Non-energy Emissions
Agriculture, Forestry and Waste

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

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

9.A Long Term Mitigation Scenarios for South Africa

9.B Technical Summary

9.C Technical Report

9.C.1 Technical Appendix

9.D Process Report

The study was supported by the following inputs:

LTMS Input Report 1: Energy emissions

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

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

LTMS Input Report 4: Economy-wide modeling

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

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1. 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 Scoping of 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 **Error! Reference source not found.**.

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.

1.2 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 1).

Table 1: 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 1 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. 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 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.[1]

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.

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

2.2 International experiences on mitigation for agriculture

This section summarises the Pew Centre publication, Global Climate Change, 'Agriculture's role in Greenhouse gas mitigation', (Paustian, K. et al. 2006). The US experience described in this article can be used as a benchmark for the role that agriculture can play in GHG mitigation in South Africa.

2.2.1 Introduction

Agriculture currently contributes substantially to GHG emissions but potentially it has the ability to act as a sink for CO_2 as well as to reduce its GHG emissions at a relatively low cost. Overall, land use change (predominantly in the tropics) and agricultural activities globally account for about one-third of the warming effect from increased GHG concentrations (Cole et al. 1997). However, ecosystem processes also act to dampen these GHG increases, primarily through the uptake and storage of CO_2 in plants and soil on land and in oceans. These uptake and storage processes - referred to hereafter as carbon 'sinks' - play a significant role in the global CO_2 cycle, so that only about one-half of the CO_2 emitted from fossil fuels accumulates in the atmosphere. The other half is absorbed by the oceans and terrestrial ecosystems (IPCC 2001). In this report the term mitigation is used to encompass both GHG emission reductions and GHG removals from the atmosphere by sinks.

Over the past decade, US agricultural soils overall have acted as a small net sink of approximately 12 million metric tons (MMT) of carbon per year, mainly due to improved soil management practices and the establishment of conservation reserve lands (USEPA 2006). These practices are helping to sequester about 23 MMT of carbon per year in mineral soils, which make up greater than 99% of annual cropland area.

Cultivated organic soils and agricultural liming contribute substantial GHG emissions - taking into account both soil emissions and sinks the result is a net sink of 12 MMT of carbon per year.

Since 1850 an estimated 160 billion metric tons of carbon from biomass and soils have been emitted worldwide as a consequence of land use and land-use changes (Houghton 2003) compared to their condition under native vegetation. Since the 1940s, as a result of improved productivity and cropping practices, controlled erosion and reduced tillage, organic carbon stocks of many agricultural soils have started to increase resulting in these soils becoming a net sink. Reforestation has also contributed to the present carbon sink.

Current and future trends in the structure of American agriculture will affect both future emissions and opportunities for GHG mitigation. Increased crop yields, along with continued adoption of conservation tillage and maintenance of conservation set-aside programs are likely to support further increases in soil carbon stocks. Higher crop yields also increase the potential for shifting some land from food production to energy crop production. The reduced use of nitrogen fertilizer since 1990 has resulted in emissions from this source remaining constant. Since 1990, a decline in cattle and sheep populations has been counterbalanced by a rise in swine and poultry populations, resulting in roughly stable agricultural methane emissions (USEPA 2006).

The current technical potential to mitigate GHGs through improved agricultural practices over the next 10 to 30 years is substantial. However, the mitigation levels that can be achieved economically are likely to be substantially lower than these technical potentials. This is because a variety of economic and social factors will influence the adoption of alternative practices and production systems, although studies to date suggest that a significant portion of agricultural mitigation practices can be characterized as low-cost options.

What needs to be considered is that changes in land use and management to achieve GHG mitigation can contribute to overall environmental improvements. Hence, a broader consideration of the costs and benefits of improved agricultural practices, beyond the realm of climate change concerns, is merited.

2.2.2 Mitigation opportunities: Increased sinks and reduced emissions

2.2.2.1 Opportunities to increase soil carbon

Historically, agricultural practices have caused large carbon losses from US cropland soils. If half or more of the original carbon stock of croplands could be regained, tens to hundreds of millions of metric tons of carbon could be stored (i.e., added to and sequestered) in soils annually over the next several decades.

