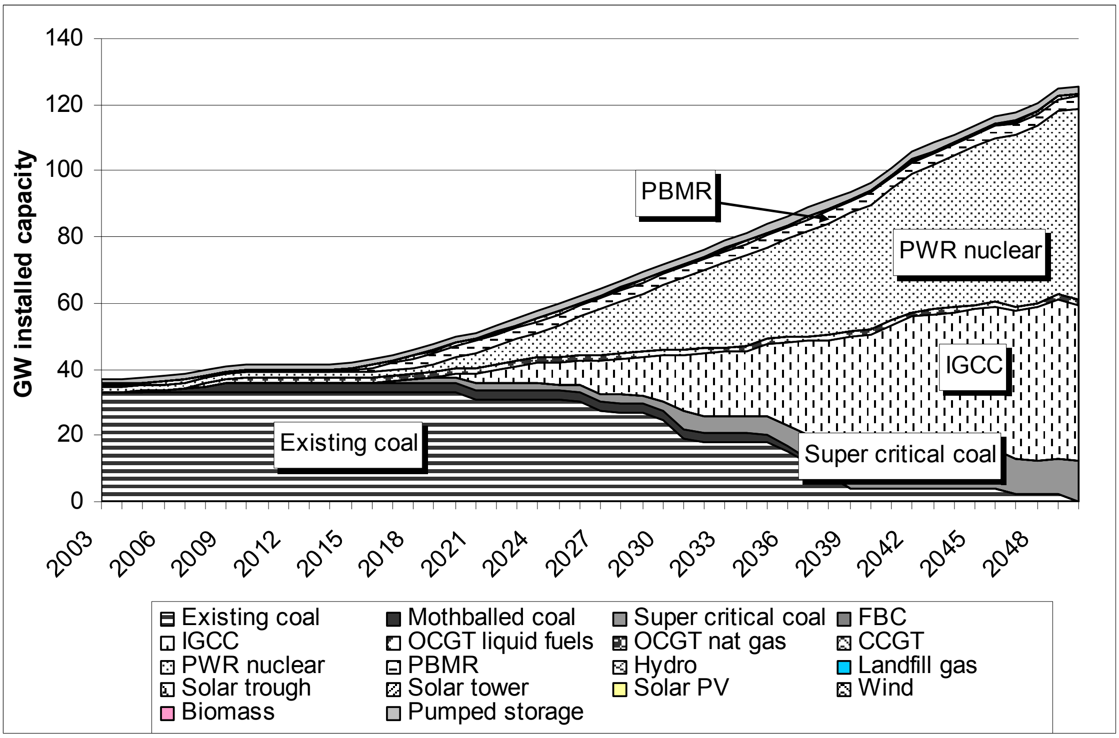
Figure 35: Emission reductions from nuclear power



4.2.6.2 Extended wedge: Nuclear power to 50%

As agreed at SBT4, the nuclear mitigation action was modelled in extended form, reaching 50% of electricity generated in 2050. As can be see in Figure 36, most of the increase in nuclear capacity comes from the PWR.

Figure 36: Electricity generating capacity for nuclear mitigation, extended

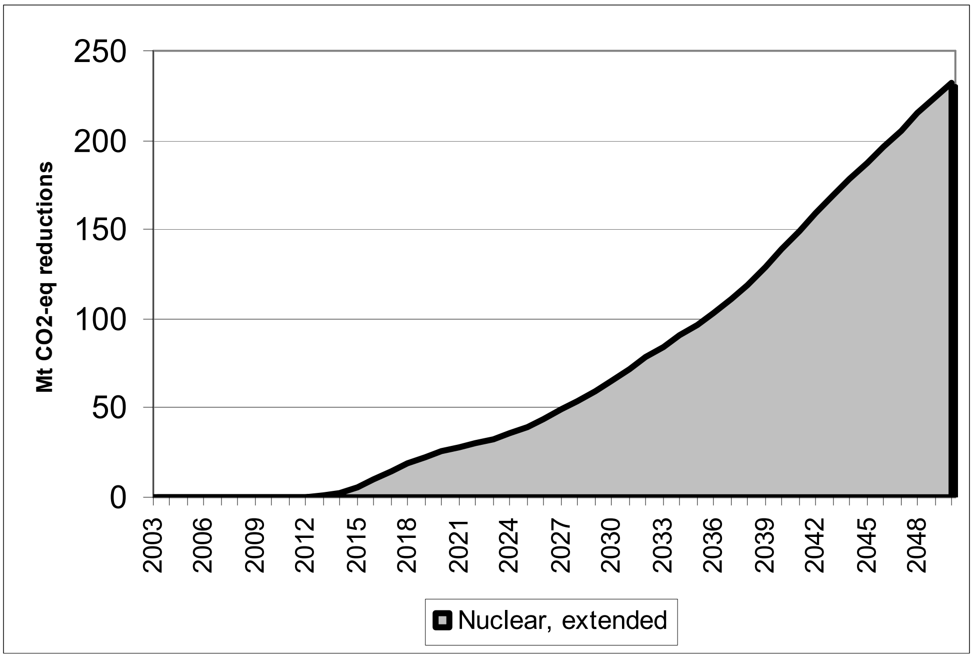


The extended wedge shows substantial emission reductions of 72 Mt CO_2-eq per year on average, totalling 3 467 Mt CO_2-eq from 2003 to 2050. This is a significant increase over nuclear at 27%, which saved less than 2000 Mt, at a slightly higher mitigation cost – from R 18 to R 20 / t CO_2-eq.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	5,445	1,433	561
Annual CO_2eq saving (Mt/yr)	72		
Cost effectiveness (R/t CO_2eq)	75	20	8
Total CO2eq saving (Mt, 2003-2050)	3,467		
% increase on GWC costs	0.68%		
% of GDP	0.15%		

Note the scale of Figure 37, which almost rises to 250 Mt CO_2-eq in 2050. In the South African context, this is a large wedge. Total emission reductions at 3 467 Mt CO_2-eq over the period.

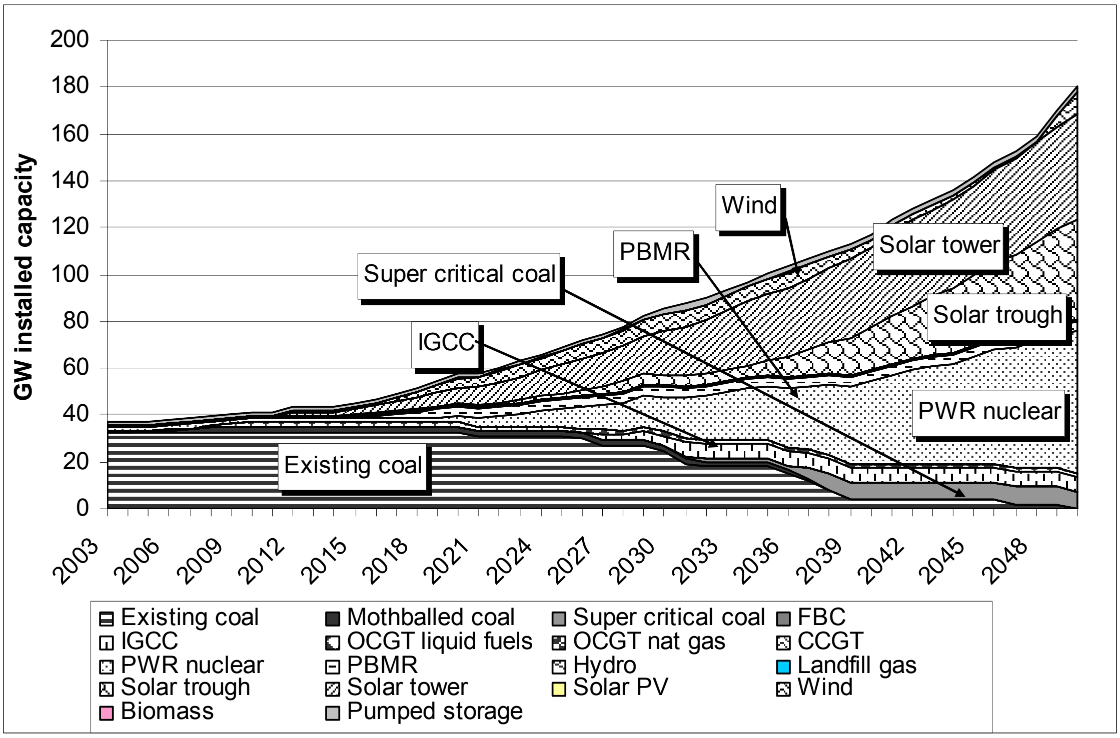
Figure 37: Emission reductions from nuclear power, 50% by 2050



4.2.7 Mitigation actions: renewable and nuclear power

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

Figure 38: Electricity generating capacity for nuclear and renewables mitigation



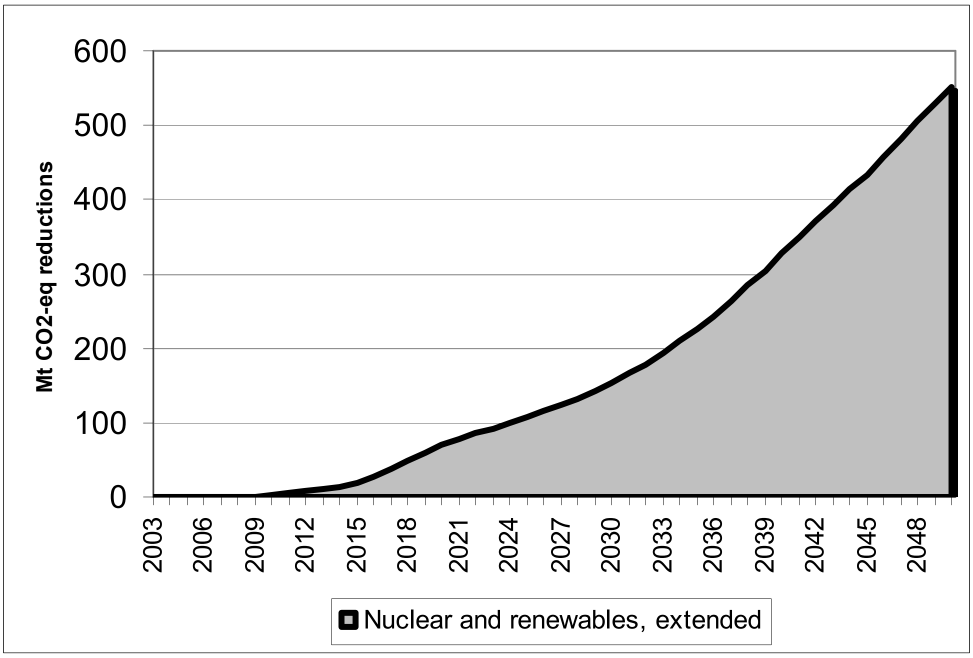
This would be like a commitment to make South Africa's electricity generation zero-carbon by 2050.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	28,963	9,007	4,160

Annual CO_2eq saving (Mt/yr)	173		
Cost effectiveness (R/t CO_2eq)	168	52	24
Total CO2eq saving (Mt, 2003-2050)	8,297		
% increase on GWC costs	3.78%		
% of GDP	0.81%		

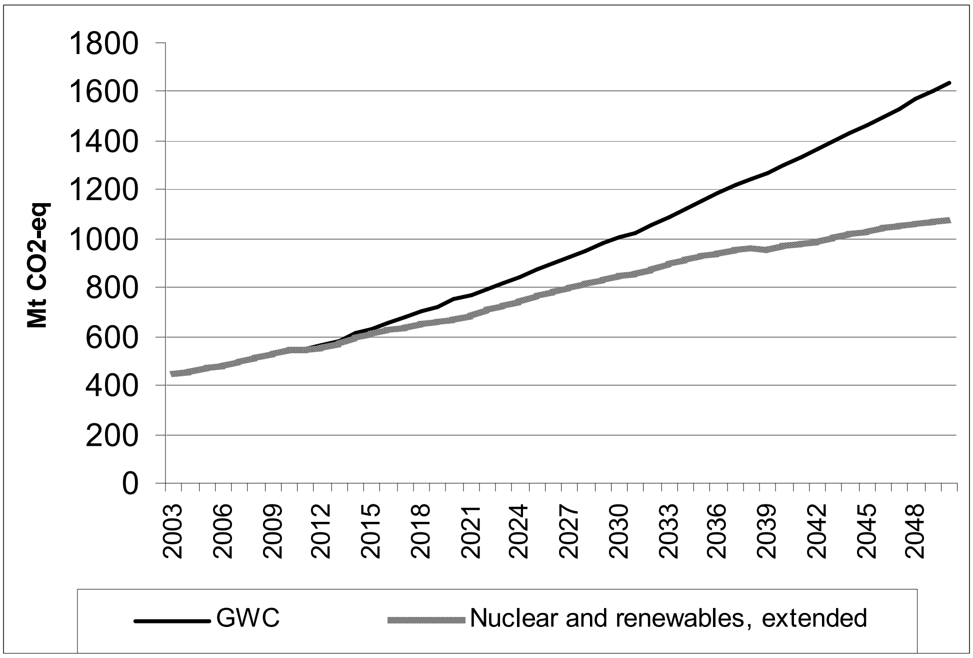
With close to a zero-carbon electricity sector in 2050, 8 297 Mt CO_2-eq can be avoided, 173 Mt on average each year. By the end of the period, emission reductions reach 560 Mt, reducing the gap to RBS to 59%. However, emissions still increase in absolute terms. Mitigation costs are R 52 / t CO_2-eq at a 10% discount rate. This combination of extended wedges stays below 1% of GDP.

Figure 39: Emission reductions from renewables and nuclear power



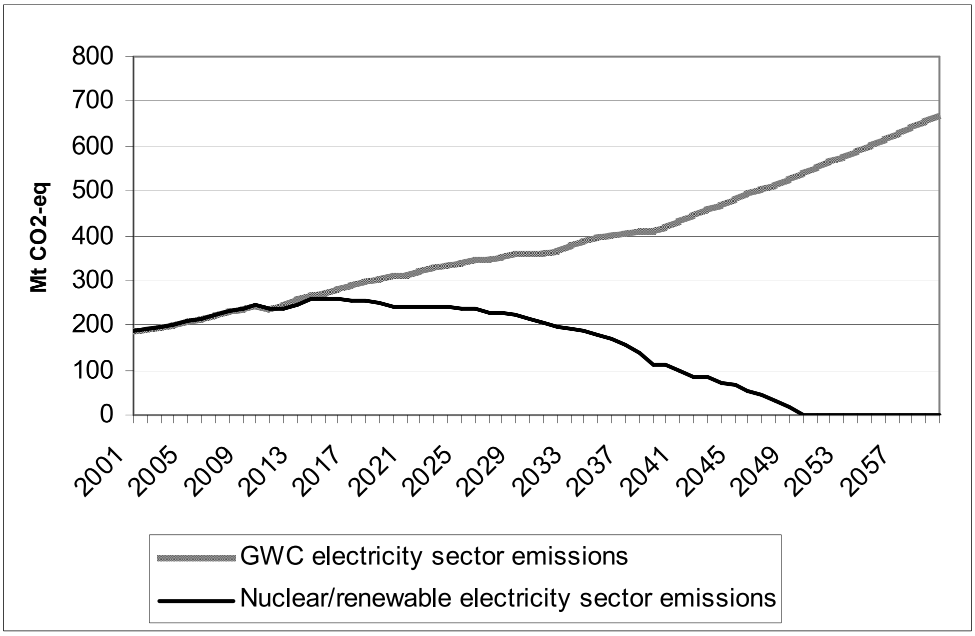
While the wedge shown in Figure 39 is large, total energy emissions in the combined nuclear and renewable case (both 50%) still do not decline over the period. Figure 40 shows total emissions in GWC compared to the combined case.

Figure 40: Emissions from renewables and nuclear power 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 'silver bullet'. A portfolio of technologies will be needed, as suggested in the IPCC's Fourth Assessment Report. (IPCC 2007) The effect on CO_2 emissions in the electricity sector, however, is more dramatic, as see in Figure 41.

Figure 41: CO_2 emissions in the electricity sector for nuclear and renewables each at 50%



4.2.8 Variants: 80% nuclear and renewables

At the request of SBT members, the research team ran two variants of the extended renewable and nuclear wedges. Both were extended so that 80% of electricity would have to be generated from nuclear and renewables respectively in 2050. The remaining 20% could come from any sources.

The modeling team found cumulative emission reductions (2003-2050) of 5095 Mt CO2-eq for the 80% nuclear and 4 780 Mt for 80% renewable variant. However, the modelers expressed low confidence in the results. These reasons were raised at the Working Group meeting of 3 October 2007, and it was agreed that these variants would not be reflected in the Scenario document. They are reported here (and summarised in the Technical Summary). The cost-effectiveness of mitigation in these two cases, at a 10% discount rate, is R12 / t CO2-eq for 80% nuclear and R 65 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 2003-2050 of 0.15 % of GDP; or 0.7% more in energy system costs.

The energy modeling team expressed low confidence in the results reported here. The fundamental reason is 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:

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, 32 percent 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 themal 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 order large numbers of nuclear plants (at the same time as other countries might do the same), 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 modeling, 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 modelers find acceptable at lower penetration rates, but that become a significant issue at higher levels.

4.2.9 Mitigation actions: 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, supercritical 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, which were part of the wedge presented at SBT4, are now in GWC by definition – no more sub-critical plants are to be built, as can be seen in Figure 42, 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 44.

Figure 42: Electricity generating capacity for cleaner coal

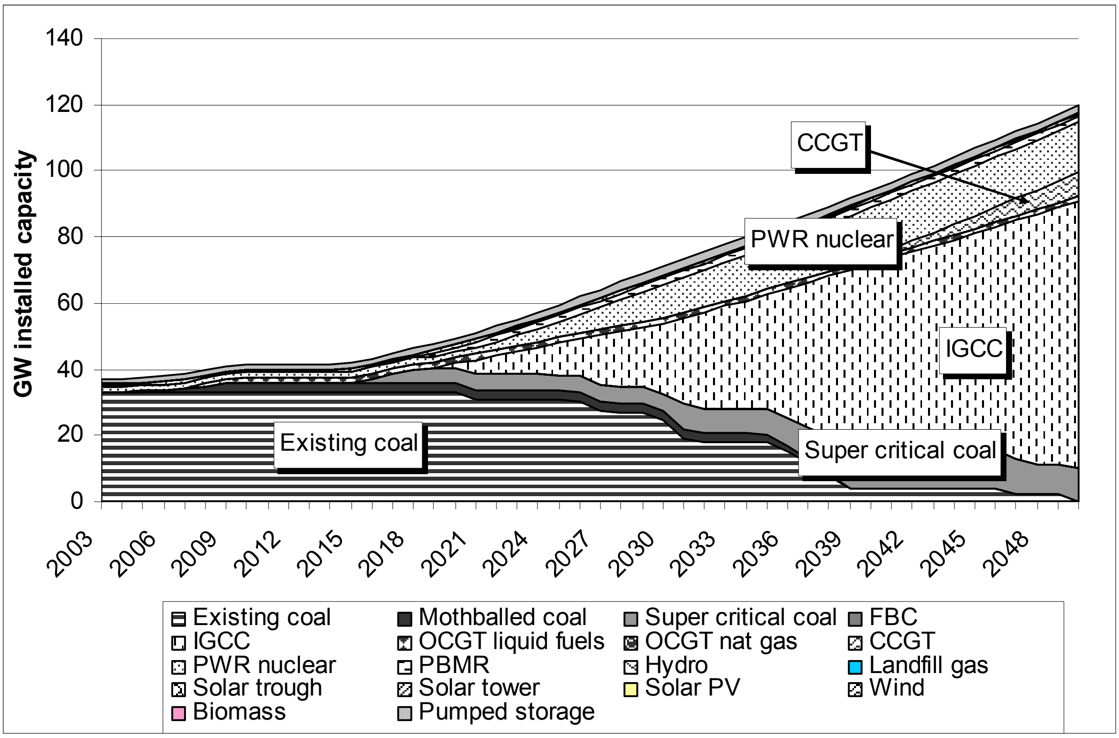


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Table 24: Electricity generating capacity by generation type in the cleaner coal case

	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
Super critical coal	0	0	0.31	4.82	7.57	12.66	10.1
FBC	0	0	0	0	0	0	0
IGCC	0.0	0.0	0.0	9.7	35.1	64.4	80.7
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	1.58	1.58	1.77	2.38	2.73	2.33	2.33
Total	37	38	42	60	82	107	120

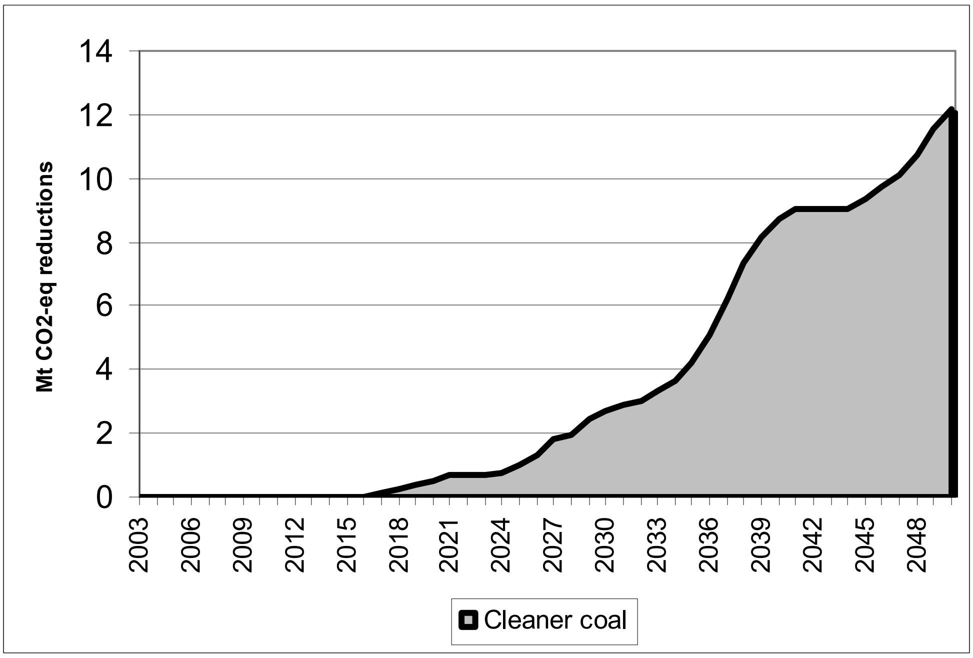
As with renewable energy technologies, learning for cleaner coal technologies is a function of global installed capacity (see Appendices). For cleaner coal technologies, data was available for super-critical coal (4%), which is included in GWC and therefore no different in the mitigation case.