Management practices that favour carbon additions to soil:

- increase of plant residues;
- slowing the rate of soil organic matter decay;
- land-use changes such as conversion of annual cropland to grassland or forest and restoration of degraded lands.

Employing these practices could result in soil carbon increasing for 20 to 30 years, after which it would tend to stabilize (CAST 2004).

2.2.2.1.1 Cropland management

Carbon inputs to soil can also be increased by:

- increasing the productivity of crops which is largely in line with farmers' management goals of achieving high productivity;
- using crop rotations with high residue yields;
- reducing or eliminating the fallow period between successive crops in annual crop rotations;
- making efficient use of fertilizer and manure.

On annual croplands, soil carbon losses can be reduced by:

- decreasing the frequency and intensity of soil tillage, in particular through conversion to no-till practices.

Use of high-residue crops and grasses. Annual crops that produce large amounts of residues, such as corn and sorghum, as well as perennial grasses typically result in higher soil carbon. Cereal-hay rotations would therefore serve to increase soil carbon content.

Reduction or elimination of fallow periods between crops. New cropping systems which do not allow for a fallow season, have proved successful in both improving soil moisture and increasing soil carbon (Peterson et al. 1998). If cover crops, such as legumes or annual grasses, are planted during the winter season they not only take up excess soil nutrients (e.g., nitrogen) to reduce leaching or other losses to the environment, fixing atmospheric nitrogen (e.g., legumes), and controlling weeds; but they also serve to augment the input of plant residues, thereby increasing soil carbon content.

Efficient use of manures, nitrogen fertilizers, and irrigation. If more than the optimum input of fertilizer, manure and irrigation are used for high rates of crop production (with attendant carbon input increases), the increases in other GHG emissions, particularly nitrous oxide, can offset part or all of the gains in soil carbon. Tailoring fertilizer and manure applications to satisfy crop nitrogen demands, so that less nitrogen is left behind in the soil, can reduce nitrous oxide emissions while building soil carbon stocks. Efficient use of irrigation water will similarly reduce nitrogen losses including nitrous oxide emissions, and minimize CO_2 emissions from energy used for pumping while maintaining high yields and crop-residue production.

Use of low- or no-till practices. Reducing soil carbon losses on croplands is primarily accomplished through reducing the frequency and intensity of soil tillage. Traditional tillage methods, which fully invert the soil, cause the greatest degree of disturbance and consequently tend to cause the most degradation of soil structure and loss of soil carbon stocks. In many areas, 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.

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. Ogle et al. (2005) analyzed data from 126 studies worldwide and estimated that soil carbon stocks in surface soil layers (to 30 centimeter [cm] depth) increased by an average of 10 to 20% over a 20-year time period under no-till practices compared with intensive tillage practices. The relative increases in carbon stocks were higher under humid than dry climates and higher under tropical than temperate temperature regimes. Finally, CO_2 emissions from machinery use are decreased by 40% for reduced tillage and 70% for no-till, relative to conventional tillage (West & Marland 2002), contributing to further reductions in GHGs from reducing tillage intensity.

2.2.2.1.2 Grazingland and hayland management

Permanent grasslands used as pastures, rangelands, and hayfields can maintain large soil carbon stocks due to several characteristics. Perennial grasses allocate a high proportion of photosynthetically fixed carbon below ground, maintain plant cover year-round, and promote the formation of stable soil aggregates. Grassland systems that have been degraded in the past or maintained under suboptimal management conditions are most conducive to sequestering additional carbon with improved land management.Intensive management strategies are usually restricted to more humid regions with high productivity potential or to regions where irrigation is used.

Conant et al. (2001) summarized more than 115 studies of grassland management effects on soil carbon and estimated rates of soil carbon increase ranging from 0.1 to 3 t/ha/a. The highest rates occurred with introduction of deep-rooted African grasses in South American savannas (Fisher et al. 1994).

2.2.2.1.3 Land-use changes to increase soil carbon

Conversion of annual cropland to grasslands or forest and restoration of severely degraded lands offer significant opportunities to increase soil carbon. Converting cultivated cropland to grassland typically increases soil carbon at rates of 0.3 to 1.0 t/ha/a for a period of a few decades (Lal et al. 1998; Conant et al. 2001).