Discount rate	*3%*	*10%*	*15%*

Incremental Annual Cost (R millions)	-74	-17	-6
Annual CO_2eq saving (Mt/yr)	3		
Cost effectiveness (R/t CO_2eq)	-21	-5	-2
Total CO2eq saving (Mt, 2003-2050)	167		
% increase on GWC costs	-0.01%		
% of GDP	0.00%		

The cleaner coal wedge in Figure 43 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 / t CO_2-eq, due to the increased efficiency of IGCC technology.

Figure 43: Emission reductions from cleaner coal



Emission reductions over time are shown in Figure 43with small reductions in this case compared to total emissions in GWC.

4.2.10 Mitigation actions: cleaner coal - limited CCS from electricity generation

Carbon capture and storage (CCS) is different to other mitigation options in that it actively captures the emissions and stores 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 2005).

Carbon capture and storage (CCS) on electricity generation is limited to 2 Mt per year, adjusted downward from the previous 20 Mt modeled for SBT4. The SBT 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 CO_2 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 44 shows, some of the CO_2 captured and stored off-sets the increase in total emissions. Secondly, there are some emission from the plant with CCS (estimated at around 15%). Thus, while the CCS action stores say 2 Mt CO_2 per year of, 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 44: CO_2 capture and storage from power plants

Source: (IPCC 2005)

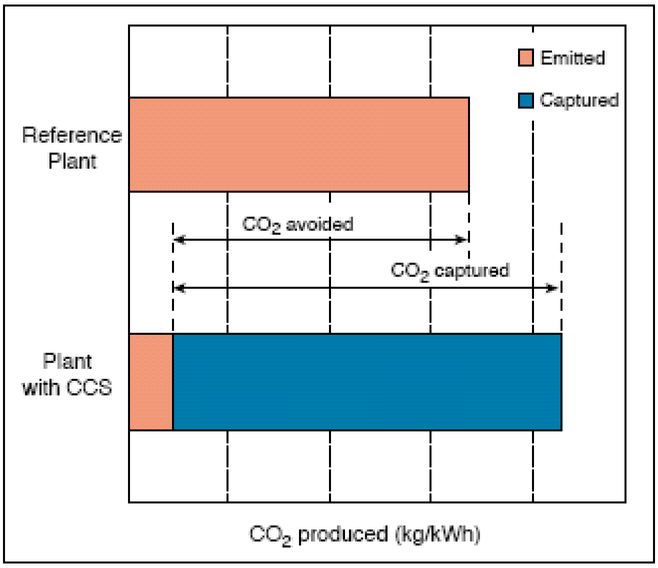


Figure TS.11. CO_2 capture and storage from power plants. The increased CO_2 production resulting from loss in overall efficiency of power plants due to the additional energy required for capture, transport and storage, and any leakage from transport result in a larger amount of "CO_2 produced per unit of product" (lower bar) relative to the reference plant (upper bar) without capture.

It should be noted that the nominal cost of CCS reported by IPCC has wide ranges, but would be over \$50 / t CO_2-eq[14]. In addition, South African geological conditions are not favourable for CCS, 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 that CCS 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 CSS-generated power.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	1,289	425	211
Annual CO_2eq saving (Mt/yr)	6		
Cost effectiveness (R/t CO_2eq)	202	67	33
Total CO2eq saving (Mt, 2003-2050)	306		
% increase on GWC costs	0.17%		
% of GDP	0.04%		

CCS limited to 20 Mt only saves an average of 9 Mt a year, due to the same kinds of systemic effects.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	1,815	677	360

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[14] Most of this (\$45 / t CO_2-eq) would be for capture, with the rest for transport (\$4), geological storage (\$4) and monitoring and verification (\$0.2).

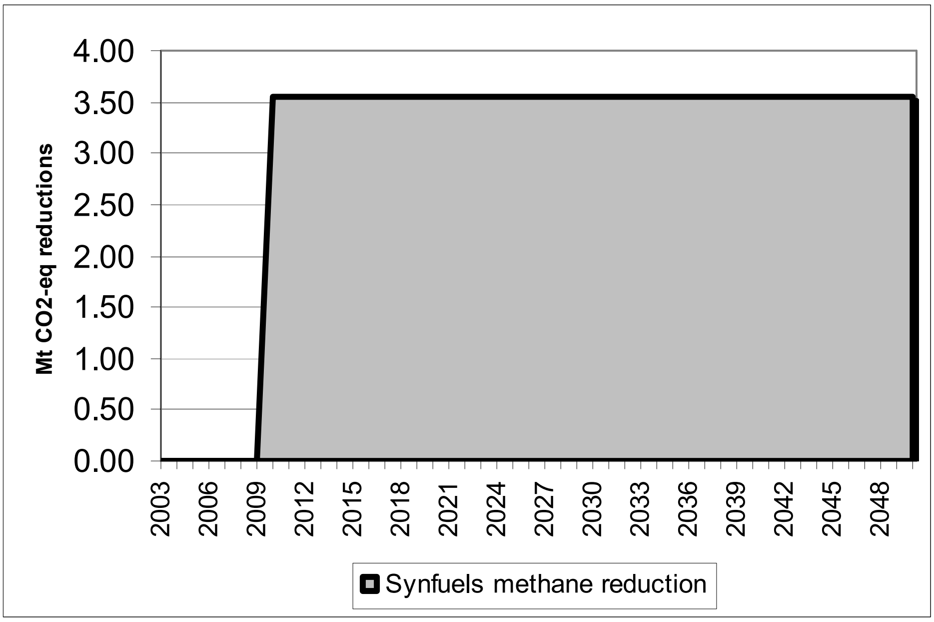
Annual CO_2eq saving (Mt/yr)	9		
Cost effectiveness (R/t CO_2eq)	194	72	38
Total CO2eq saving (Mt, 2003-2050)	449		
% increase on GWC costs	0.25%		
% of GDP	0.05%		

4.2.11 Mitigation actions: Existing CTL with methane destruction

This option involves destroying the CH_4 emissions from the existing CTL plants at Secunda using thermal oxidisers; 3.738 Mt CO_2-eq is destroyed per year from 2011 onwards, which reduced total emissions by 0.35% in 2030 and by 0.22% in 2050. 146 Mt CO_2-eq of emissions are avoided in total over the period, at a levellised cost of R8 per ton CO_2-eq.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	18	26	31
Annual CO_2eq saving (Mt/yr)	3		
Cost effectiveness (R/t CO_2eq)	6	8	10
Total CO2eq saving (Mt, 2003-2050)	146		
% of GDP	0.001%		

Figure 45: Synfuels methane destruction



4.2.12 Mitigation actions: Carbon capture and storage in CTL

At SBT4 it was decided to limit CCS options to a limit of 2 Mt per year, reflecting current global capacity. Due to the nature and scale of the CO_2 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 CO_2 stream from Secunda. As can be seen from the tables below, 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.

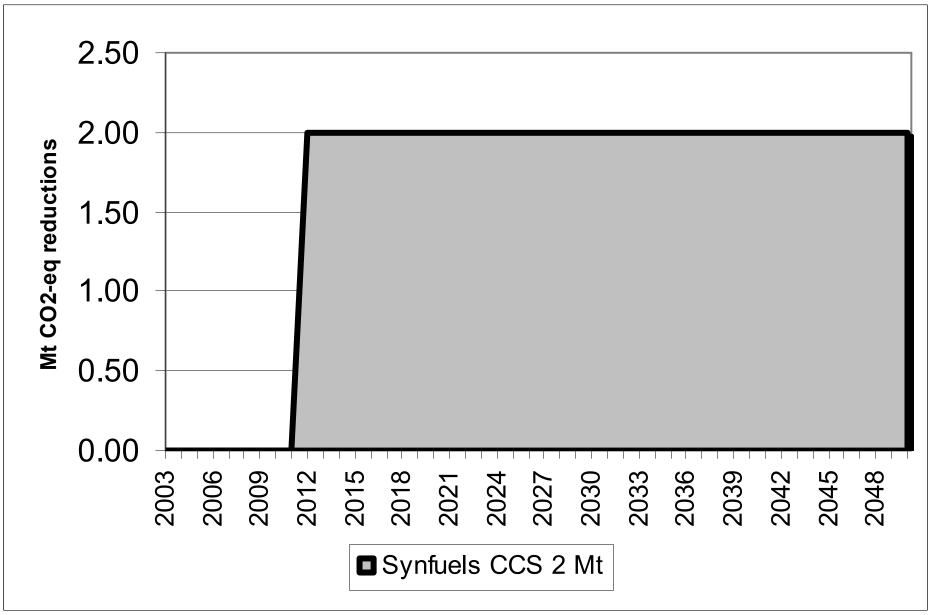
4.2.12.1 2 Mt CCS for existing Secunda plants

The 2 Mt option saves 78 Mt of CO_2 emissions over the period at a high cost of R 476/ton of CO_2 .

Discount rate	*3%*	*10%*	*15%*

Incremental Annual Cost (R millions)	1,060	773	591
Annual CO_2eq saving (Mt/yr)	2		
Cost effectiveness (R/t CO_2eq)	653	476	364
Total CO2eq saving (Mt, 2003-2050)	78		
% of GDP	0.04%		

Figure 46: 2 Mt per year CCS from Secunda

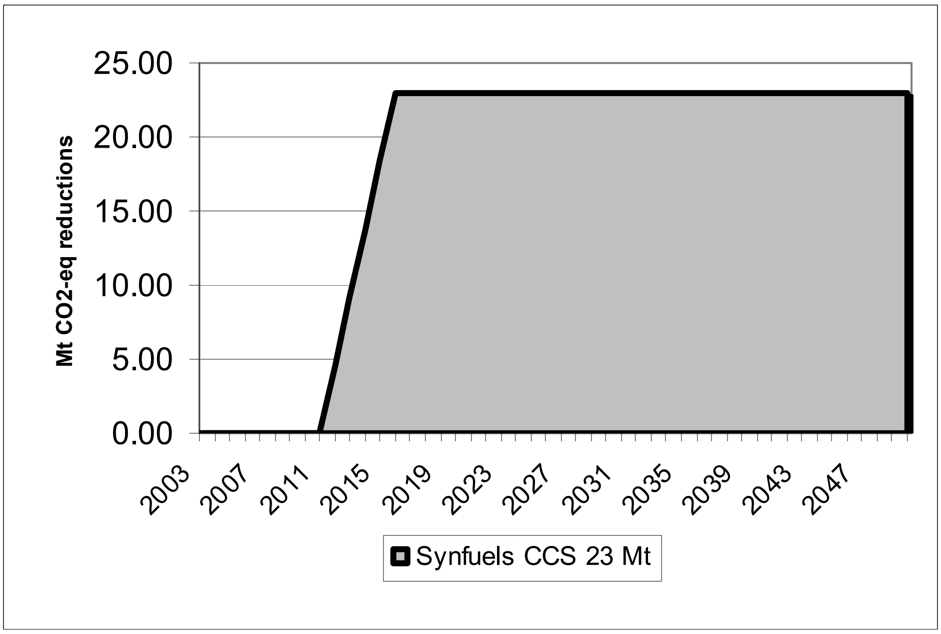


4.2.12.2 23 Mt CCS for existing Secunda plants

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.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	2,169	1,865	1,535
Annual CO_2eq saving (Mt/yr)	18		
Cost effectiveness (R/t CO_2eq)	122	105	87
Total CO2eq saving (Mt, 2003-2050)	851		
% of GDP	0.08%		

Figure 47: CCS from Secunda, 23 Mt CO_2 per year

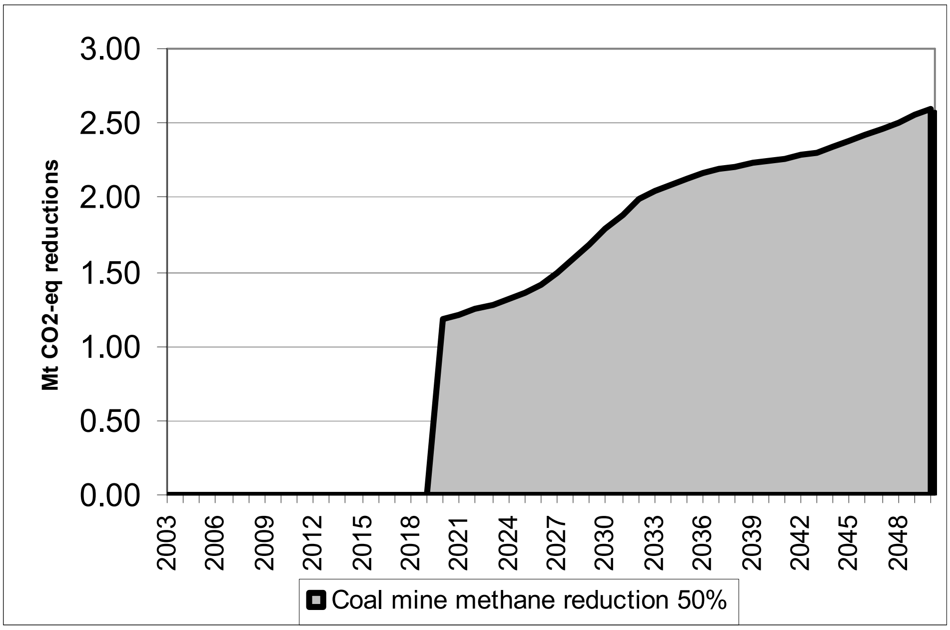


4.2.13 Mitigation actions: Coal mine methane

Costs for destroying methane emissions (using thermal oxidisers) from coal mining were modular (assuming underground mining); therefore, only one option was considered – 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 this was 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.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	997	439	232
Annual CO_2eq saving (Mt/yr)	1.3		
Cost effectiveness (R/t CO_2eq)	786	346	183
Total CO2eq saving (Mt, 2003-2050)	61		
% of GDP	0.06%		

Figure 48: Coal mine methane reduction

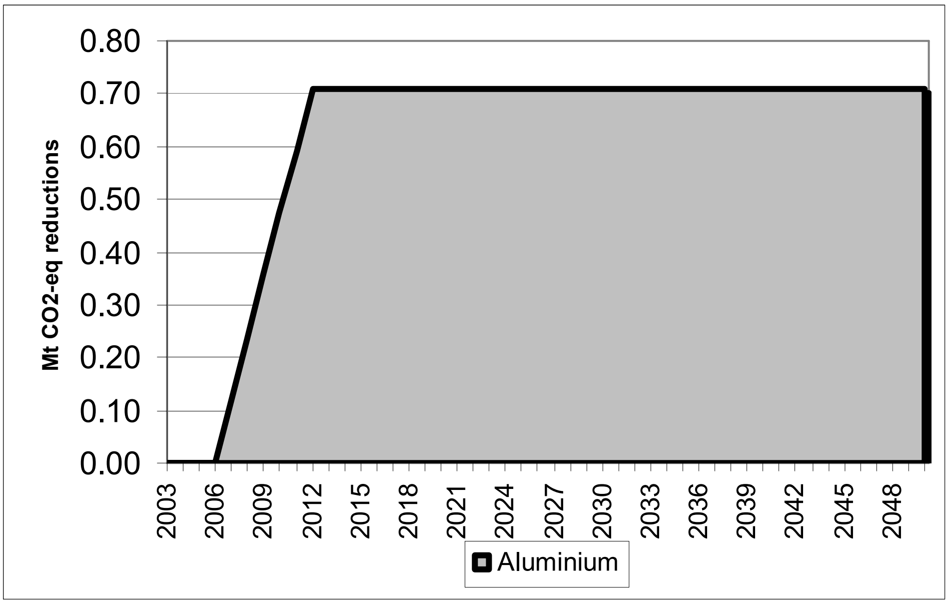


4.2.14 Mitigation actions: Aluminium PFC destruction

The impact of 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 therefore slight; 29 Mt CO_2-eq are mitigated during the total period, which reduced 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.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	0.10	0.11	0.12
Annual CO_2eq saving (Mt/yr)		0.6	
Cost effectiveness (R/t CO_2eq)	0.15	0.16	0.18
Total CO2eq saving (Mt, 2003-2050)		29	
% of GDP		0.000004%	

Figure 49: PFC destruction in the aluminium industry



4.2.15 Mitigation action in livestock management

4.2.15.1 Sector description

In South Africa ruminant livestock production is largely 75% based on rangelands. About 15% of the total number of cattle is in feedlots and about 10% is 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), characterized 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 byproduct 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 livestock will never reach the numbers that were in the region before intense human settlement, their emissions will not be considered as an additional anthropogenic emission.

4.2.15.2 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).

As no data are available for the fraction of the cattle that are rangefed rather than grainfed, it was assumed that 15% of the total cattle excluding dairy is in feedlot and the rest are free-range.

The enteric methane emissions of livestock are dependant 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, made more productive herd through move from rangelands to feedlots with improved feed. This scenario represents S3 scenario.

A reduction of enteric emissions of CH_4 could be achieved if the herd composition were optimized for maximum production and the feed quality. 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.

As a mitigation option, the total number 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 offtake. 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 will be 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) (J Classen, pers. communication) 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 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 urbanized, but the growth of the range-fed beef and small-stock populations is limited, it was assumed that the shortfall would largely be made up by a rise in the number of pigs and chickens. This assumption is inline with international trends. The increase is estimated from the GDP growth and the numbers will stabilize 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 (J Classen, pers. communication).

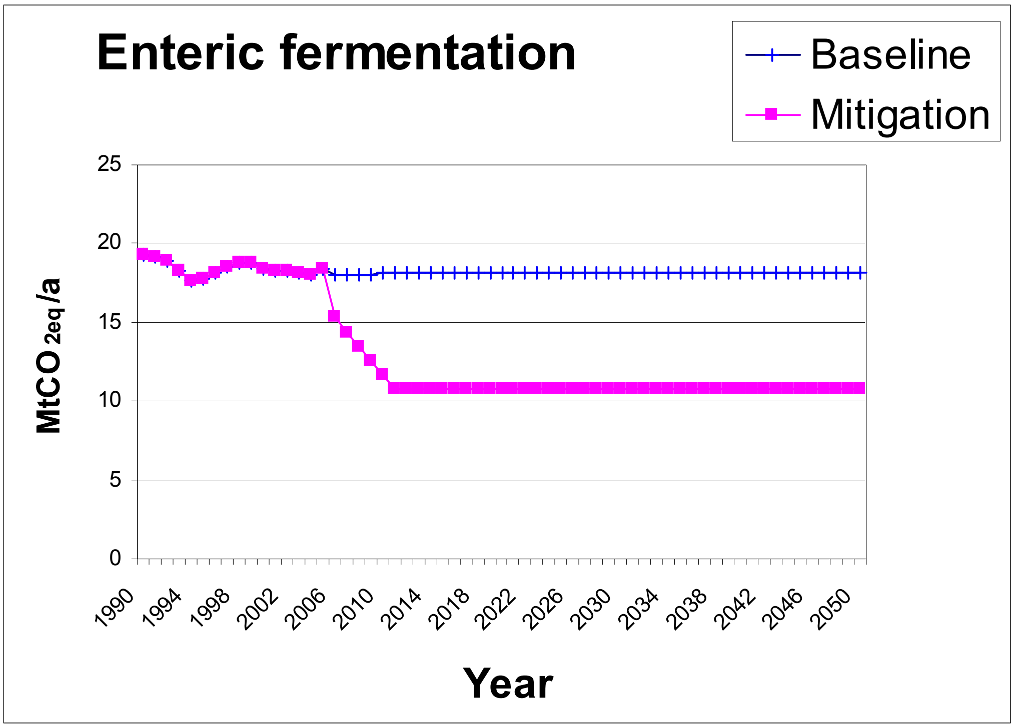
The updated income rates (to keep the baseline consistent these are assumed to be applicable after 2005) were provided by the DoA (J Classen, pers. communication) for some of the categories and for others an increase, using the CPIX index, was assumed.