Highly degraded sites, such as severely eroded areas, reclaimed surface mines and saline soils represent situations with high potential carbon sequestration rates but also higher costs and technical difficulties associated with the reclamation.

Cultivated organic soils represent another land restoration opportunity. These lands are a significant source of agricultural CO_2 emissions, with high rates of up to 10 to 20 t/ha/a of carbon (Ogle et al. 2003). Hence, wetland restoration may be a mitigation option. However, restored wetlands may emit methane, which would need to be considered in assessing the overall mitigation potential of this type of restoration.

*2.2.2.1.4 Tot**al agricultural soil carbon sequestration potentia**l*

Carbon sequestration rates vary by climate, topography, soil type, past management history and current practices. Various global and national estimates for potential soil carbon sequestration have been made. These estimates are usually based on overall carbon gain for a suite of practices and the available area on which these practices could be applied, resulting in estimates of biological or technical potential.

However there are numerous uncertainties surrounding such estimates of carbon sequestration potential. On the one hand, development of new technologies specifically targeted at increasing soil carbon (through plant breeding or new soil amendments) could increase potentials. On the other hand, rising temperatures due to global warming will likely stimulate soil organic matter decomposition, which may reduce or eliminate the potential to further increase soil carbon stocks.Finally, the amount of carbon sequestration which is actually achieved will depend on economic, social, and policy factors.

2.2.2.1.5 Reducing agricultural nitrous oxide and methane emissions

Nitrous oxide (N_2O) and methane (CH_4) emissions result from both crop and livestock operations and account for approximately 80% of U.S. agricultural greenhouse gas emissions on a GWP basis. Despite challenges, there is considerable scope for reducing these emissions.

Nitrous oxide constitutes the largest agricultural source of GHG emissions in terms of warming potential (48%), and almost 70% of total US nitrous oxide emissions are from soils. The best option for reducing these emissions is to use fertilizers more efficiently; adoption of best fertilization practices could reduce agricultural N_2O emissions by 30 to 40% (CAST 2004). Livestock are the main source of agricultural CH_4 emissions. Increasing the efficiency of production (meat, milk) per animal can decrease these emissions and also reduce costs. Manure management accounts for 25% of U.S. agricultural CH_4 emissions; anaerobic (i.e., oxygen-free) digesters that capture and use the methane as an energy source— thereby displacing fossil fuels—offer a nearly ideal solution for these emissions.

2.2.2.1.6 Reducing nitrous oxide and methane emissions from soils

A characteristic of modern agriculture is the huge increase in nitrogen supplied—not only as mineral fertilizer but also through nitrogen-fixing crops (e.g., alfalfa, clover, and soybeans) and animal manure—to boost crop productivity (Mosier et al. 2001). Methane emissions from agricultural soils are mainly associated with flooded soils such as rice-growing areas and wetlands. Most soils are not a major source of CH_4 and, in fact, most non-flooded soils remove some CH_4 from the atmosphere.

Nitrous oxide: Unlike the case for CO_2 and CH_4, there are no significant biological sinks for atmospheric N_2O. Since agricultural N_2O emissions correlate with the amount of nitrogen available in soils, mitigation rests largely on increasing the efficiency of nitrogen use without compromising crop yields.

Greater than 50% of the major cropland area in the United States is rated as having high nitrogen balances, resulting in soils highly susceptible to losses of N_2O to the atmosphere and nitrate (NO_3 –) to water bodies (USDA 2003)

Both the application rate and timing are factors in the efficiency of nitrogen use. The application of fertilizer after the start of the growing season provides better synchrony with plant demands. Slow-release fertilizers, such as sulfur-coated urea, which delay the release of fertilizer applied at planting time until plant nitrogen uptake capacity is higher, can also be used. Injecting fertilizer and manure into the soil, near the zone of active root uptake, both reduces nitrogen losses and increases plant nitrogen use, resulting in less residual nitrogen that can be lost as N_2O.

2.2.2.1.7 Reducing livestock-related methane and nitrous oxide emissions

Livestock-related emissions from digestive processes and animal wastes account for 26% of total agricultural emissions. Although enteric (digestive tract) emissions are more significant (70% of agricultural CH_4 emissions), emissions from livestock wastes have a greater potential for mitigation. Improving manure-handling facilities, for example by covering animal-waste lagoons and capturing and burning the CH_4, can reduce emissions while providing renewable energy and income. Capture and combustion of CH_4 from animal wastes also reduces other environmental problems, including odours and nitrate pollution. Overall the best option for reducing digestive process emissions is to increase the efficiency of livestock production.

Manure storage and management. Manure management in the United States currently accounts for 25% of agricultural CH_4 and 6% of agricultural N_2O emissions. In addition to GHG production, problems associated with odour and nutrient pollution from animal wastes are widespread. Hence, improvements in manure handling that address both GHG reductions and odour and nutrient problems are of great interest.

Manure produced by livestock can emit N_2O and/or CH_4 during storage and following application to soil. In general, storage under anaerobic conditions (lacking oxygen, such as in waste lagoons) will produce CH_4 while N_2O emissions will be suppressed. Conversely, piled storage and composting of manure will promote largely aerobic decomposition, suppressing CH_4 emissions but promoting N_2O emissions. Anaerobic digesters in conjunction with lagoon storage systems offer a nearly ideal option – N_2O emissions are suppressed and CH_4 can be used as an energy source, thereby displacing fossil fuels.

Opportunities for mitigating N_2O emissions from stockpiled or composted manure are relatively limited. Perhaps the most effective measure for reducing manure-related N_2O emissions from stockpiled or composted manure is to apply the manure at rates based on crop needs, thus maximizing plant uptake of manure-derived nitrogen.

Enteric fermentation. Methane is produced in the digestive tract of animals, particularly in ruminants such as cows, sheep, goats, and camels. This source of CH_4 emissions is termed enteric fermentation. In the United States these emissions amount to about 70% of agricultural CH_4 emissions and 20% of total agricultural GHG emissions on a carbon-equivalent basis.

Because CH_4 emissions from enteric fermentation are influenced by the feed quality and digestive efficiency of the animals, improving these will reduce CH_4 emissions. In simple terms, the more rapidly food is processed and passed through the rumen (first stomach of ruminants), the less time there is for CH_4 production. Where feed quality and digestibility are already at a relatively high level, further improvements from conventional changes in feed rations are likely to be modest. However, where diets are not optimal, improvements in the diet can reduce emissions. One area where substantial improvements are possible is in improving forage quality for grazing animals on smaller livestock operations through better pasture management (DeRamus et al. 2003). Various feed additives such as edible vegetable oils and certain antibiotics can also be used to inhibit the rumen bacteria that produce CH_4 (Teather and Forster 1998).

For a given animal type and food quality, CH_4 production will be roughly proportional to food intake. Thus, increasing the amount of product (meat, milk) per unit of food consumed will effectively reduce CH_4 emissions per unit of product. Ways to increase the production efficiency of individual animals include improved animal genetics (breeding) and animal health.

2.3 Methodology for modelling emissions from livestock enteric emissions

2.3.1 Historical data, assumptions and calculations for enteric fermentation

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. 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 (DoA 2006). However, this data does not include the free-range informal cattle. For the total cattle figures the values from the UN Food and Agriculture Organisation were used (FAO 2006). The following livestock figures were used in the model.

Table 2: Historical data for livestock (1990 to 2005)

Source: Own compilation, based on Scholes et al (2000), FAO (2006)

Year	***Cattle total***	***Dairy***	***Goat***	***Sheep***	***Pigs***
Units	***Million***	***1000***	***1000***	***1000***	***1000***
1990	13.3	1100	2774	29979	1665
1991	13.5	1260	2453	28631	1654
1992	13.5	1090	2285	27448	1653
1993	13.1	1150	2159	25670	1570
1994	12.5	1050	2337	25851	1585
1995	12.6	1130	2369	25481	1707
1996	13	1140	2406	25566	1699
1997	13.4	1100	2394	25010	1736
1998	13.7	1070	2360	25079	1780
1999	13.8	1080	2325	24463	1647
2000	13.6	1370	2355	23586	1678
2001	13.5	1360	2427	22998	1710
2002	13.6	1210	2216	22614	1663
2003	13.5	1070	2160	22693	1663
2004	13.5	1020	2164	22289	1651
2005	13.8	1130	2138	22236	1656

The fluctuations between years are mainly dependant on rainfall and availability of grazing. As no data is available for free-range cattle it was assumed that 15% of the total cattle excluding dairy is in feedlot and the rest is free-range.