The further details on data sources, assumptions used and the methodology for calculation of emissions are provided in the Appendix.

4.2.15.3 Modelling results for enteric fermentation

The final results of emissions are presented in Figure 50

Figure 50: Baseline and mitigation option emissions from enteric fermentation (Gg CO_2eq/a)



The period for determining Net Present Value (NPV) and annualized cost is 48 years (from 2003 to 2050). The historical data from 2003 to 2005 is included to ensure consistency with other ,models. This NPV is calculated separately for income and cost.

Cost efficiency was calculated as annualized mitigation less baseline cost divided by mitigated amount of CO_2eq.

Table 25: Results of financial calculations for enteric fermentation emissions

Parameter	***Scenario***	
NPV Costs (R million)	Baseline	R 166 569.65
	Mitigation	R 175 416.08
NPV Income (R million)	Baseline	R 297 588.21
	Mitigation	R 303 215.58
NPV Net Costs (Costs-Income) (R million)	Baseline	R -131 018.56
	Mitigation	R -127 799.49
Levelised net costs (negative = benefit)	Baseline	R -13 238.31
(R million/a)	Mitigation	R -12 913.05
Annualised CO2 Eq (Mt/a) enteric	Baseline	18.11
	Mitigation	11.58
Reduction in emissions (Mt/a)		**6.53**
Mitigation costs less baseline annual costs (Rand/a)		325 259 270
Cost effectiveness (R/ton CO_{2eq})		46.7

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/a, 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. A workshop with representatives from the agricultural community, held on 28 June 2007, accepted this assumption, but suggested that specific associations (e.g. SA Feedlot industry, National Emergent Red Meat Producers Organisation, MPO- Milk Producers Association) be contacted in order to obtain a better projection of future growth.

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 showed that the change of feed in dairy cattle could have negative costs and con-current mitigation (Sirohi, et.al., 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 modeled and provide more accurate and more consistent results.

4.2.16 Mitigation action in manure management

4.2.16.1 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 percent of U.S. agricultural CH_4 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. There is a trend towards increasing use of feedlots (the reasons underlying this trend are discussed in the section on enteric fermentation above).

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 ends up in the effluent water, which is then typically used for irrigation, delivering a fertilization 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 fertilizer. 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.

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

The decomposition of manure under anaerobic conditions produces CH_4. 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 CH_4 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 CH_4 produced during the storage and treatment of manure is 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 are as recommended by IPCC guidelines (IPCC, 1996).

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

To model mitigation, it was assumed that 10% of the dairy and feedlot wastes are anaerobically digested or consumed in a biomass converter. 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 in lagoons and the rest processed in digesters.

While previous study(Scholes at.el., 2000) suggested to process about 40% of manure in digesters or converters the more recent research shows that it is not such a favourable solution(GRACE, 2004). The digesters can only be installed for large number of animals (a few hundreds), they are unreliable and inefficient and most importantly they do not solve GHG problem. They emits ammonia in excess of air pollution standards, which adds N_2O to atmosphere and this is much worst than adding CH_4. And finally they extremely expensive and have short life span (about 10 years). The only limitation of dry spread is availability of farm land where the manure can be disposed. If a large feedlot is located in peri-urban area and additional cost of transport will be required. Also the environmental impacts of potential pollution from N and P from manure should be considered. According to GRACE, 2004 the best solution is to not keep more animal that the land can accommodate.

The further details on data sources, assumptions used and the methodology for calculation of emissions are provided in the Appendix.

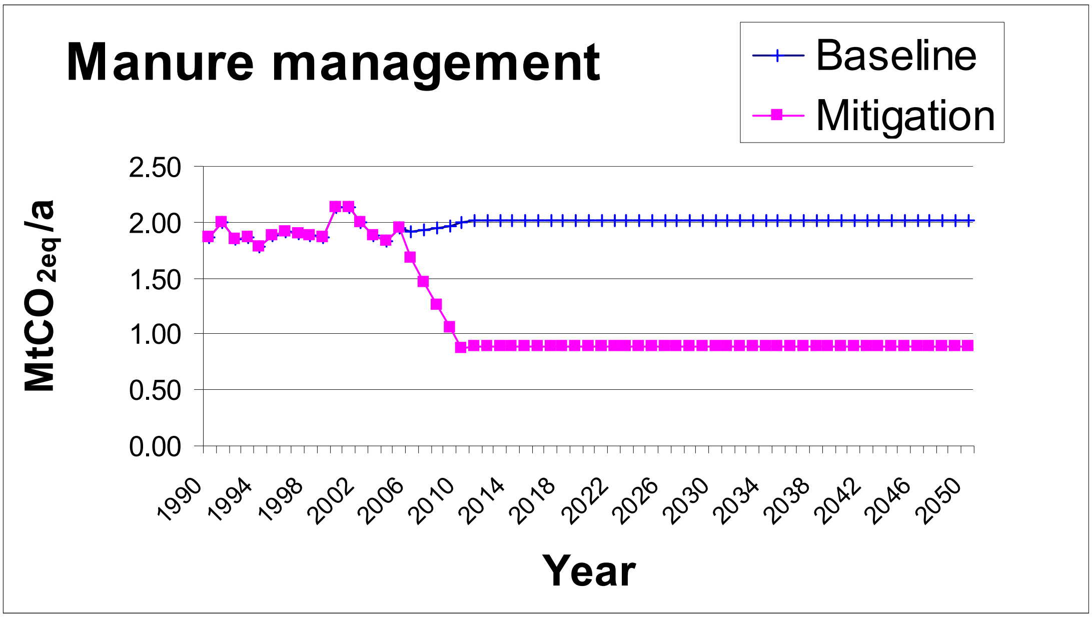
4.2.16.3 Calculation of costs

The costs of dry spreading are assumed to be R1.20/ton manure, lagoons R10/ton and digesters and converters R30/t. These values are approximate and based on information from human sewage disposal facilities.

4.2.16.4 Modelling results for livestock manure

The final results of emissions are presented in Figure 51 below:

Figure 51: Baseline and mitigation option emissions from manure management (Mt CO2eq/a)



The financial calculation results are summarised in the table below.

Table 26: Results of financial calculations for emissions from livestock manure (assuming 80% for dairy and feedlot disposed as dry spread)

Parameters	***Scenario***	***Value***
NPV Costs (R million)	Baseline	2 882.5
	Mitigation	2 687.9
Levelised net costs (R million/a)	Baseline	291.2
	Mitigation	271.6
Annualised CO_{2eq} (Mt/a)-manure	Baseline	2.00
	Mitigation	0.99
Reduction in emissions (Mt/a)		**1.01**
Mitigation costs less baseline annual costs (R/a)		-19 659 674
Cost effectiveness (R/ton CO_{2eq}) - manure		-19.43

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 benefit achievable in previous option, the mitigation cost is quite high. However this option might have to be used to minimise pollution of land and water from dry spread of manure.

Table 27: Results of financial calculations for emissions from livestock manure (assuming 50% disposed as dry spread and 40% into digesters)

Parameters	***Scenario***	***Value***
NPV Costs (R million)	Baseline	2882
	Mitigation	4597
Levelised net costs (R million/a)	Baseline	291
	Mitigation	465
Annualised CO_{2eq} (Mt/a)-manure	Baseline	2.00
	Mitigation	1.08
Reduction in emissions (Mt/a)		0.92
Mitigation costs less baseline annual costs (R/a)		173277889
Cost effectiveness (R/ton CO_{2eq}) - manure		189.25

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 3 groups: broiler, layer and breeder, and different life cycle and manure management methods should be applied to each. More details are provided in the Appendix.

4.2.17 Mitigation action in tillage

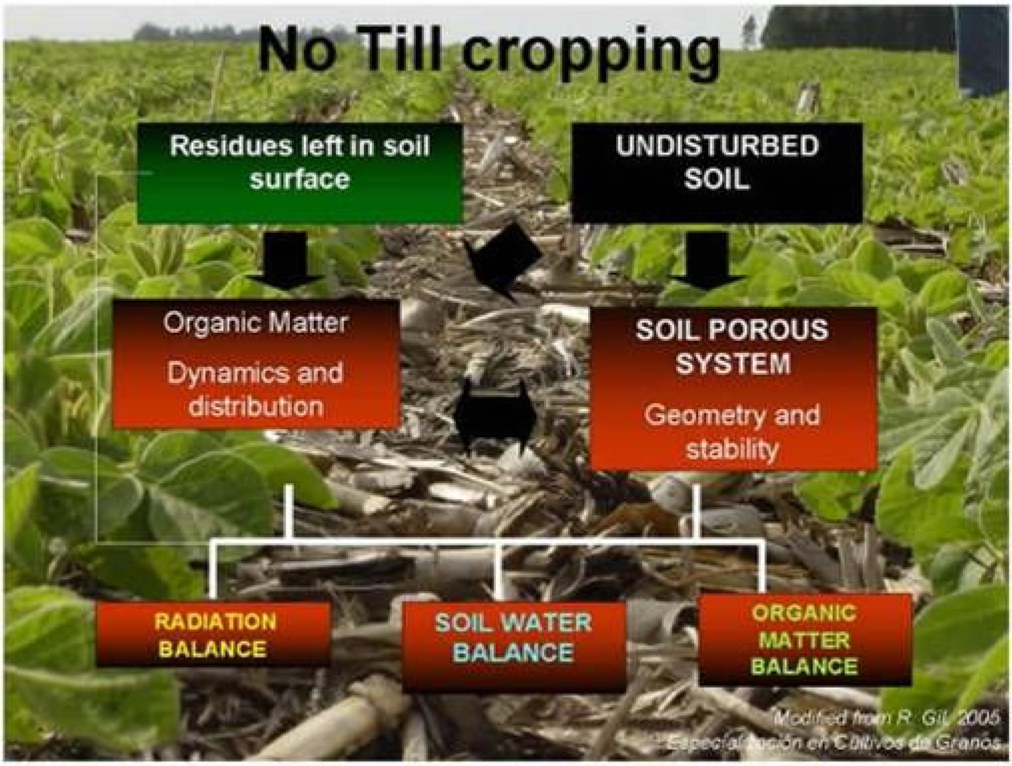
4.2.17.1 Sector description

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.

Figure 52: Schematic description of advantages of no-till practice

Source: http://www.notill.co.za/notill/



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 social cost of about 4% of agricultural GDP (Scholes, *at.el.*, 2000).

There are two main barriers to their widespread adoption: lack of access to information; and the high capital cost of the specialized equipment needed.

There are many co-benefits of this practice and some of them are particularly suitable for emerging farmers. The African Conservation Tillage Network (http://www.act.org.zw/) was founded in 1998 with the objective of promoting conservation agriculture. Unfortunately this network became inactive since 2003. In Zimbabwe about 75% of farmers practiced some form of conservation tillage (Ashburner *at. el.*, 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 a 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, K. et al. 2006) estimated that soil carbon stocks in surface soil layers (to 30cm depth) increased by an average of 10 to 20% over a 20-year time period under no-till practices compared with intensive tillage practices.

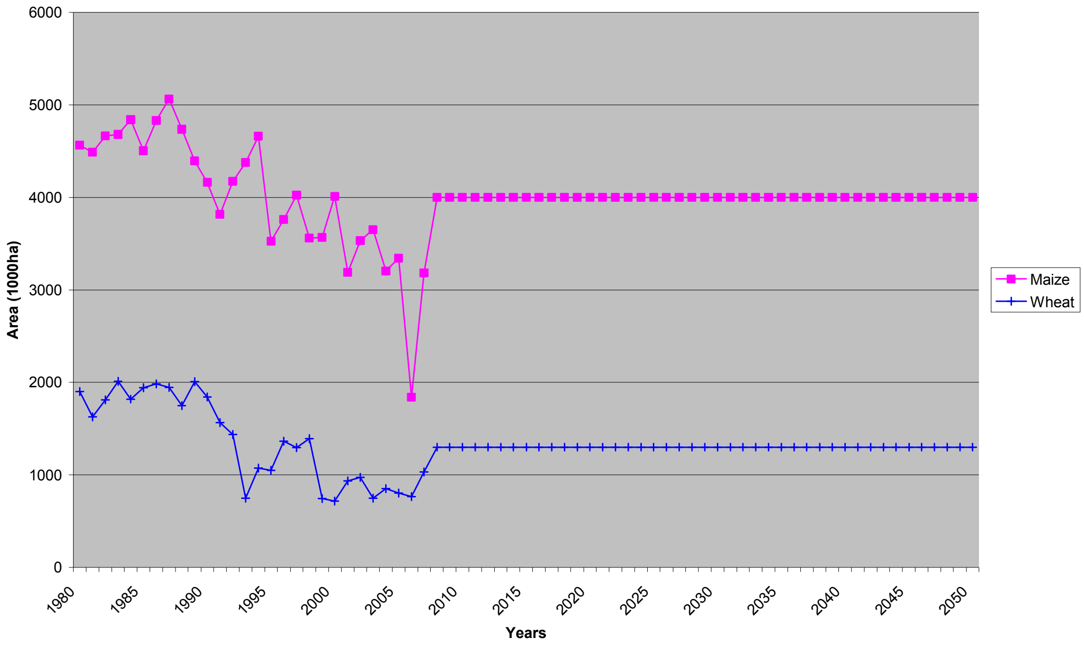
The further details on data sources, assumptions used and the methodology for calculation of emissions are provided in Appendix 10.

4.2.17.2 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 this study.

The area under cultivation was updated using the latest data from the Abstract of Agricultural statistics, 2006 for the period 1970 to 2000 and the latest data (up to 2006) from the Crops Estimates Committee (http://www.sagis.org.za/Flatpages/Oesskattingdekbrief.htm). 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 53 below.

Figure 53: Area for production of maize and wheat (1000ha)



In the model, calculations are based on the assumption that, in cultivated lands, carbon storage is reduced to half of original (pre-cultivation) storage as a result of tilling, over a period of about 30 years. It also assumes that 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. The decline and rebuild phases are both described using exponential curves (i.e. they are initially rapid, but approach their endpoints asymptotically).

It is assumed that since 1970 no new land has been cleared for agriculture. This is approximately true according to the national statistics, but in reality there is a continuous shifting in and out of production of a small fraction of the fields, especially in marginal areas.

For most of the models, 2003 was used as the starting point.For this model, 2003 cannot be used as the starting point since data is available up to 2006. Therefore mitigation starts from 2007.

For this model, two scenarios are considered:

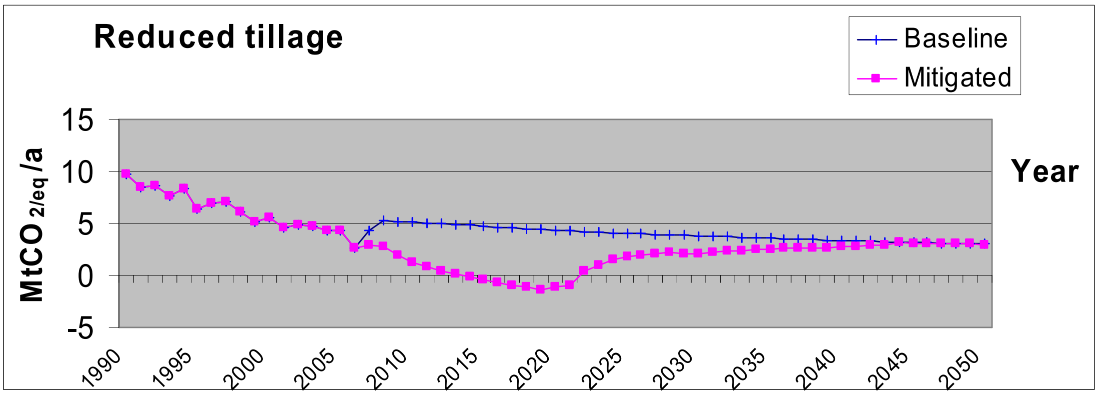
- **In the first scenario it was assumed that reduced tillage can be adopted on 80% of the lands. This scenario represents S4 (or S5) scenario**
- **In the second scenario, the adoption of reduced tillage was much lower (about 30%, and differentiated between wheat and maize), according to the recommendation of DoA ((J Classen, pers. communication). This scenario can be used for S3 scenario.**

More details are provided in the section below.

4.2.17.3 Modelling results for reduced tillage adoption

Scenario 1 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 higher mitigation is achieved (see Figure 54 below). According to the stakeholder contribution at the non-energy workshop on 28 June 2007, 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.

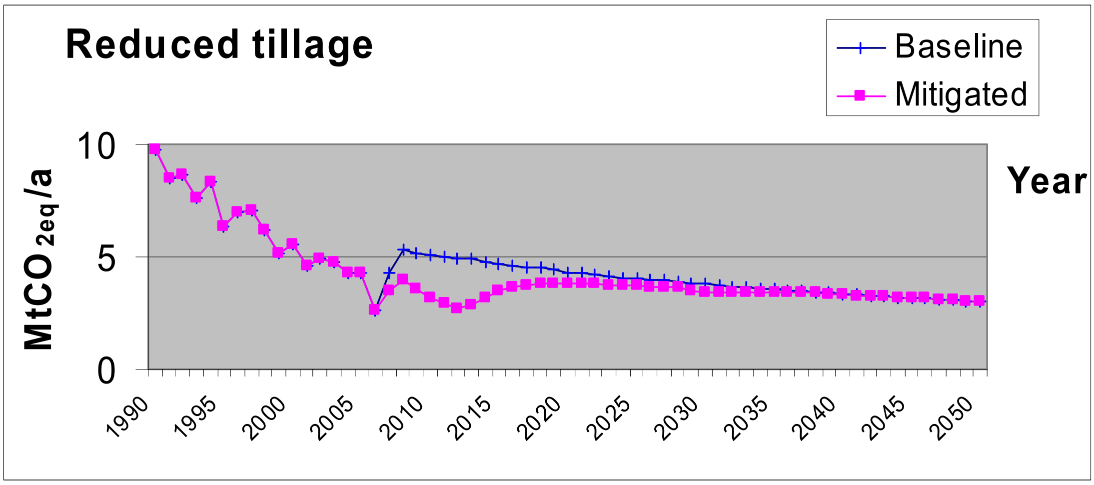
Figure 54: Mitigation by adoption of reduced tillage



The adoption of reduced tillage turns the soil into a sink for a while, but eventually it becomes a source as no additional lands applied the no-till system and the effect of the adoption 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 scenario 2, the model was 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.

Figure 55: Mitigation by adoption of reduced tillage as suggested by the DoA (scenario2 = S3)



These results show much lower mitigation and more smooth changes as a result of reduced tillage adoption.

It is assumed that 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.

Table 28: Financial calculation results for scenario 1 (assumes 80% adoption of reduced tillage)

Parameter	***Scenario***	***Value***
NPV: Costs (Rmillion)	Baseline	0
	Mitigation	505
Levelised costs (R million)	Baseline	0
	Mitigation	51.01
Annual CO_2eq (Mt/a) emitted	Baseline	3.95
	Mitigation	1.87
Annual CO_2eq reduction in emissions (Mt/a)		2.08
Mitigation costs less baseline annual costs (R/a)		51 012 430
Cost effectiveness (R/t CO2eq)		24.49

Table 29: Financial calculation results for scenario 2 (assumes 40% adoption for wheat and 20% for maize)

Parameter	***Scenario***	***Value***
NPV: Costs (Rmillion)	Baseline	0
	Mitigation	505
Levelised costs (R million)	Baseline	0
	Mitigation	28
Annual CO_2eq (Mt/a) emitted	Baseline	3.95

	Mitigation	3.46
Annual CO_2eq reduction in emissions (Mt/a)		0.49
Mitigation costs less baseline annual costs (R/a)		28 077 736
Cost effectiveness (R/t CO2eq)		57.58

In both scenarios, the 'annual CO_2-eq **emitted**' is lower for mitigation than for the baseline. For the 1st scenario it even becomes sink for a while, therefore mitigation results in larger decrease in emissions.

4.2.17.4 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 (Piteman Botha, pers comm.) and was discussed at the non energy workshop on 28 June 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 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 are decreased by 40 percent for reduced tillage and 70 percent 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 life cycle assessment of biofuel production is also needed to determine the true impact climate on 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 (see http://www.earthpolicy.org/Books/Seg/PB2ch08_ss3.htm) 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, pers. communication).

4.2.18 Mitigation actions in waste

4.2.18.1 Description of Waste Sector

According to the previous GHG inventory (Van der Merwe & Scholes, 1998) the amount of waste generated in 1990 was 6933 Mt/a, based on a generation rate of 0.87 kg/capita/day. It is estimated that the disposal of solid waste contributed more than 2% to the total GHG emissions through emissions of CH_4 form urban landfills.

CH_4 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 6 to 9 months after the waste is placed in a landfill. CH_4 makes up 40-50% of LFG. The remaining component is CO_2 mixed with trace amounts of volatile fatty acids (VFA), hydrogen sulphide (H_2S), mercaptans (R-SH) and ammonia/amines (R-NH_2). The mercaptan and amine compounds have particularly strong and offensive odours even at low concentrations.

The production of LFG 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 CH_4 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 sites: open dumps, controlled or managed dumps, and landfills. Open dumps are usually shallow and characterized by open fills with loosely compacted waste layers. Managed dumps are similar to open dumps, but are better organized and may have some level of controls in place. It can be assumed that 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, 1998) for the design and operation of landfills are mandated by government in terms of cover material, landfill design, etc. As the landfill uses a porous soil cover (bio-cover) in its operations, a portion of the CH_4 is oxidized as it passes through these soil layers and converted to CO_2. More information on bio-cover is provided in the Appendix

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 it was 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, it is required to implement a gas management system (PDG, 2004: p.8).

All landfill sites in South Africa are required to be registered and permitted in accordance with the Minimum Requirements for Waste Disposal by Landfill (1998), as issued by the DWAF. The new Waste Management Bill, published for comments in November 2006 by DEAT will amend or further expand upon the regulatory requirements.

To achieve a sustainable waste management regime the approach to waste management should be minimization, recovery, recycling and treatment, with landfilling being the last option (DEAT, 1999). 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.

4.2.18.2 Methodology for modelling mitigation in the Solid Waste sector

For this model the assumption was made that only municipal solid waste (including commercial and domestic waste) is included. It is assumed that there is no need to consider other sources of waste (such as mining waste or hazardous waste) because their amounts or organic content is 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 30 below (Mayet 1993).

Table 30: Income level vs. domestic waste generation rate

Source: Mayet (1993)

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 - R10 000
[3] R0 - R5 000

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, 2007a), which developed a model to support the planning of Johannesburg Waste Services.

The Mayet's model was applied in the DWAF (2001) 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/a. It differed from information obtained from intensive survey of waste received at landfills by 25% (see Table 1 in the Appendix). 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 an order of magnitude out.

The emission rates assumed in the South African GHG inventory (Van der Merwe & Scholes, 1998) are used to determine the amount of CH_4 generated.

The projections for population data, percent of urbanisation produced for the MARKAL model and the same distribution into 3 socio-economic groups as used in the DWAF (2001) report were used to calculate waste generated till 2050. The distribution between socio-economic groups determined in the DWAF (2001) 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 was applied to calculation of the waste generation rates.

The amount of waste generated was multiplied by percent 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 population will contribute to solid waste disposal. However it is assumed that this trend will be balanced by a general reduction in the organic portion of the waste disposed at landfills.

The South African GHG inventory (Van der Merwe & Scholes, 1998) assumed that 0.004 Mt f CH_4 / year was recovered for 3 projects, where methane was either used or flared. This reduction is only 1.1% of the CH_4 generated. It is assumed that by 2003 this had increased to 10%.

The final amount of CH_4 emitted from urban landfills is calculated for 2001 to be 13.5 Mt of $CO_{2\ eq}$. This compares well with total national emission in 2000 of 16.3 Mt $CO_{2\ eq}$ used by EPA, 2005(p.III-5).

4.2.18.3 Mitigation options

In general, solid waste management is given a low priority in developing countries (Godfrey and 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, 2005). The requirements of 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 materialize as well as well thought out and executed interim measures.* '(Ball, 2006)

According to the LTMS project stakeholders' contribution and the investigations by the project team the mitigation options to be considered are summarised in Table 8 below.

There are four mitigation options that were considered: waste minimization, , composting and methane capture from municipal waste (with and without use for energy).

It is suggested that for the baseline option the mitigation targets are lower and will be achieved later than for scenario 5.

Table 31: Mitigation options in waste sector

Sources	***Actions***	***Drivers***	***Start year***	***% of emissions reductionbaseline/required by science***	***Year for maximum penetration (baseline/ required by science)***	***Barriers***
Municipal Waste	Waste minimization	Polokwane Declaration, (DEAT, 2005)	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 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 amount flared and used for energy generation.
- The City of Johannesburg (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.
- The large landfill sites that will use LFG for energy production can use only about 70% of CH_4 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 electrecity generation can flare the LFG, so the percentage reduction listed in the table above 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.

4.2.18.4 Mitigation costs

The eThekwini municipality has developed a LFG utilisation project, which pioneered the CDM pathway for Africa, by becoming a 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/a.

The City of Cape Town is considering use of LFG (MS Haider, pers. communication) 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, then 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 (S Jewaskiewitz from Envitech Solutions, pers communication) provided a much lower estimate of about R14 Million of capital costs and about R1 Million of operation and maintenance costs for flaring 42Mm3/a of LFG from 4 largest sites in Durban area. This can be translated to about R7/t to R14/t of mitigated CO_{2eq}. The larger is the site, the cheaper is 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 MARKAL model and is not repeated here.

The latest study on composting by the CSIR (Phiri, 2007b) 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 form the compost sale is added this option looks to be valuable opportunity for wealth creation for the local communities.

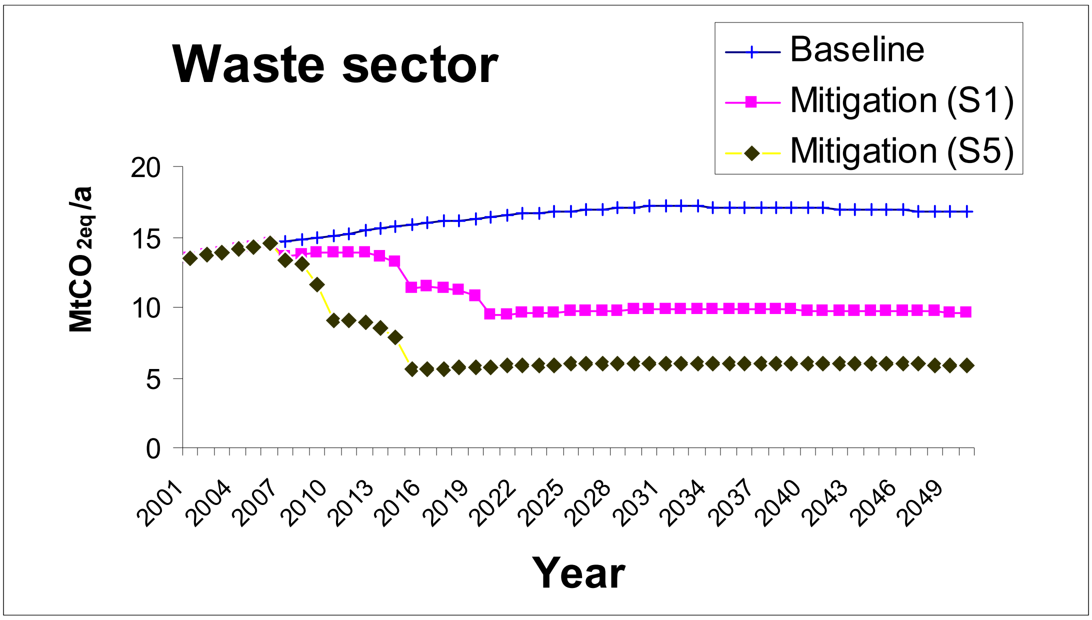
The City of Cape Town is negotiating a contract for composting where R90/t will be paid to remove and then compost chipped garden waste. However this value was not published yet. A simplified assumption was made that the cost of composting is the same as the cost of disposal and therefore no additional cost for composting should be added when mitigation is compared to 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 global Marginal Cost Analysis by EPA, 2005 about 40% reduction in landfill emissions in South Africa could be achieved almost at zero cost (see Figure E-2). But the breakeven cost of composting is above \$200/tCO_2eq mitigated and for flaring it is about \$25/ tCO_2eq mitigated.

4.2.18.5 Modelling results for solid waste

The results of the modelling are presented in Figure 56 below.

Figure 56: Baseline and mitigation emissions in waste sector for scenario 1



Only mitigation cost of flaring is included for financial calculations (see assumptions on the costs in the section above). It is R14/t CO_2 eq based on 10% discount rate, for flaring only. An additional set of calculations was provided for a number of Durban waste sites (S Jewaskiewitz, pers communication, 16 July, 2007). These calculations provided a range of costs from R4.06 to 9.26 R/t CO_2 eq. However, for this project, it is suggested that the more conservative value of R14/ /t CO_2 eq., be retained.

4.2.18.6 Model limitations and further research

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

1. The same distribution into 3 socio-economic groups as used in the DWAF (2001) 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.
2. The calculations for annual mitigated amount are based on the amount of waste generated during that year.
3. The waste minimisation impact was not modelled.
4. It was assumed that only half of the waste is disposed at the large landfill sites suitable for energy generation.
5. The cost of composting is equal to cost of disposal.

The assumption for the rate of conversion of waste disposed, into CH4 emission, is reasonable, and a better figure can not be obtained without modelling the decay of organic matter at each major site.

According to the stakeholder contribution at the non-energy workshop on 28 June 2007, 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. So, if the modelled value is 100% higher as a result of the corrected assumption, it will have no noticeable impact. The emission form 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 new GHG inventory is completed this assumption should be re-examined.

This model highlights the 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.

4.2.19 Mitigation actions using fire control and savannah thickening

4.2.19.1 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 mirrored changes in ecological thinking, from stable-state to variability in space and time. A study in National Kruger 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. A framework for integrated veldfire management was prepared. It is estimated that the annual cost of wildfire is about R743 million/a, while baseline cost of Fire Protection Associations is about R104 million/a. So, even without considering GHG potential mitigation as a result of fire reduction, the investment in fire control is economically justifiable. There are many other costs that were discussed. For example, the highest impact of fires is on forest plantations and therefore forest industry spends about R150 million/a on fire control operations. Consequently, the fire return frequency at forest plantation is about 200 years compared to 5 to 10 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 *et.al*), 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 grow to heights of 3 - 4m, saplings escape the trap and become mature trees.'* The model also tested the impact of increased CO_2 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.'* It should be noted that this process was started a few decades ago and it is predicted that the area of savannas 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 using by extending the calculation till 2050 and enhancing the economic model.

4.2.19.2 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 realizing 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. Fire frequency reduction is an attainable target. For this model mitigation **by 50% reduction in the fire frequency is assumed**.

Although a large quantity of CO_2 is generated as 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 CH_4 and N_2O 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 CH_4 and N_2O).

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 personal 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 of 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 are 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 financial calculations below model only the required increase in fire protection.

The further details on assumptions used and the methodology for calculation of emissions are provided in the Appendix.

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

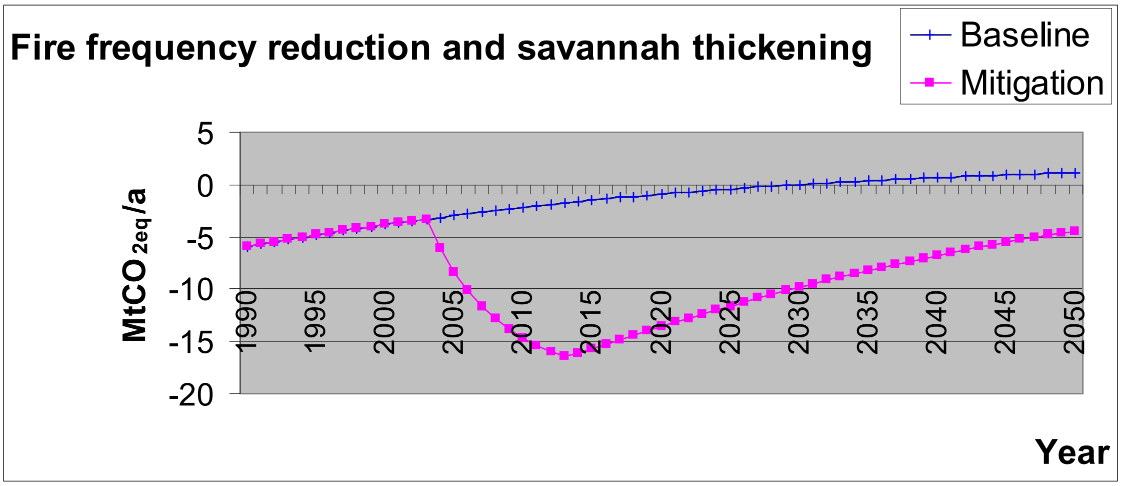
Increase in woody biomass is considered for two land cover types – fertile and infertile savannas. It is assumed that the growth from the original woody biomass to a climatically-determined maximum is function of fire return frequency and of rainfall.

The increase in CO_2 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 many of the savannas have already thickened).

4.2.19.4 Modelling results for land-use changes

The emission comparison for the baseline and mitigation scenarios is presented in Figure 57. For most of the study period, carbon is sequestered and only at the end are slight emissions projected.

Figure 57: Baseline and mitigation sequestration from fire control and savanna thickening (Mt CO2eq/a)



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 C 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 was adjusted to the 2003 base year using the CPIX factor.

Furthermore, the original model considered the cost of the loss of grazing and was found that about 10% of free-range cattle will be affected. 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.

Table 32: Results of financial calculations for fire control and savanna thickening

Parameter	***Scenario***	***Value***
NPV: Costs (R million)	Baseline	R 20,563
	Mitigation	R 18,626
Levelised costs (R million)	Baseline	R 2,078
	Mitigation	R 1,882
Annual CO_2eq (Mt/a) sequestered	Baseline	-0.5
	Mitigation	-10.0
Annual CO_2eq saving (Mt/a)		-9.5
Mitigation costs less baseline annual costs (R/a)		-195,781
Cost effectiveness (R/t CO_{2eq}) (benefit)		-20.63

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.

4.2.19.5 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 which change with time. However plantations make a relatively small contribution to fire emissions and therefore this error would not be significant. The SANBI produced maps that show the areas under each type of vegetation. These areas differ slightly from those used by the model. (G Midgley, pers communication, 20 July 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/a, 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 use 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, 2006). Overall, biomass use for household energy is a small, not well-known share of total energy demand

In a recent review of strategy options for fuelwood, Shackleton et al, (2004, p. 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/a to more than 7.5 t/a, typically between 3 and 4 t/a.

- *Fuelwood use is widespread, with over 95 percent 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 urbanization.*
- *The gross annual value of demand to the national economy is estimated to be R3 – 4 billion.'*

The fuelwood supply and demand was evaluated as one of the ecosystem services that could support achievements of the Millennium Development Goals by Scholes & Biggs (2004).

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

4.2.20 Mitigation actions in forestry sector

4.2.20.1 Situation in South Africa

Indigenous forests occupy only 0.3% of the South African land surface. The other major indigenous wooded biome, savannas, 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 and Scholes, 1999), of which roughly half is softwood, and half hardwood. According to the www.Forestry.co.za only 1 425 714 ha were under commercial plantations in 2005.

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 early 1980s to over 22 million cubic metres last year (Hendriks, 2006).

The plantation area has expanded by roughly 11 900 ha per year since 1985 (based on data provided on www.Forestry.co.za). This is about 1.45 times higher than the average rate of 8 265 ha/yr 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 (based on data provided by the forestry industry on www.Forestry.co.za)

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

There are a number of constraints on the area planted to forests (Scholes at. el, 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.
- Competition for suitable land from other, more profitable (or socially desired) land uses.
- Loss of biodiversity, 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 (Hendriks, 2006).

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

When plantations 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 at. el, 2000).

The modelling methodology and most of the data was derived from the previous mitigation study (Scholes at. el, 2000). However, a new mitigation option is suggested based on the recent DWAF, 2004 report. This study projected demand and supply of roundwood till 2030 and showed a shortfall of supply of over 14Mm^3/a. To meet this demand an additional 775 000 ha have to be afforested. Although this is almost double of the 330 000 ha of afforestation in the mitigation option modelled in Scholes at. el, 2000, it seems to be in line with the new strategy of the DWAF (Hendricks, 2007). This projection seems unrealistic considering the planned forestry extension of about 100 000ha over the next 10 years.

Afforestation by *Eucalyptus* and pines is the most significant compared to the area planted to wattles.. For the baseline scenario the rate of expansion of the total plantation area is assumed to be 11 000 ha/y (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 re-forestation be included in the model, according to B Scholes (pers communication) this will not noticeably affect the results.

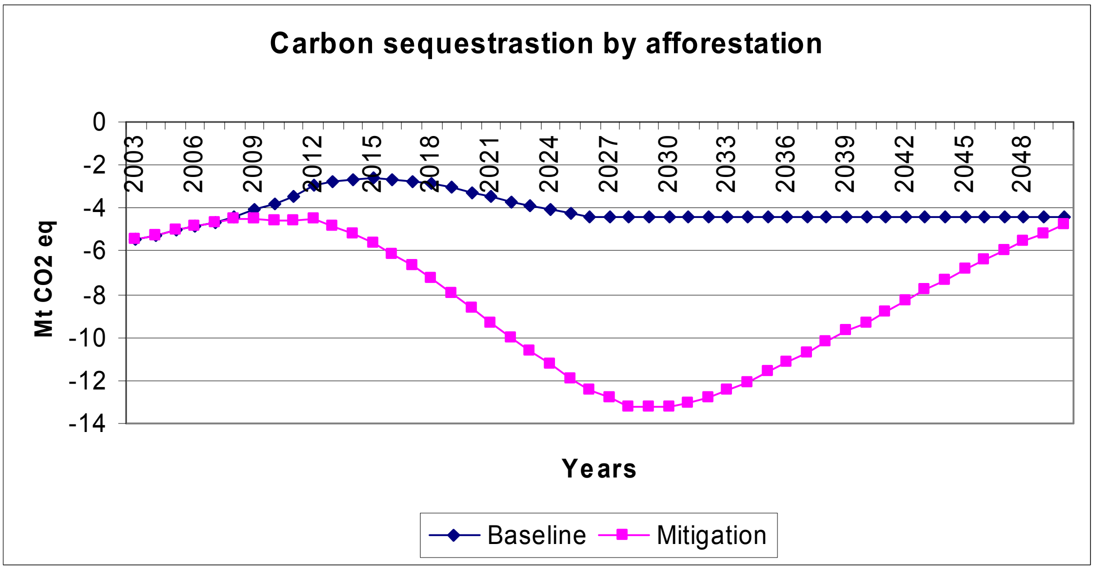
For the mitigation option it is assumed that **the net extension area will increase by 200% from 2008 to 2030 to allow an additional 760 000 ha** (close to the value suggested in DWAF, 2004). Since GDP growth will flatten down to about 3% after 2030 (see Figure 5 in section 3: Key assumptions), the same extension rate as prior to 2008 is applied after 2030.

This mitigation option is unusual because it provides highest mitigation while supporting GDP growth.

4.2.20.3 Modelling results for afforestation

The modelling results are presented in the figure below.

Figure 58: Baseline and mitigation sequestration from afforestation (Mt CO_{2eq}/a)



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 and Rusk, 2003)

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

Table 33: Results of financial calculations for afforestation

Parameter	***Scenario***	***Value***
NPV Costs (R million)	Baseline	48156
	Mitigation	53715
NPV Income (R million)	Baseline	47347
	Mitigation	51301
NPV Net Costs (Costs-Income) (R million)	Baseline	808
	Mitigation	2413
Levelised net costs	Baseline	R 81.66
(R million/a)	Mitigation	R 243.85
Annualised CO2 Eq (Mt/a) (negative for sink)	Baseline	-4.08
	Mitigation	-8.29
Increase in sink (Mt/a)		4.21
Mitigation costs less baseline annual costs (Rand/a)		162 183 918
Cost effectiveness (R/ton CO_{2eq})		38.51

4.3 Mitigation actions: Economic instruments

The SBT 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.