Data for poultry is only available for 1988 (51 787 000) and 2002 (185073 000) for commercial farmers (DoA 2006). However other data sources give much higher values. For example USDA FAS Poultry and Products Annual 2006 report for South Africa provides the value of 624 million birds for 2005 (http://www.thepoultrysite.com/articles/671/south-africa-poultry-and-products-annual-2006). The SA Poultry Association reported that in average for 2006 12.5 million birds were slaughtered per week, which is 650 million/a (http://www.sapoultry.co.za/download /broiler_stats.pdf). There were 15.8 million of layer flock (for egg production) in 1999 (www.nda.agric.za/docs/MarketExtension/9BroilersEggs.pdf). It is increased to 20.5 million in 2006 (www.sapoultry.co.za/download/egg_stats.pdf) In addition there were more than 5 million breeder flock in 2006. It was assumed that the chicken life cycle is 60 days and the number of chicken in the model was corrected by applying the factor of 60days/365 days per year as suggested by IPCC guidelines (IPCC 2006). However the local data suggests that slaughter age for broiler chickens reduced from 45 to 38 days from 1992 to 2002 (Kleyn 2004). To improve the model accuracy the poultry farming need to be split into 3 groups: broiler, layer and breeder and different life cycle and manure management methods should be applied to each.

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 quality of food is very critical and it is expressed as DE, digestibility of the feed in% (e.g. 60%). The assumptions for average mass and DE for different types of livestock are summarised below.

Table 3: Mass and digestive energy for different types of livestock
Source: Scholes et al (2000)

Type	*Mass (kg)*	*DE (%)*
Free-range	400	50
Dairy (milk)	550	65
Feedlot	250	70
Sheep	30	56
Pigs	70	75
Goats	40	55

The pregnant, lactating and draft (oxen) animals have different energy requirements and for each type of livestock an assumption was made that 30% of herd belongs to these groups. For dairy cattle it was assumed that 87% of herd is pregnant or lactating and none of the feedlot. 3% of draft was assumed for free-range cattle. In order to calculate gross energy intake by livestock (GE, expressed in MJ/d) the following coefficients were used.

Table 4: Energy coefficients for different types of livestock
Source: Scholes et al (2000)

Energy coefficients (abbreviations used in equation)	*Free-range*	*Dairy (milk)*	*Feedlot*	*Sheep*	*Pigs*	*Goats*
Feeding energy % (Fenergy)	37	10	0	37	0	37
Weight gain (kg/d) (Wgain)	0.3	0.4	1.2	0.08	0.5	0.08
Milk/day (kg)	2	15	0	0.5	6	0.7
Milk fat % (MilkF)	3	3.5	4	6	3	6
Hours draft work/day(Wh/d)	4	0	0	0	0	0

Resulting GE differ from slightly from values listed in IPCC guidelines, but for this version it was decided to accept model results as more representative for South African conditions.

The gross energy intake (GE expressed in MJ/d) was used to calculate emissions of methane. The emission coefficients used are presented in the table below.

Table 5: Emission coefficients for different types of livestock
Source: Scholes et al (2000)

Type	*CH4 emission coefficient*
Free-range	0.06
Dairy (milk)	0.06
Feedlot	0.04
Sheep	0.07
Pigs	0.04
Goats	0.07

These emission coefficients represent methane conversion factors (percent of gross energy in feed converted to methane) and were used to calculate the emission factor in kg/head/a.

$$EF_{CH4}(i)= GE_i*CH_{4prod}*365/55.65$$

Where:
365 – conversion from days to year
55.65 (MJ/kg CH_4) is the energy content of CH_4

Finally the total emissions were summarised for all livestock types ‘i’ and converted into Gg of CH_4 as follows

$$\sum CH4\ (Gg/a) = \sum EFi_{CH4}*Num_i\ /10^6$$

Where:
Num_i is the number of livestock of the type ‘i’
It is divided by 10^6 to convert units into Gg/a.

Assumptions for baseline and mitigation option

The reduction of enteric emissions of CH_4 could be achieved if the herd composition is optimized, the feed improved and cattle is moved from free-range grazing to feedlots.