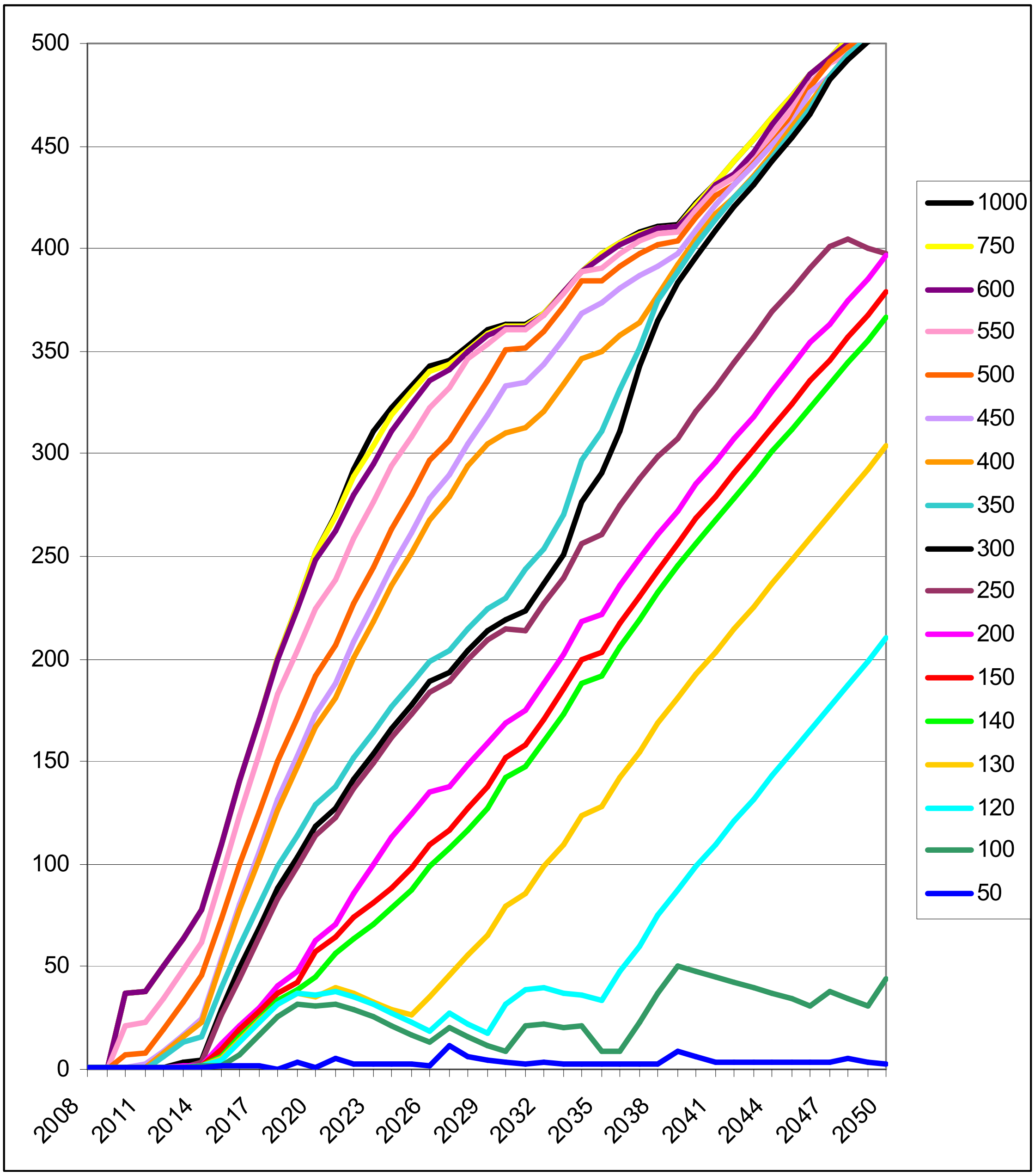
The full effect of the CO_2 tax will not be evident if the model cannot choose different options. In running the tax cases, bounds need to be freed up compared to GWC. All the tax cases therefore allow more building of nuclear and renewables, as well as switching to more efficiency on the demand side. 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.

4.3.1 Mitigation actions: CO_2 tax

4.3.1.1 The mitigation impact of different tax levels

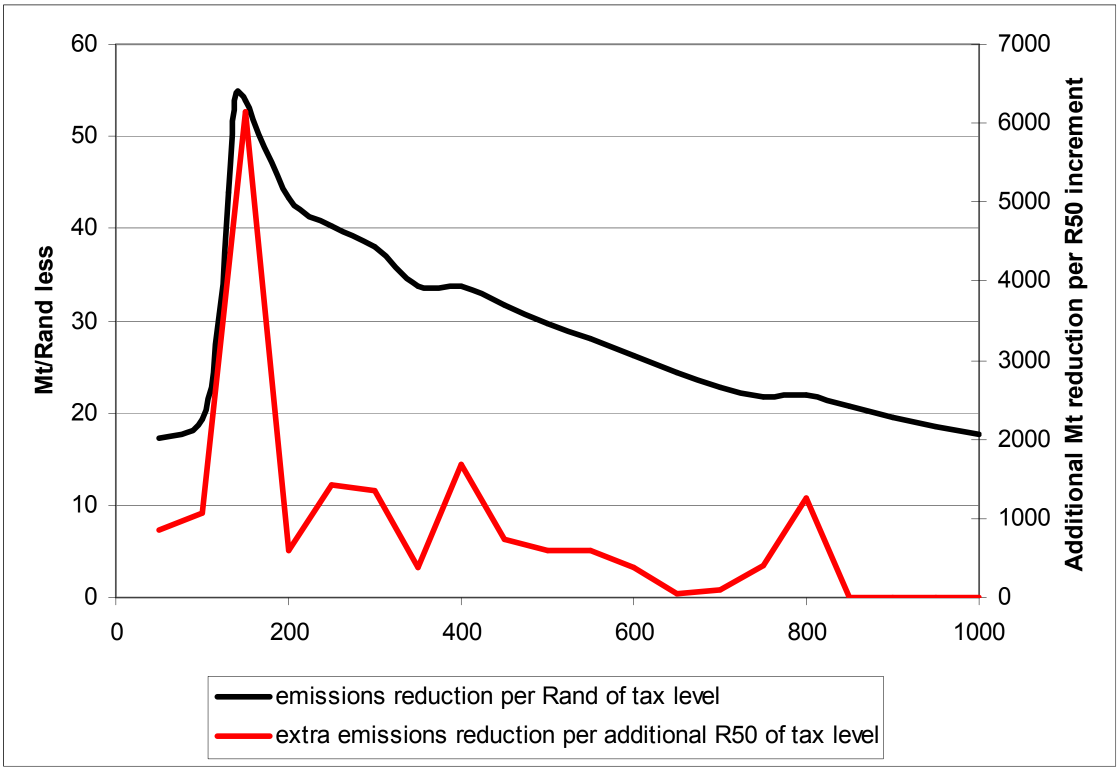
Given the limited technologies and energy carriers currently available, there are limits to the impact that a carbon tax would have on the energy system as a whole – after a certain threshold, imposing a higher tax makes no difference to the level of CO_2 emissions, since all possibilities for switching 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. The figure below 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 R 100 and R200, around R140. From R200 to R300, and from R300 to R400, there are significant increases in emissions savings, although from R400 to 1000 additional gains are insignificant. This is illustrated in Figure 60, in which it can be seen that the average impact of higher tax levels peaks sharply at around R140, and declines steadily after that.

Figure 59: Mitigation impact of different tax levels



The marginal benefit of increasing the tax level provides some more detail: a large initial peak in the R100-200 region is followed by a small number of peaks, culminating in a small R750-800 peak, after which raising the tax level has minimal impact on emissions.

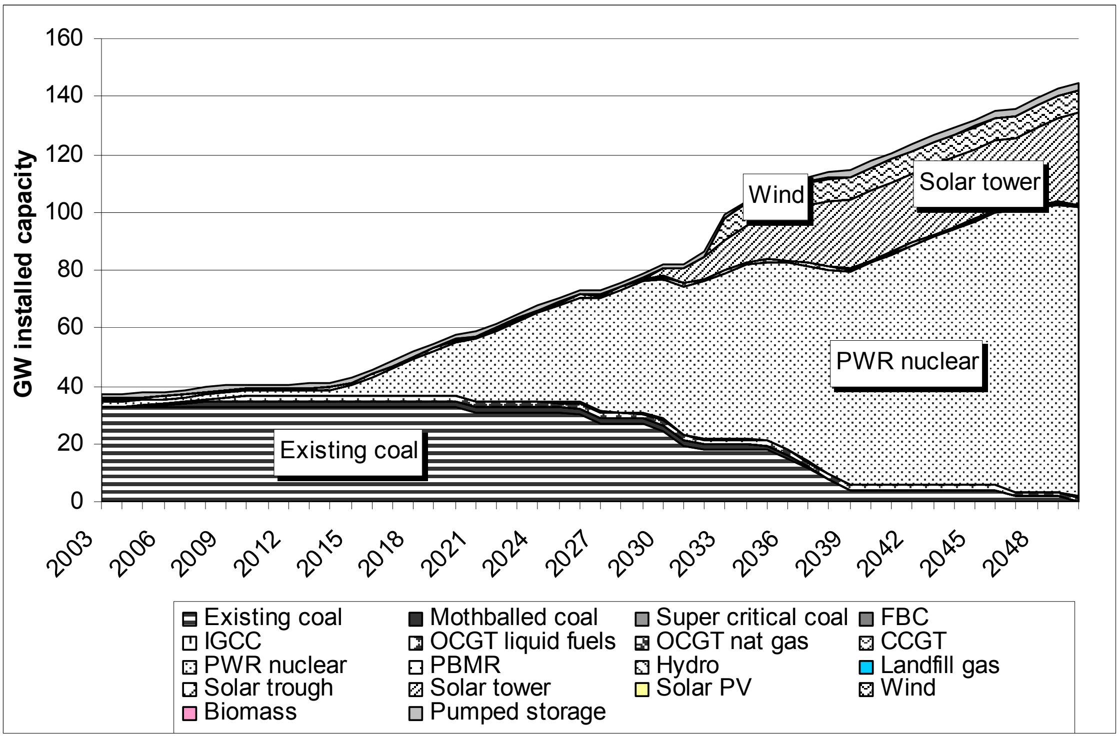
Figure 60: Average and marginal impact of various tax levels



4.3.1.2 Escalating tax

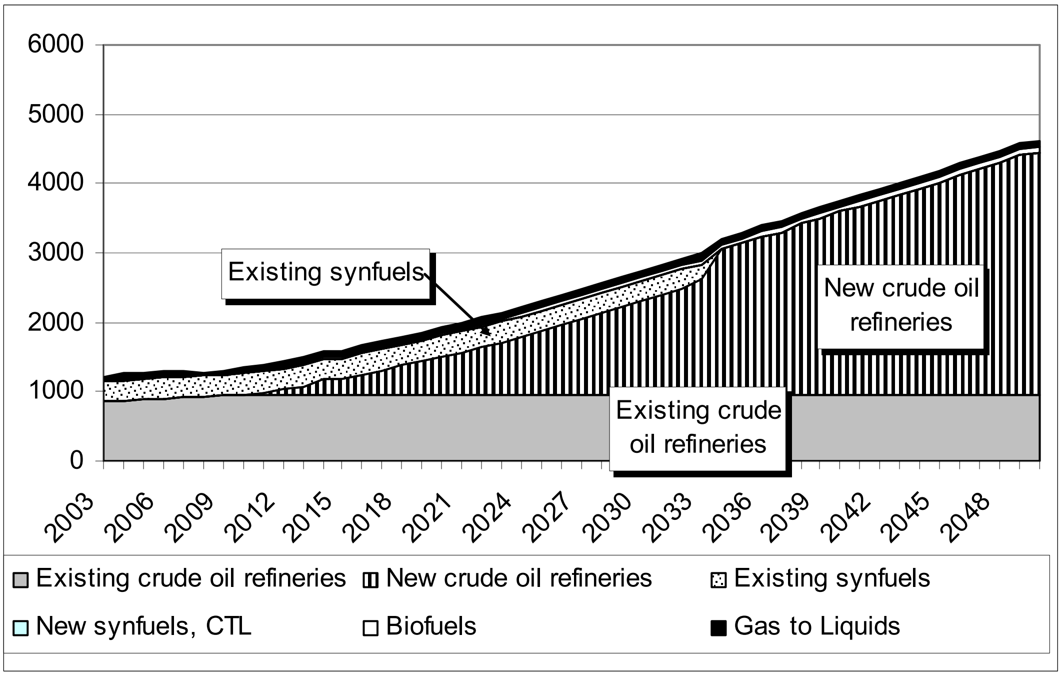
In the tax case which was modelled, an escalating tax rate is applied. The tax level starts at R 100 / t CO_2-eq in 2008, rises to R250 by 2020, i.e. in a period when the *rate of growth* of emissions might need to be slowed, even if absolute emissions still rise. It is then kept at that level for a 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 R 750, 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 the figure below:

Figure 61: Electricity generating capacity by plant type: escalating CO_2 tax



In addition, as can be seen in Figure 62 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.

Figure 62: Ouput from refineries and synfuel plants: escalating CO_2 tax

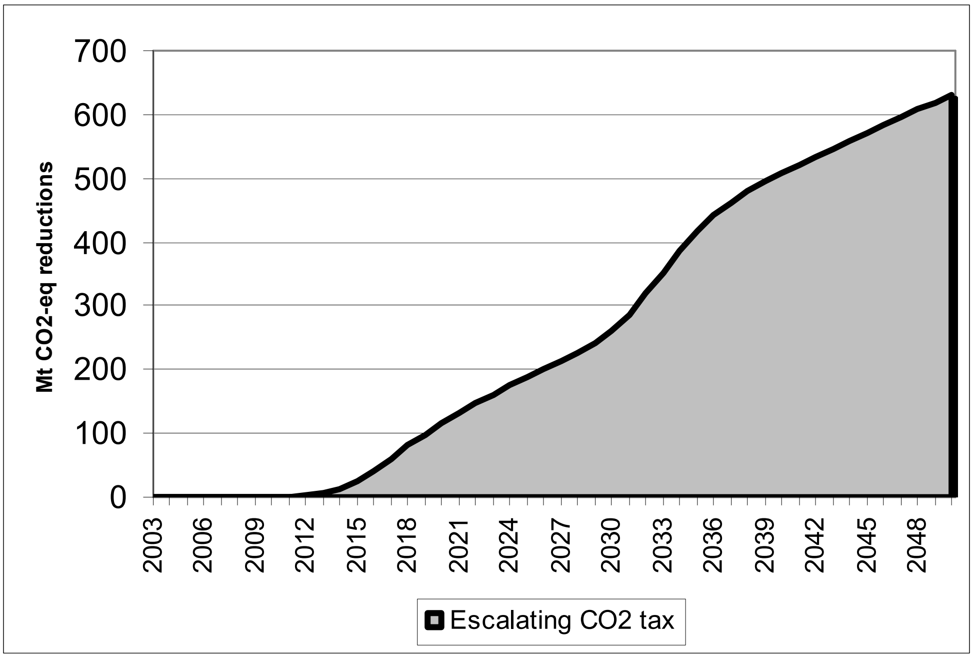


The application of the tax mitigates 12 287 Mt of CO_2-eq over the period, at a cost of R42 per ton.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	32,769	10,714	4,848
Annual CO_2eq saving (Mt/yr)	256		
Cost effectiveness (R/t CO_2eq)	128	42	19

Total CO2eq saving (Mt, 2003-2050)	12,287
% increase on GWC costs	4.28%
% of GDP	0.92%

Figure 63: Emission reductions from an escalating CO_2 tax



4.3.1.3 Previous tax levels analysed

In previous analysis, CO_2 taxes of R 100 and R 1000 / t CO_2-eq were examined. A tax of R100/ton of CO_2 is placed on all CO_2 emissions. The emissions reductions are concentrated in the last two decades, when a slightly higher proportion of low-CO_2 emitting technologies are built – 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 CO_2 tax declines and disappears.

The R100 tax reduced emissions by 1 804 Mt CO_2-eq from 2003 to 2050, while at R 1000, 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 R 1000 tax is close to 2% total mitigation cost, relative to the size of the economy.

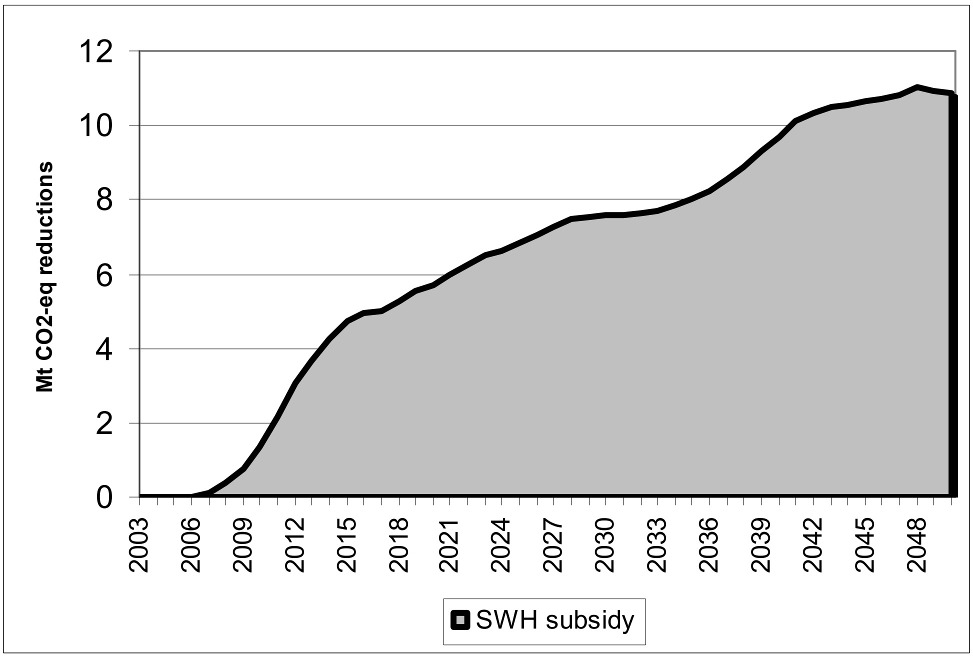
4.3.2 Subsidy for Solar Water Heaters

A subsidy of on 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.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	-2,932	-1,328	-773
Annual CO_2eq saving (Mt/yr)	6		
Cost effectiveness (R/t CO_2eq)	-459	-208	-121
Total CO2eq saving (Mt, 2003-2050)	307		
% increase on GWC costs	-0.43%		
% of GDP	-0.09%		

Figure 64 shows that, 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 -R 208 / t CO_2-eq.

Figure 64: Emission reductions from subsidising residential SWH

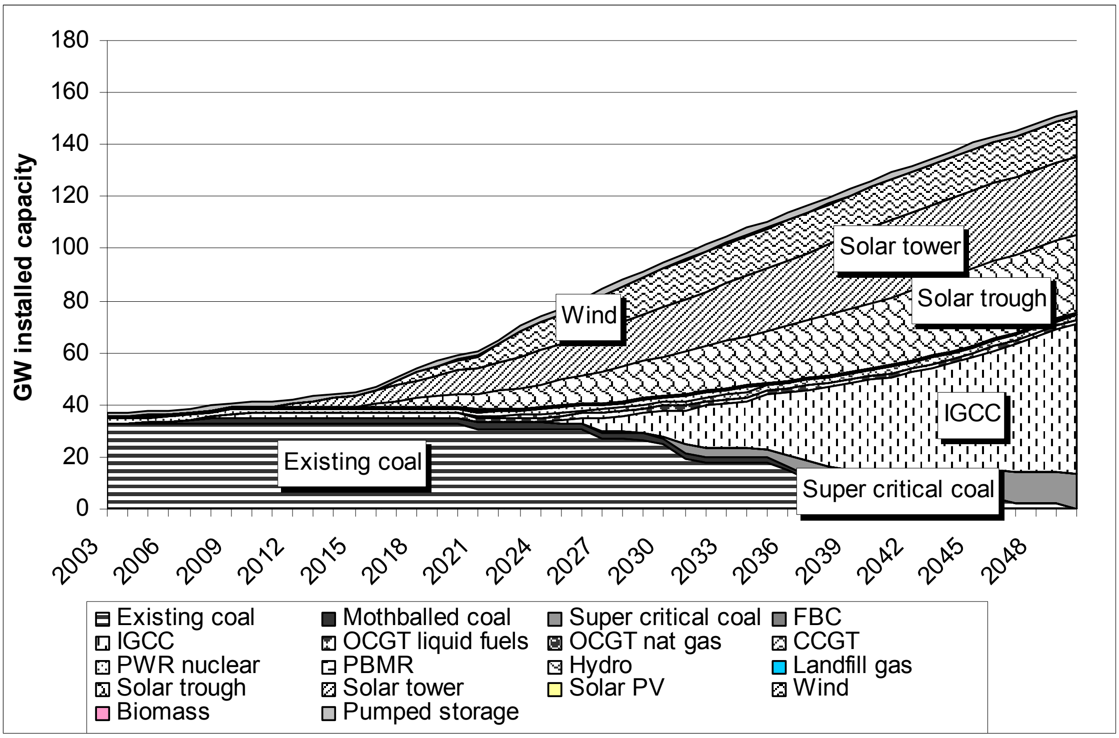


4.3.3 Subsidy for renewable electricity

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 65. The two solar thermal electric technologies appear as in other renewables wedges, but noticeably more wind is built. The overall size of the grid is over 150 GW by 2050.