As a mitigation option, the total number cattle was reduced starting in 2006 from 13.8 Mil heads/a to 9.7 Mil by 5% per year till it reached reduction of 30% by 2011. It was 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. According to the Department of Agriculture (DoA) (J Classen, pers. communication) with the promotion of emerging farmers this change will be almost impossible 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 has eventually been reduced by 30% to achieve significant mitigation level.

A new assumption was added that the number of pigs and chicken will raise according to GDP growth till 2010 and then stabilize (poultry reaches above 250 000 heads/a by 2010).

It is assumed that ship and goat herd sizes are stabilized at 2005 levels. An additional assumption could be added that dairy cattle will grow at a rate of 0.6%/a (J Classen, pers. communication), but it should not exceed 1.5 million.

It is assumed that the feeding, even in free-range will improve and this will reduce the energy required for feeding from 37% to 30% and improve weight gain form 0.3 to 0.5kg.

Similarly, the feeding energy for sheep was reduced to 30% (from 37% - see table 3). It was also assumed that for mitigation option weight gain (kg/d) is increased to 0.1 from 0.08 for sheep.

The most important improvement for mitigation is better digestability. It was assumed that DE will from 50% for free-range cattle to 55% and for sheep to 60%.

The historical data for up to 2005 was replaced in the model and all the calculations extended till 2050. Although a large number of input values and assumptions have been changed, the total mitigation achieved is very similar to mitigation calculated by original model (see Figure in the section on results).

Calculation of costs for baseline and mitigation option and cost efficiency

The cost of production was based on three groups of expenditure: cost of food, veterinary services and fixed costs. The assumptions on the costs and productivity coefficients are summarised below. The new updated productivity rates were provided by the DoA (J Classen, pers. communication). It was assumed that new values are applicable for the period after 2005 in order to keep baseline consistent. It was further assumed that ‘Feed’ cost is proportional to increase in production for post 2005. The rest of the costs were calculated from values in the existing model by applying CPIX index correction.

Production cost in R/head was calculated as follows:

$$Production\ cost_i = (Feed_i/AU+Vet_i/AU+Fixed_i/AU)*Prod_i/100$$

Where:
AU – animal unit

The calculated cost is divided by 100 to converts from cents to Rands.

Table 6: Costs of production and productivity for different types of livestock (post 2005)
Source: Own compilation, based on Scholes et al (2000); Classen (2006)

Type	Production (kg/head/y)	Cost	Production costs(R per head)		
			Feed/AU	Vet/AU	Fixed/AU
Free-range	55	457.6	97	118.1	36.6
Dairy (milk)	2500	81.9	1603	277.8	166.3
Feedlot	150	624.2	720	133.1	83.2
Sheep	45	1020.1	31	95.1	332.7
Pigs	85	364.9	217	16.6	76.5
Poultry	27	398.0	90	0.8	16.6

National cost of production (expressed in R Mil)is calculated as follows:

$$\text{Prod Cost} = \sum \text{Num}_i * \text{Prod}_i * \text{Cost}_i / 10^6$$

Where:
Prod(i) is production rate for group 'i' expressed in kg/head/a
It was divided by 10^6(to convert to R mil)

The national income was calculated in the same way.

The updated income rates (assumed that applicable after 2005 to keep baseline consistent) were provided by the DoA (J Claase, pers. communication) for some of the categories and for other increase using CPIX index was assumed. The values of products used by updated model presented in the table below.

Table 7: Costs of income (value) for different types of livestock
Source: Own compilation, based on Scholes et al (2000); Claasen (2006)

Type	Value (till 2005) (c/kg)	Value (post 2005) (c/kg)
Free-range	800	1331
Dairy (milk)	129	199.7
Feedlot	900	1497
Sheep	935	2012
Pigs	746	1020
Poultry	384	639

2.4 Methodology for modelling emissions from livestock manure management

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

This section describes how to estimate CH_4 produced during the storage and treatment of manure. The emissions associated with the burning of dung for fuel are excluded The decomposition of manure under anaerobic conditions (i.e., in the absence of oxygen), during storage and treatment, 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 calculation starts with determining VS, the volatile solid excretion per day on a dry-organic matter basis (expressed in kg VS/day). It is calculated as follows:

$$VS= GE/18.45*(1-DE/100)*(1-ASH)$$

Where:
GE = gross energy intake (MJ day-1)
DE = digestibility of the feed (percent)
ASH = the ash content of manure calculated as a fraction of the dry matter feed intake (e.g., 0.08 for cattle).
18.45 = conversion factor for dietary GE per kg of dry matter (MJ kg-1). This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock.