Figure 65: Electricity generation capacity with renewables subsidy (GW)

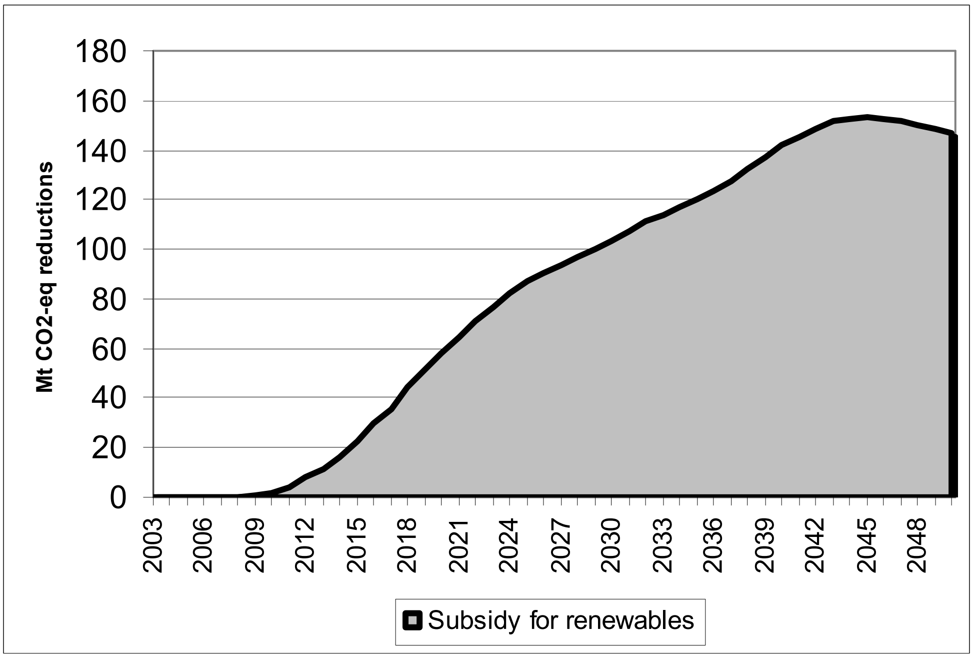


These changes in response to the subsidy result in emission reductions of 81 Mt per year, adding up to 3 887 Mt CO_2-eq over the period. The average mitigation cost at 10% discount rate is R 125 / t CO_2-eq. Overall, the cost of abatement through this measure would be 0.77% of GDP.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	26,811	10,130	5,080
Annual CO_2eq saving (Mt/yr)	81		
Cost effectiveness (R/t CO_2eq)	331	125	63
Total CO2eq saving (Mt, 2003-2050)	3,887		
% increase on GWC costs	3.65%		
% of GDP	0.77%		

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.

Figure 66: Emission reductions from subsidising renewables for electricity generation



4.4 Required by science (RBS)

The IPCC's Second Assessment report had indicated the need for a 60-80% reduction in order to achieve stabilization 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 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. 4.5oC) within the 'likely' range of 2-4.5oC 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 2007: 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 were considered not tolerable, then the global target needs to be -50% by 2050.

Based on this information, SBT2 agreed to consider reductions of - 30 – 40% of the base year levels by 2050. This is the scenario of actions 'required by science' (RBS).[15] This is the only scenario that sets a climate targets, and works backwards to specific actions. The question is how this might impact on SA's economy – might it even result in negative growth?

In the energy modeling, an attempt was made to implement the RBS scenario. Emissions in 2050 were constrained to 30% compared to base year (2003) levels, with limited results:

- Initial analysis in Markal showed that RBS cannot be achieved with in a least-cost minimisation framework and the 'ambitious but realistic' limits on resources, technologies, and policies implied in that framework. The RBS climate target cannot be met within this framework. [16]
- Even applied to the reference case, the resulting Markal scenario provide 'infeasible' – in other words, the linear programme found no solution that could meet the level of energy demand and meet all the constraints (including the new climate-constraint).
- This in itself is a result – the energy modelling provides an assessment of technologies that are 'ambitious but realistic', i.e. penetration rates of new technologies are bounded to levels found in other countries; there are limits on resource availability (e.g. sites for hydro-electricity in SA). The RBS climate target cannot be met within this framework. This suggest that either one need to redefine what is realistic (e.g., re-considering the extent to which mitigation options can be achieved 'realistically'); or the analysis needs to be conducted outside of the confines of a constrained modeling approach.

With the analysis to date, no results are available for the costs of an RBS scenario. The emission reductions required, however, are implicit in the target itself. To indicate the level of emission reductions that would be required by science, we assume that emissions continue to increase only for a short while, peaking by 2015 at 550 Mt CO_2-eq (already slightly lower than GWC), before declining according to a polynomial interpolation to the target of -30% of base year levels by 2050. This allows at least an emissions path to be sketched, but as yet without information on the cost implications.

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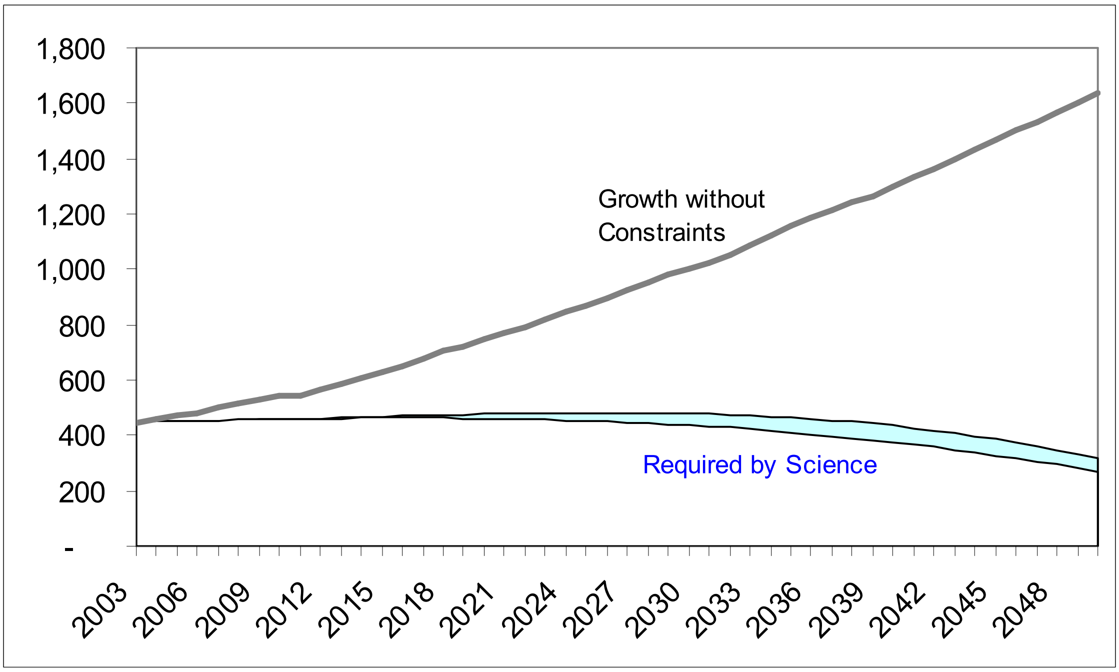
[15] In other words, it assumes that SA would act in a way that it wants everyone else to act, following the Kant's categorical imperative: 'Act only according to that maxim whereby you can at the same time will that it should become a universal law' (Immanuel Kant, *Metaphysics of Morals*)

[16] In the language of MARKAL, RBS run with the same bounds as CDP but a climate constraint turns out to be 'infeasible'. The linear programme cannot find a solution which meets all the constraints (climate target and all the energy system equations built in). This does not mean that RBS cannot be achieved in other frameworks. This should not come as a surprise – Albert Einstein already observed that '[p]roblems cannot be solved by the same level of thinking that created them.'

Figure 67: Emission reductions required by science compared to GWC



As suggested by SBT5, the RBS scenario has been adjusted downward and shows a range. The lower lline, reducing to -40% by 2050, shows a a global or collective bottom line, while the cloud related to South Africa's contribution to this, and not every country has the same responsibility. 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 34: 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 67 is constructed on a storyline that represents emissions peaking soon and then declining to specified level. 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%. 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.

5. Combined cases

GWC sees total emissions – energy, non-energy and industrial process combined – multiply by just under four times. Even with the effort put into current development plans, reductions are relatively small compare to growth. A target requiring an absolute reduction is significantly more ambitious. Combining cases progressively move emissions down from GWC to RBS, providing an analytical basis for the Strategic Options in the LTMS Scenario document.

5.1 Combined cases – initial wedges (Start Now)

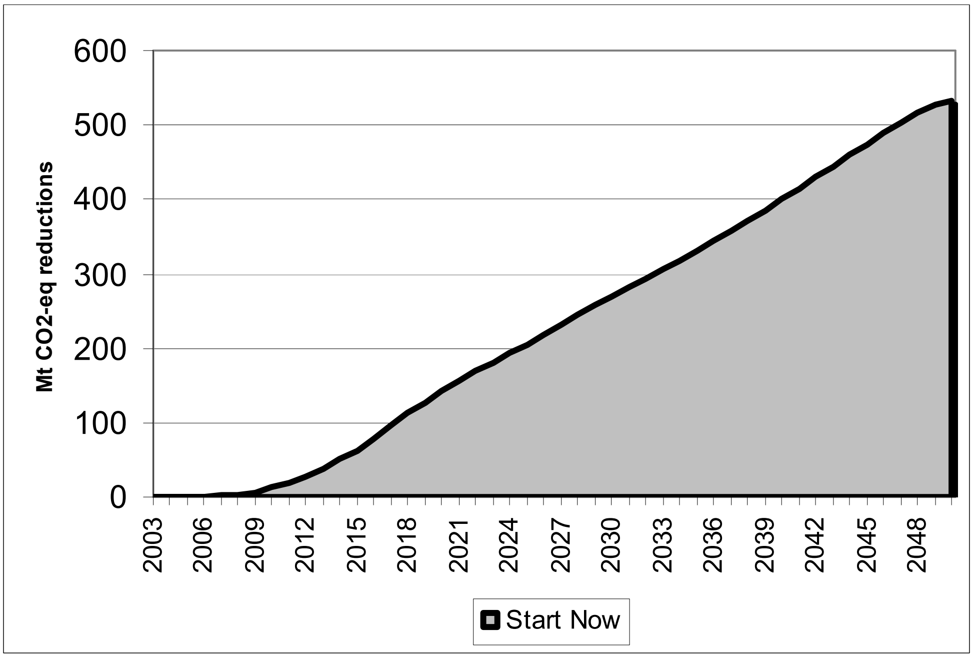
This case combines the wedges as initially modelled for SBT4, but excluding the CO_2 tax, which is reported as part of economic instruments. This combined case includes efficiency in various sectors (industry, commerce, residential, vehicles), options in transport including SUVs, hybrids and passenger modal shifts; cleaner coal, renewables and nuclear for electricity generations and CCS with the agreed limit.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	-18,965	-2,971	-467
Annual CO_2eq saving (Mt/yr)	231		
Cost effectiveness (R/t CO_2eq)	-82	-13	-2
Total CO2eq saving (Mt, 2003-2050)	11,079		
% increase on GWC costs	-2.18%		
% of GDP	-0.48%		

The combined wedges reduce a cumulative amount of 11 079 Mt CO_2-eq from 2003 to 2050. The large wedge is shown in Figure 68 has average annual emission reductions of 231 Mt CO_2-eq. With substantial energy efficiency options and relatively (to the extended case) modest positive cost wedges, this can be done at –R13 t CO_2-eq. 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%.

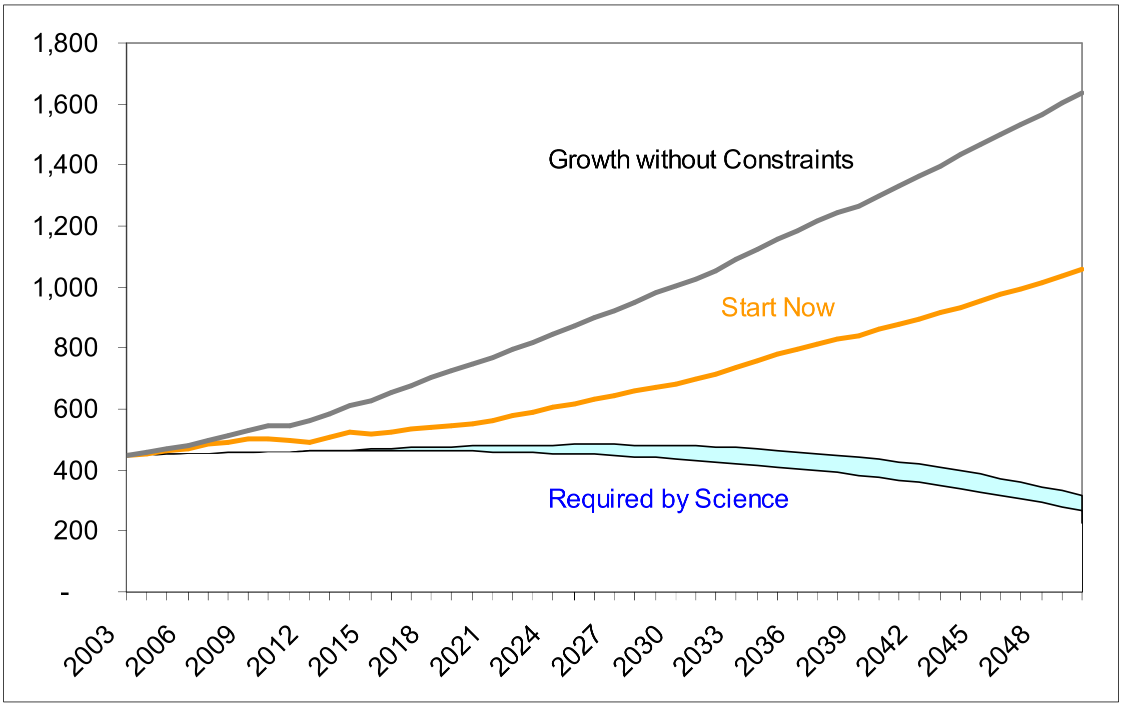
The emission reductions and costs shown above are only for the energy system. As this report has made clear, there are further emission reductions from non-energy emissions. These *are* taken into account when calculating the difference between the strategic options and *total* GWC emissions. In other words, the lines for the combined cases in Figure 69, Figure 71 and Figure 73 all include the emission reductions in other sectors.

Figure 68: Emission reductions from combined initial wedges



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 69.

Figure 69: Emissions with combined initial wedges compared to GWC



5.2 Combined cases – extended wedges (Scale Up)

This combined case draws on the extended wedges modeled since SBT4. The extended nuclear and renewables wedges are included here (without learning). For cleaner coal technologies, the limit of storing CO_2 is relaxed to 20 Mt CO_2 per year.[17] It is extended further by including biofuels and electric vehicles, in addition to all previous transport wedges. Finally, the lower limit on SUVs is also assumed in this combination. The efficiency cases are the same as in the combination of initial wedges.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	25,772	11,209	5,842
Annual CO_2eq saving (Mt/yr)	287		
Cost effectiveness (R/t CO_2eq)	90	39	20
Total CO2eq saving (Mt, 2003-2050)	13,761		
% increase on GWC costs	3.63%		
% of GDP	0.77%		

The results for the combined extended case show that significantly higher emission reductions (13 761 Mt CO_2-eq) can be achieved over the period, or an average of 287 per year. However, this gain is now at a net positive cost or R 39 / t CO_2-eq. The mitigation costs represent a share of 0.77% of GDP.

Figure 70: Emission reductions from combined extended wedges

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[17] This was the limit on which the SBT4 results were based. It was proposed that he limit was then reduced to 2 Mt CO_2 per year, the scale of largest planned project. This has been implemented for the CCS wedge, but in the extended case, we have relaxed this again, since other technologies are also extended.

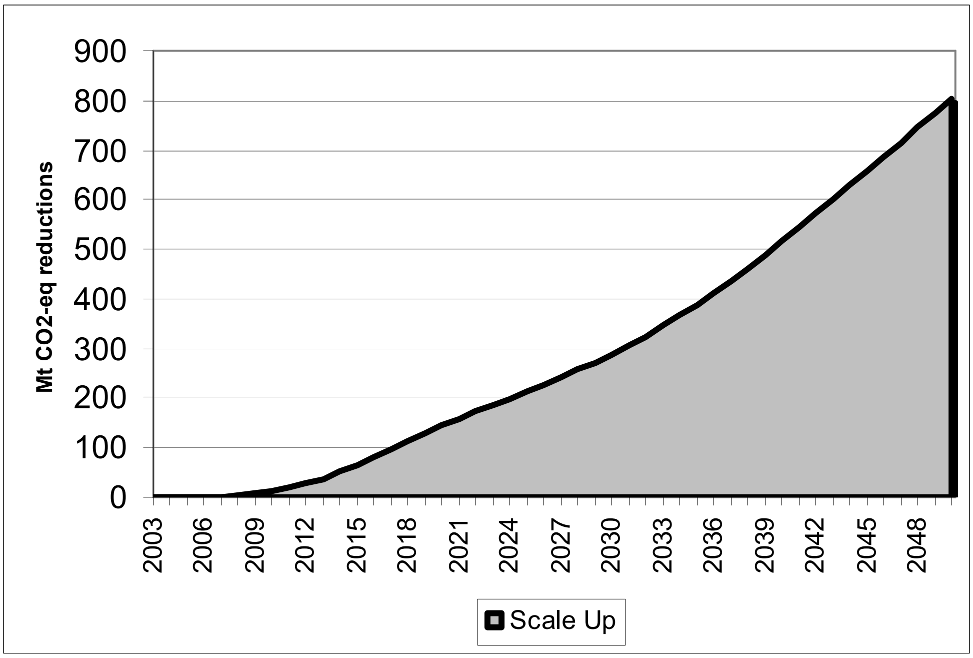
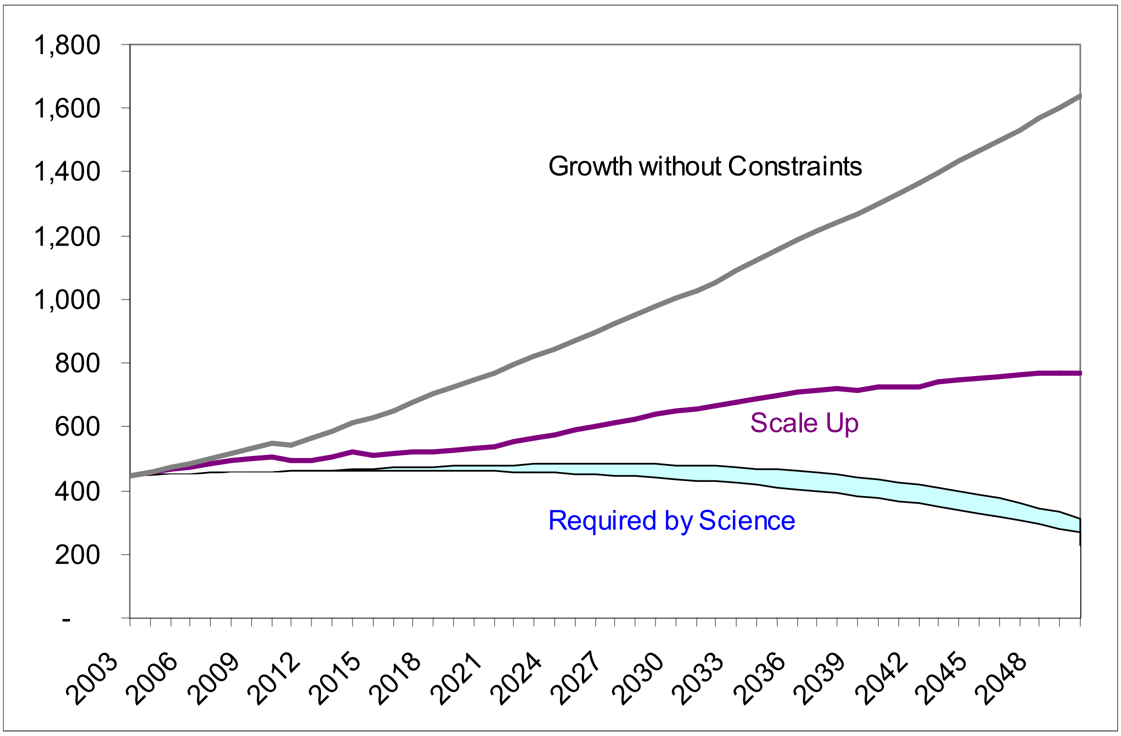


Figure 71: Emissions with combined extended wedges compared to GWC



Relative to GWC, emissions are even more substantially reduced than in the initial case, although this varies over time (for a comparison, see section 6.1). Figure 71 shows that absolute emissions increase for most of the period, but then flatten out in the last decade.

The extended combined case adds more positive cost mitigation wedges. Again, there are substantial relative emission reductions. A key difference to the initial combined case is that emission stabilise, albeit only right at the end of the period. Expressed in terms of the gap between GWC and RBS, the combined extended case has closed more than half (64%) of this gap in the year 2050. The scale of emission reductions in the wedge shown in Figure 70 is larger than all except the wedge combining the economic instruments.

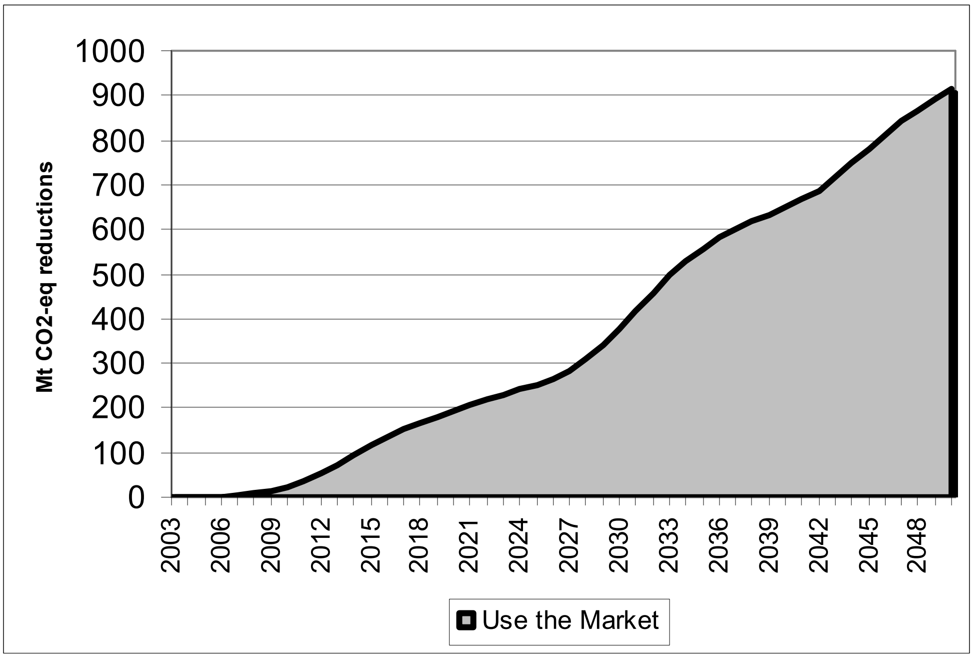
5.3 Combined economic instruments (Use the Market)

This combined case includes the three subsidies – SWH, renewables and biofuels – together with a higher CO_2 tax. To see the full 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 higher, as in the subsidy case.

Discount rate	*3%*	*10%*	*15%*
Incremental Annual Cost (R millions)	2,358	3,522	2,507
Annual CO_2eq saving (Mt/yr)	363		
Cost effectiveness (R/t CO_2eq)	6	10	7
Total CO2eq saving (Mt, 2003-2050)	17,434		
% increase on GWC costs	0.60%		
% of GDP	0.11%		

This combined case results in the largest wedge analysed for LTMS, as shown in Figure 72. Total emission reductions over the period are 17 434 Mt, at an average of 363 Mt CO_2-eq per year. Clearly the actions that would be taken in response to a combination of taxes and subsidies would constitute 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).

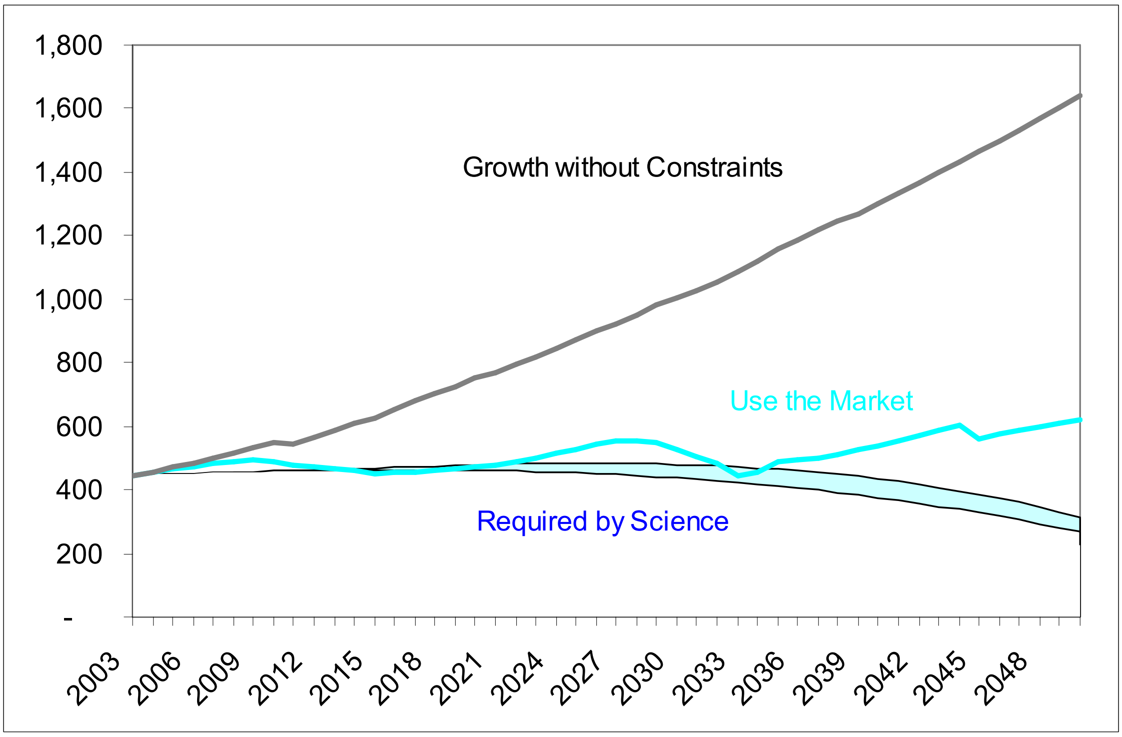
Figure 72: Emission reductions from combined economic instruments



The emission reductions in response to a combination of economic instruments are large in the South African context, with reductions averaging more than 2003 energy sector emissions. Compared to GWC (see Figure 73), emissions fluctuate around base year levels up to 2036. However, in the second half of the period, emissions grow again.

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. **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 73: Emissions with combined economic instruments compared to GWC



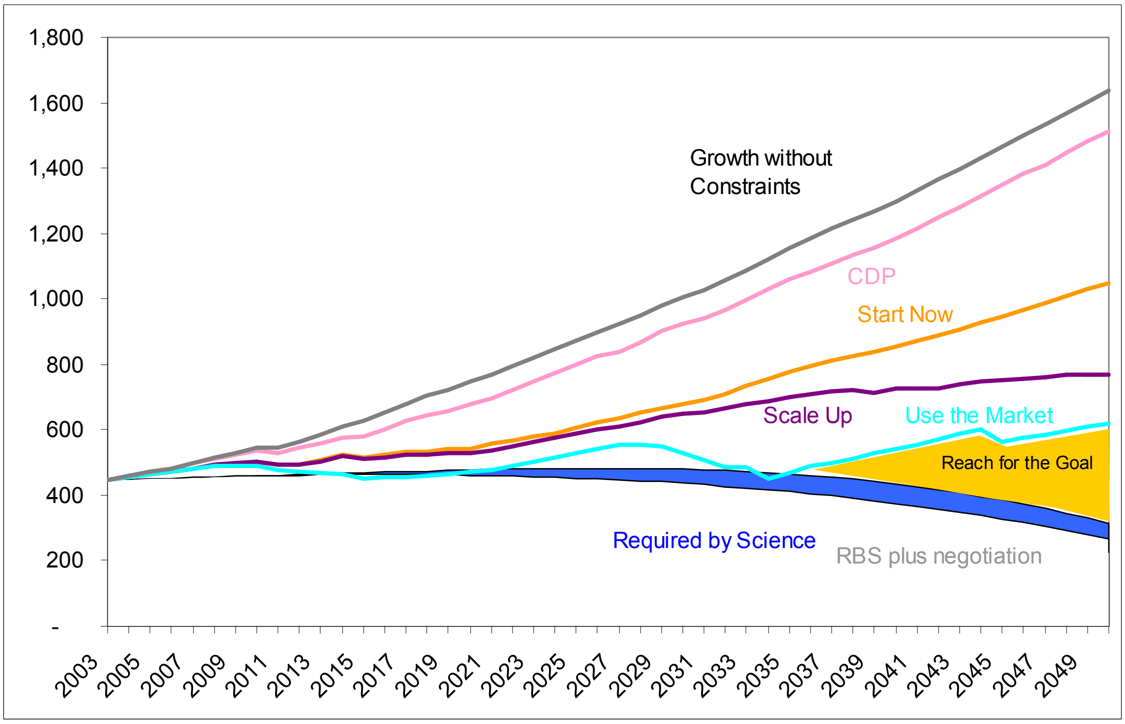
Since the combined economic case includes both taxes and subsidies, it generates tax revenues on the one hand, but requires financing of subsidies within this case. The revenues, discounted over the period at 10%, amount to R 553 billion. **Policy options that might be investigated are using tax revenue from a CO_2 tax to fund subsidies, making the overall basket of interventions closer to revenue-neutral.**

6. Summary results and implications

6.1 GWC, RBS and combined lines

The emissions reductions from the three combined cases are shown in summary form in Figure 74 Figure 74, by showing them against the Growth without Constraints scenario. Including the other side of the envelope, the Required by Science scenario, shows the challenge even against the most ambitious combinations modelled. By combining wedges in different ways, as described above, the combined case give one overview of results. Section 6.2 provides a comprehensive table in which all wedges are reported.

Figure 74: Emissions in GWC, RBS and combined cases – initial, extended and economic instruments



The figure shows the initial and extended wedges following a fairly similar emissions trajectory for much of the period. Indeed, the initial wedges reduce emission slightly more, but towards the latter decades of the period, the extended case reduces emissions further. A key difference is that initial wedges 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.

Economic instruments, driven primarily by a higher CO_2 tax, initially follow the -30% to -40% from 2003 levels in RBS. Up to 2035, this combined case is in the same region the RBS 'cloud'. However, the combined economic instruments increase again from 2035-2050. By the end of the period, they are approaching the level reached by the extended wedges.

By 2050, the gap between GWC emissions and the RBS average is 1 349 Mt CO_2-eq, for that year alone. Combining wedges, the initial ones reduce the gap by 581 Mt or 43%. Extended wedges in 2050 close two-thirds of the gap (64%). While economic instruments emission go below RBS earlier in the period, by 2050 it is 76% of the way to closing the gap – Use the Markets closes the gap three-quarters of the way.

However, at the same time, 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 case do absolute emissions decline by 2050.**

6.2 Summary table of all wedges

The large number of wedges analysed in this Technical Report is summarised in Table 35. Table 35 shows all the wedges, in the energy sector, non-energy (agriculture, waste and forestry) as well as industrial process emissions. It reports the key parameters of mitigation cost (R / t CO_2-eq), the cumulative emission reductions from 2003 – 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 2003-2050 cumulatively), respectively.

Table 35: 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 / t CO2-eq)*	*GHG emission reduction, Mt CO2-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%
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 savannah 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	3	3,990	13	6	0.0%	0.1%

Mitigation action	*Mitigation cost (R / t CO2-eq)*	*GHG emission reduction, Mt CO2-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
learning, extended						
Synfuels methane reduction	8	146	14	30	0.0%	n/a
Waste management	14	432	15	20	n/a	n/a
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 CO2 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%
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%

The wide variety of mitigation actions is reflected in the range of emission reductions and costs reported and summarised for comparison in Table 35. Single wedges range from large *savings* to the economy per ton of CO_2 mitigated, for example for passenger modal shifts at close to -R 1 100, positive cost options, such as almost + R 2 000 per ton of CO_2-eq for hybrids.[18] Emission reductions in aggregate are obviously largest for combined cases, with the escalating CO_2 tax the largest reduction from a single wedge.

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[18] 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.

Energy efficiency is generally a negative cost option, i.e. the savings from reduced energy use outweigh the programme costs. Commercial (-R203 / t CO_2-eq) and residential (-R198 / t CO_2-eq) energy efficiency are more cost effective than industrial (-R34 / t CO_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 avoided emissions of over 400 Mt CO_2-eq over time.

In **electricity generation,** cleaner coal is the smallest of the three wedges. Given that super-critical is the default new coal option and IGCC is built extensively in GWC, relatively modest emission reductions are possible here. Carbon capture and storage provides 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 CO_2.

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 38 c / kWh for renewable electricity shows cumulative emission reductions that are greater than the other renewables cases (at 3 887 Mt CO_2-eq from 2003-2050), 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 its own, learning makes the difference between positive and negative 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 from modes 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, more attractive than freight – it 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 R 269 / t CO_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 2003-2050. While the reductions are smaller than some energy mitigation options, non-energy options provide some negative cost options (manure management, fire control and savannah thickening), but not the cheapest on offer (even ignoring transport). Also, some agricultural mitigation actions are have significant positive costs (enteric fermentation, reduced tillage, afforestation). For waste, note that the costs of flaring only are considered, at R 14 / t CO_2-eq.

The **waste sector** can provide substantial emission reductions at 432 Mt CO_2 -eq for the 48 year period, not including waste minimization. Reduction of fire frequency (rather than complete fire prevention) interacts with savannah thickening in that reduced fire is a major driver of thickening. Together, fire control and savannah thickening sequester carbon equivalent to 455 Mt CO_2, at a negative mitigation cost of R 15 / t CO_2-eq. Mitigation from reduced tillage is limited – firstly, 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 sequester 202 Mt CO_2-eq at R 39 / t CO_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 CO_2 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.

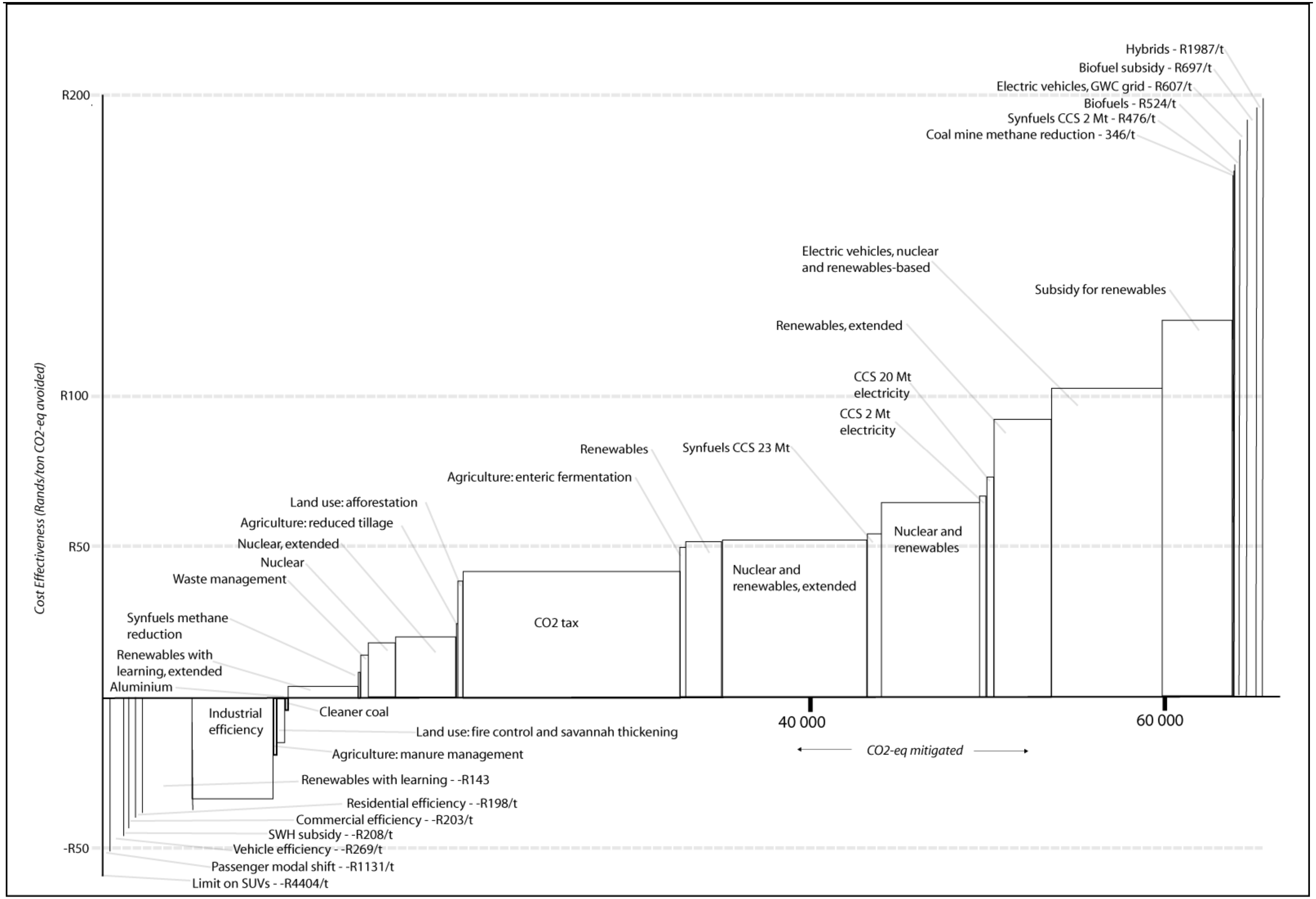
The large number of wedges analysed in this Technical Report is summarised in Table 35.

It shows all the wedges, in the energy sector, non-energy (agriculture, waste and forestry) as well as industrial process emissions. It reports the key parameters of mitigation cost (R / t CO_2-eq), the cumulative emission reductions from 2003 – 2050 and a comparative perspective on total mitigation costs. Total mitigation costs are shown in the last two columns in relation to the size of the economy (average share of GDP) and a percentage change in total energy system costs in GWC. Table 35 also provides ranking of the actions by these two key results parameters, firstly on R / t CO_2-eq, and secondly on GHG emission reduction from 2003 to 2050. In other words, it makes clear which are the most cost-effective options and which are the 'big hits'.

6.3 Mitigation cost curve

The costs and emission reductions of most wedges are summarised in a single figure, the mitigation cost curve. Figure 75 shows the mitigation cost curve in the usual format. The units on the y-axis are R / t CO_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 how much emissions are reduced. Since there are both negative and positive cost options, the x-axis extends above and below the zero line.

Figure 75: Mitigation cost curve for South Africa


Cost Effectiveness (Rands/ton CO2-eq avoided)
R200
R100
R50
-R50
40 000
60 000
CO2-eq mitigated
Hybrids - R1987/t
Biofuel subsidy - R697/t
Electric vehicles, GWC grid - R607/t
Biofuels - R524/t
Synfuels CCS 2 Mt - R476/t
Coal mine methane reduction - 346/t
Electric vehicles, nuclear and renewables-based
Subsidy for renewables
Renewables, extended
CCS 20 Mt electricity
CCS 2 Mt electricity
Renewables
Synfuels CCS 23 Mt
Agriculture: enteric fermentation
Land use: afforestation
Agriculture: reduced tillage
Nuclear, extended
Nuclear
Waste management
Synfuels methane reduction
Renewables with learning, extended
Aluminium
Nuclear and renewables
Nuclear and renewables, extended
CO2 tax
Industrial efficiency
Cleaner coal
Land use: fire control and savannah thickening
Agriculture: manure management
Renewables with learning - -R143
Residential efficiency - -R198/t
Commercial efficiency - -R203/t
SWH subsidy - -R208/t
Vehicle efficiency - -R269/t
Passenger modal shift - -R1131/t
Limit on SUVs - -R4404/t

6.4 Cumulative shares of GDP

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 35 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 section 2.2.5 of the Technical Report.

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 too 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 the Stern threshold of 1% of GDP level were acceptable overall costs to the South African economy, it is of interest to see where this level is crossed. We 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 76

Figure 76 and the sequence of runs in the table below it. The first run (Run00) includes SUV's, the wedge with the highest negative cost in Table 35. Run1 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 shown 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.

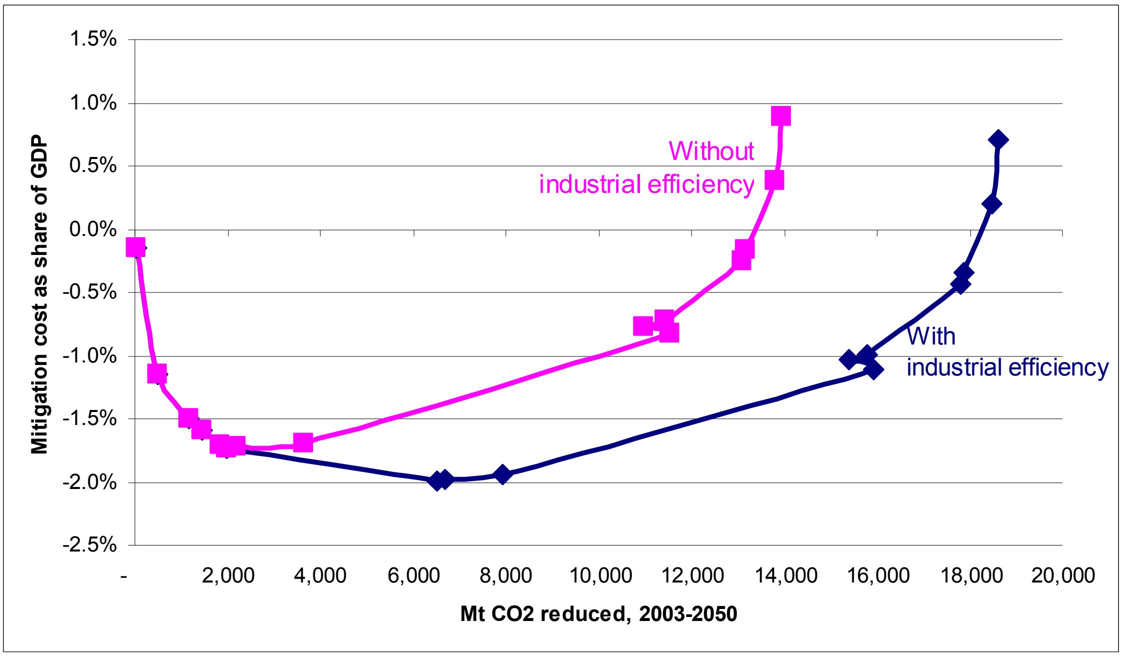
As is seen in the results, combining a set of negative cost options – mostly energy efficiency in various sectors - would make the share of GDP more negative, so that the curve initial slopes downward.

	With industrial efficiency		***Without industrial efficiency***	
Wedge added in this run	***Mt CO2, 2003-2050***	***% GDP***	***Mt CO2, 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 CO2 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%

Figure 76Figure 76 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*, then 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 76 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.



	With industrial efficiency		***Without industrial efficiency***	
Wedge added in this run	***Mt CO2, 2003-2050***	***% GDP***	***Mt CO2, 2003-2050***	***% GDP***
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Electric vehicles in GWC grid	18,493	0.20%	13,800	0.38%
Hybrids	18,629	0.71%	13,936	0.89%

Figure 76: Mitigation costs as share of GDP, for cumulatively combined wedges

6.5 Transition to a low-carbon society

Perhaps the most difficult, but also most fundamental approach to mitigation would be to change our economy away from its energy-intensive path.

This issue was discussed at meeting of eminent economists was held on 3 October 2007 as part of the LTMS process.[19] The potential for South Africa to re-define its competitive advantage from historically low energy prices to climate-friendly technology was debated.

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 2007b, 2007a).

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 exports most of the final product.

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 dti'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 combined 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, but in the long-run, the challenge is to consider the energy-intensity of our economy, structurally. It seems that economies tend 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 re-define what we mean by competitive advantage. This could have several dimensions.

One dimension would be to focus on parts of the economy which are not as sensitive to energy price rises. Specific policies that can help 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 feed up 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

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[19] The meeting was hosted by Business Unity South Africa and chaired by Roger Baxter (Chamber of Mines).

currently spend little of their costs on energy. 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 have to have the support of significant institutions in the major-emitting industrial sectors.

The meeting of economists noted that industrial policy often really changed in paradigm in reaction to a crisis, or due necessity. The sense was that climate change is not yet widely seen as a real crisis by decision-makers in industry.

A transition to a low-carbon economy is also consistent with the best available scientific information internationally. The IPCC 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.

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.

Changing the structure of the economy is a long-term task, but then climate change is a long-term problem. A low-carbon economy will not emerge overnight. That means that energy –intensive industries will continue to exist, and a comprehensive strategy will have to include transition for these sectors and the workers in them. Policies that could assist energy-intensive industry would include promoting higher value-added sectors, as well as ambitious energy efficiency targets (since the potential for energy savings are greater).

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.

7. Implications

7.1 Regulatory vs economic instruments

The various mitigation actions and resultant wedges can be achieved in different ways. Some of the wedges in section 4.2 require the model to achieve a certain target, e.g. 27% of electricity generated from renewables, nuclear or cleaner coal. In thinking about policy options, these wedges could be understood as regulation. In the example above, the modelled effect could be achieved through a Portfolio Standard.[20]

An alternative to setting the quantity of a technology or practice would be to change relative prices (Weitzman 1974). The economic instrument wedges reported in section 4.3 model the effects of

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[20] Renewable Portfolio Standards are popular in the USA (Wiser *et al.* 2002; Rabe 2006); while other approaches, notably feed-in tariffs, are in place in many European countries (Midttun & Koefoed 2003; ESD 2004; Gan *et al.* 2007). The UK has a Renewable Obligation (UK 2001), which is more like a tender and bid process . There is a debate about which are most appropriate in SA (Winkler 2005; Morris 2002).

taxes and subsidies. Rather than directly requiring a fixed quantity, the indirect effect of the CO_2 tax is to favour technologies with lower emissions – but no less effective, as can be seen in the results.

A third approach are performance standards. An example would be to require that all new vehicles have 120 gCO2 / km by a given year. A key question is whether such standards are mandatory (and if so, what consequences of non-compliance would be) or voluntary.

7.2 Economy-Wide Analysis for the Long-Term Mitigation Scenarios

7.2.1 Overview

An attempt has been made to capture some of the economy-wide impacts of the mitigation scenarios described in detail elsewhere. The aim of this attempt is to get a notion of some of the short-term economic trade-offs or costs that should be considered by policy makers. The basic 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.

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 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 that are 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 our 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, we believe that evidence from a wide body of literature describing models that can undertake such analysis offers an improvement to a simple "back of the envelope" calculations and policy makers will gain understanding. The marginal costs of undertaking such analysis has, in the past 10 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.

The macroeconomic analysis is undertaken with a Computable General Equilibrium (CGE)[21] 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.[22] The economic impacts of each of the mitigation scenarios known here as the ***Start Now*** (initial wedges), ***Scale Up*** (extended wedges) and ***Use the Market*** (economic instruments with increased energy efficiency) scenarios, are analysed in a comparative static setting against a benchmark that can be interpreted as growth without constraints or GWC. Results from the energy modelling (MARKAL model) are used as scenario input parameters. For the ***Start Now*** and ***Scale Up*** scenarios three sets of input parameters are extracted from MARKAL so as to investigate:

1) **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;

2) **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);

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

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

3) **investments** (capital outlay) required under each mitigation action relative to GWC investment levels.

What can we expect from modelling such scenarios in our policy analysis framework?

1) **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 is assumed to be relatively labour intensive compared to coal-fired and nuclear plants. Nuclear, on the other hand, is highly skill intensive and has a low labour intensity when compared to other electricity generation processes.
2) **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.
3) **investments** (capital outlay) offers a short term demand stimulus associated with the installation of energy efficient production processes. However, the final outcome depends on how 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 declines, which reduces final demand, while the increase in investments increase final demand. Compositional effects arise due to the fact that structure of household demand is different from that of investment demand in terms of the types of commodities consumed.
4) **CO_2 emission tax:** is modelled here as an implied tax on the prices of coal, crude oil and natural gas of a given emissions tax level. If a CO_2 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, albeit to a limited extent, induces changes in energy demand, e.g. some fuel switching to gas in industry. The extent of the distortionary 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 off set the initial negative impact of the tax to varying degrees.

7.2.2 Simulations and Results

The final scenarios tested with the CGE model can be described broadly in the following way:

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, e.g., electricity supply from coal declines to 46 %, with nuclear and renewables each contributing around 27 % in 2050.[23] There are also changes in transport to more efficient vehicles and shifting to public transport.

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[23] These are the shares defined in the energy modeling, 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).

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. Key driver is a CO_2 tax, starting at current carbon prices and escalating (R250 / t CO_2 to R 750).[24] Note that the CGE modeling does not include the incentives that are included in the energy modeling, 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 CO_2 emissions taxes, ranging from R25 to R1000 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, 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 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. Our approach, although more conservative, is considered more appropriate given the general consensus that mitigation actions will probably lead to rising energy prices. A lower substitutability also reflects the fact that commodities produced using different processes are ultimately not homogenous, and that some adjustment costs will have to be borne by the economy.

7.2.2.1 **"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 the financing thereof is treated, and therefore does not offer significant changes. It can also be expected to change if substation were pushed further and beyond its 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 (high-skilled), on the other hand, are fully employed at flexible wages, reflecting a skill constraints in the South African economy. The main report shows the employment and wage effects for these two groups of workers respectively.

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[24] 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 R 100 and R 250 / t CO_2. In the overall study, it starts in 2008 at R 100 / t CO_2 , rises to R250 initially, then stabilises and only reaches R 750 in the last decade (2040-2050).

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%) 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 off-set by other measures.

An extensive literature in energy research that demonstrates job GAINS from energy efficiency, both due to direct employment in such programmes, but mostly due to the savings on energy expenditure. This is a finding across different energy economies.[25] Given the results above, this needs to be further examined for semi-skilled workers.

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 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.

7.2.2.2 Use the Market

The *Use the Market* scenario takes a very different angle than the *Start Now* and *Scale Up* scenarios as far as energy efficiency is concerned. The focus in this scenario is much more on economic instruments (taxes and incentives), which 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 per cent above the reference case investment levels. The CO_2 emissions taxes that form a core part of the *Use the Market* scenario are implemented as an incremental tax in the MARKAL model, ranging from about R250 per ton of emissions in 2008 and increasing to R750 by 2050.[26]

The CGE model is well suited to evaluate the impact of emissions taxes. As a proxy for an actual CO_2 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 CO_2 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 CO_2 tax causes GDP to decline significantly, even in the shorter time-period considered in the economy-wide modeling, i.e. up to 2015. GDP declines by 2 per cent in 2015 Earlier runs of the model in longer time-frames did not find a feasible solution beyond 2030, which indicates that the suggested CO_2 emission tax is too high and / or the time-frame too long.. Consistent with other

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[25] (Geller *et al.* 1992)(Laitner 2001; Biewald *et al.* 1995; DME 2004)(Jochem 2000). The study by Laitner *et al (2001)* cites much of the early work. See also http://www.aceee.org/pubs/ed922.htm.

[26] See footnote 24 on revised tax levels

applications for South Africa we conclude that that lower tax rates are more realistic. In a range of R25-75, it appears possible to off-set negative economic effects through complementary policies.[27] However, the break-point in economic effects appears to occur between R 100 to R 200, for example in relation to Stern's 1% of GDP benchmark. Table 38 in the Appendix shows that employment changes (assumed food-price recycling) stay positive up to R 100 for semi-skilled and R 200 for unskilled workers. At R100, wage changes are still slight (and ambiguous in sign).

In the range of R25 – 200, it may be possible to off-set 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 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 CO_2 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 CO_2 taxes between R 25 – 200 / ton of CO_2. 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 SA can expect Euro 6-10 / t CO_2 , i.e R 60-100 / ton, and in European emissions trading, prices are higher. Hence assuming R 200 / t in future is not a big leap – although of course a tax level is a different 'price' to a CDM credit.

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

Welfare declines are experienced by all households, with poorer households escaping the worst effect 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 of 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 modeling). Note that our 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.. CO_2 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, note that our 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.

7.2.3 Conclusions of economy-wide modeling

A summary of the economy-wide results is shown in the next set of tables.

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

Table 36: Condensed summary of results of economy-wide modeling

	Structural Shift	***Efficiency***	***Investment***	***Impact on GDP***	***Employment / job impact***	***Poverty / welfare***
	Description of inputs to economic model			Results		
Start Now / combined initial wedges	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
Scale Up /combined extended wedges	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 / CO_2 tax	Uses economic instruments. Key driver is a CO2 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 modeling for SWH, biofuels and renewable electricity not assessed in CGE modeling]	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 who gain initially from food subsidy; impact depends on fiscal options, low income households can be targeted directly

Table 37: Broad characteristics and results of underlying scenarios, as used in economy-wide modeling

Component	***Broad modeling 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.
Carbon taxes	Taxes are ultimately 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. 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 CO2 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 suggests that the subsidisation of a less efficient production process is not an 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 CO2, and despite using the most efficient of the revenue recycling options available, there will be negative economic impact on economic output.

8. Sensitivity analysis

Three types of sensitivity analysis were conducted. The first sensitivity was to discount rate – three different discount rates were calculated offline for mitigation costs, three of which were reported for each wedge in this Technical Report. The results of sensitivity analysis for two other paramters – GDP and energy prices – are reported below.

8.1 Sensitivity to GDP

The most influential driver of emission in the modeling is GDP. Politically, this is assumed to lie between 3 and 6%. Any percentage growth sustained over a long period of time becomes exponential. Projections of 4.5 - 6% GDP growth over long periods of time are probably not realistic – actually growth is never smoothly exponential.

The energy modeling team conducted initial sensitivity analysis with 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 / t CO_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 2003-2050, 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.

The key change implemented after SBT4 in this regard is that the composition of GDP is no longer assumed to remain as it is currently. Based in particular on input received from macro-economists[28]

8.2 Sensitivity to energy prices

Energy prices are key parameters on which to conduct sensitivity analysis. In accordance with an SBT5 decision, the following price changes were modelled:

1. Oil / gas / petroleum product sensitivity
    a. On the oil prices
        i. First, starting from $ 55 / bbl rising in 2003 to $ 100 / bbl in 2030 and extrapolated at the same rate beyond
        ii. Secondly, from $ 55 / bbl rising in 2003 to $ 150 / bbl in 2030 and extrapolated at the same rate beyond
    b. The ratios of increase in energy prices would then be used to make equivalent adjustment to import prices for liquid fuels, as well as local and import prices for natural gas. This will be run together with the oil prices, i.e. one sensitivity on crude oil, all imported petroleum products and natural gas.

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[28] See notes of meeting of (meeting of 12 July 2007)

2. Coal price sensitivity
    a. A separate sensitivity analysis will be done on the coal price, increased at the ratio of the *first* oil price sensitivity
3. Nuclear fuel price sensitivity
    a. A separate sensitivity analysis will be done on the price of imported nuclear fuel, increased at the ratio of the *first* oil price sensitivity

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 below). The four price changes above were modelled .Significant impacts resulted from oil and coal prices changes, but 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 1400Mt, 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 the table below:

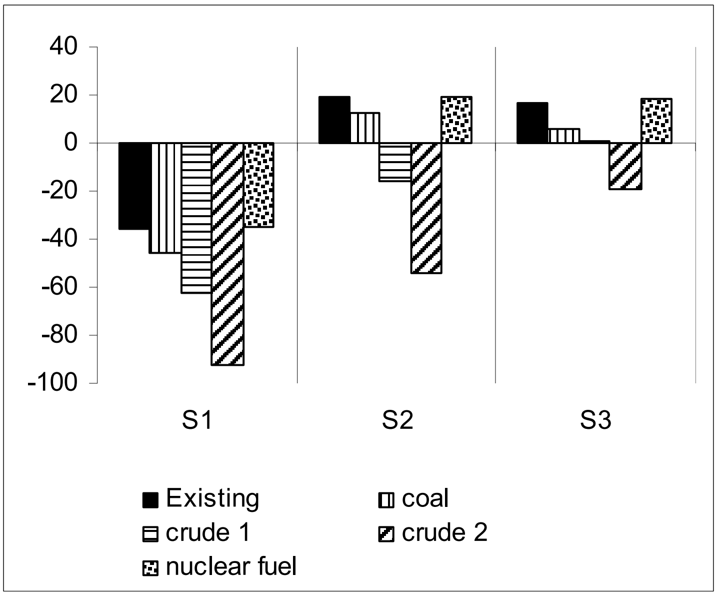
	% increase in total system costs	**Increase as a % of GDP**
Coal price increase	6%	1.2%
Crude price increase 1	15%	3%
Crude price increase 2	31%	6%
Nuclear fuel price increase	0.1%	0.0%

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 as outlined above 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):

	Existing	**coal**	**crude 1**	**crude 2**	**nuclear fuel**
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 77.

Figure 77: Impact of price on cost-effectiveness

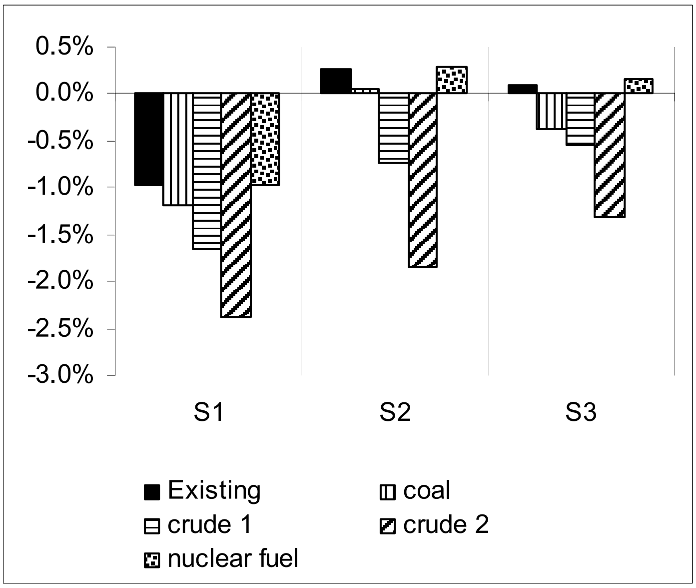


Aside from the slight differences in the nuclear case (due to a slight shift from nuclear power), increased fuel prices reduce the cost of mitigation. The same trend is reflected in the change in percentage of GDP required by the energy system, whereby increased hydrocarbon prices result in a lower additional 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.

	Existing	*coal*	*crude 1*	*crude 2*	*nuclear fuel*
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 share of GDP is shown in Figure 77.

Figure 78: Impact of price on cost-effectiveness

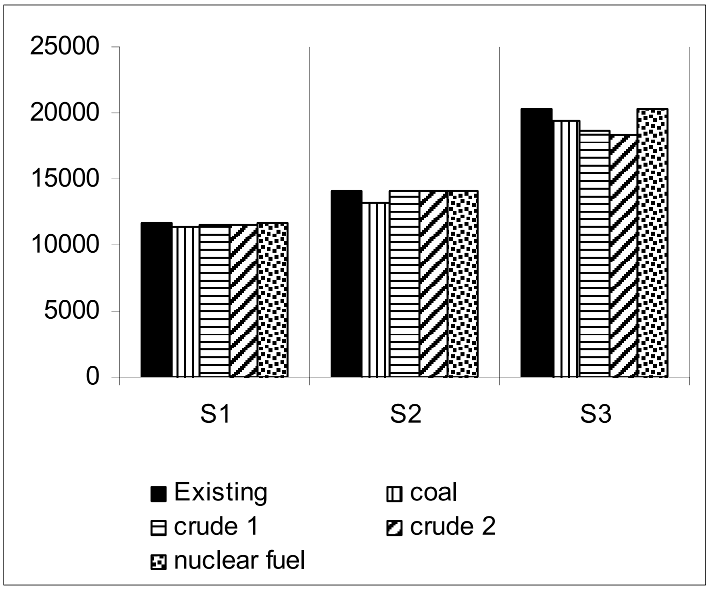


Resulting mitigation is slightly lower in the increased price cases, although these differences are slight, except for the increased coal price case, due to the lower use of synfuels in the new baseline, excluding this as a mitigation option.

	Existing	***coal***	***crude 1***	***crude 2***	***nuclear fuel***
Start Now	11611	11309	11565	11560	11621
Scale Up	14126	13175	14048	14039	14139
Use the Market	20200	19340	18630	18407	20281

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 the table below:

Figure 79: Impact of energy price changes on emission reductions



Scenario	*Coal*	*Crude 1*	*Crude 2*	*Nuclear fuel*
Start Now	Significantly less emissions from synfuels use (1400Mt), another 400Mt saved due to shift away from coal for electricity generation	Insignificant – slight sift away from natural gas and liquid fuels for electricity generation	Insignificant – slight sift 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 356Mt	Insignificant – slight sift away from natural gas and liquid fuels for electricity generation	Insignificant – slight sift away from natural gas and liquid fuels for electricity generation	Insignficant
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 (2730 Mt), from increased use of synfuels and coal in industry (no switch to gas)	Even more CO_2 emissions (3840 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 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 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.

8.2.1 Sensitivity analysis for specific wedges

As requested at SBT 6, additional sensitivities were run for specific wedges: the Cleaner Coal, Industrial Efficiency, Subsidy for Renewables, and Extended Nuclear and Renewables wedges were run with a higher coal price, as specified above, and the Improved Vehicle Efficiency, Electric Vehicles in GWC Grid, Hybrids and Passenger Modal Shift wedges were run with the higher of the two oil prices as specified above. No variation on the uranium price was conducted here, since the above sensitivities showed little response – since most of the investment in nuclear power is in capital expenditure, not fuel costs. The results are contained in Table 38 and Table 39. The results with existing assumptions for energy prices are included in brackets in each cell for comparison.

Table 38: Sensitivity of selected wedges to high coal prices

Numbers in brackets are with existing energy price assumptions, see text	***Mitigation cost (R / t CO2-eq)***	***GHG emission reduction, Mt CO2-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)	4675 (4572)	-1.70% (-1.24%)	-0.39% (-0.26%)
Subsidy for renewables	105 (125)	4590 (3887)	3.23% (3.65%)	0.73% (0.77%)
Nuclear, extended	7 (20)	3186 (3467)	0.17% (0.68%)	0.04% (0.15%)
Renewables, extended	72 (92)	3698 (3285)	2.10% (2.64%)	0.48% (0.56%)

Table 39: Sensitivity of selected wedges to high oil prices

Numbers in brackets are with existing energy price assumptions, see text	***Mitigation cost (R / t CO2-eq)***	***GHG emission reduction, Mt CO2-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	1244 (1987)	371 (381)	2.56% (6.27%)	0.74% (0.52%)
Passenger modal shift	-1907 (-1131)	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.