Then Bo, the maximum methane-producing capacity of the manure is determined. The Bo coefficient, F_{Bo} varies by species and diet and expressed in (m^3/kg VS). These coefficient for different types of livestock are provided in the table below.

Table 8: Maximum methane production coefficients (B_o) for manure production by different types of livestock

Type	F_{Bo}
Freerange	0.1
Dairy	0.13
Feedlot	0.12
Sheep	0.2
Goats	0.2
Swine	0.29
Poultry	0.32

Then the CH_4 emissions expressed in (Gg/a) for every type of livestock (‘i’) are calculated by summarizing the emission from each type of manure management system (‘s’)

$$CH4(i) =VS_i*365*Bo_i*0.67*\sum(MS_s*MCF_s)*Num(i)$$

Where
VS_i - volatile solid excretion per day for livestock of type ‘i’
365 – conversion from days to year
Bo - the maximum methane-producing capacity of the manure, varies by species and diet (m^3/kg VS).
0.67 = conversion factor of CH_4 in m^3 to CH_4 in kilograms
MCF_s = methane conversion factors for each manure management system’s’
MS_s = fraction of livestock category, manure handled using manure management system ‘s’(dimensionless)
Num(i) is a number of livestock of type ‘i’

The fractions of manure handled by different manure management systems are presented in the table below.

Table 9: MS coefficients for baseline (% manure handled by different types of management system)

MS	*Freerange*	*Dairy*	*Feedlot*	*Sheep*	*Goats*	*Pigs*	*Poultry*
% lagoon	0	50	20	0	0	50	20
% digester	0	0	0	0	0	0	0
%spread	100	50	80	100	100	50	80

2.4.2 Assumptions and calculations for mitigation for manure management

The mitigation scenario assumes the same growth in the beef, pork and poultry feedlots as in the business-as-usual scenario, but that 40% of the beef, pork and poultry feedlot wastes are anaerobically digested or consumed in a biomass converter. One tenth is treated in open lagoons, and the remainder is dry spread. The differences between baseline and mitigation option are highlighted in red the table below.

Table 10: MS coefficients for mitigation option (% manure handled by different types of management system)

MS	*Freerange*	*Dairy*	*Feedlot*	*Sheep*	*Goats*	*Pigs*	*Poultry*
% lagoon	0	10	10	0	0	10	10
% digester	0	40	40	0	0	50	40
%spread	100	50	50	100	100	40	50

The cost of disposal are calculated by summarizing the costs for each type of manure management system (‘s’)

$$Cost = \sum Num(i)*VS_i*365*\sum(MS_s*Cost_s)$$

Where
Num(i) is a number of livestock of type ‘i’
VS_i - volatile solid excretion per day for livestock of type ‘i’
365 – conversion from days to year
MS_s = fraction of livestock category, manure handled using manure management system ‘s’(dimensionless)
$Cost_s$ = cost of disposal for manure management system ‘s’(R)

2.5 Methodology for modelling emissions from reduced tillage

2.5.1 Historical data, assumptions and calculations for tillage

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

2.5.1.1 Area under cultivation

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 (www.sagis.org.za/Flatpages/Oesskattingdekbrief.htm). The Abstract of Agricultural statistics includes both commercial and developing agriculture, while the Crops Estimates Committee provides data for commercial agriculture and for developing agriculture separately. For the last two years only data for commercial agriculture was provided. An assumption has been made that the areas under developing agriculture amount to 15% of those under commercial agriculture. The area under maize was significantly reduced in 2005/2006 season because of the drop in the price of maize. However according to Crops Estimates Committee, a 73% increase is expected for 2006/7 year. Thereafter the original assumption of 4000 000 ha under maize, was used. The same data sources were used for grain. From 2008 the original assumption of 1300 000 ha under wheat was used.For the year 2007, an average between the areas for 2006 and 2008 was assumed. Dryland grain production is the only form of grain production being considered. 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 presented in the figure below.

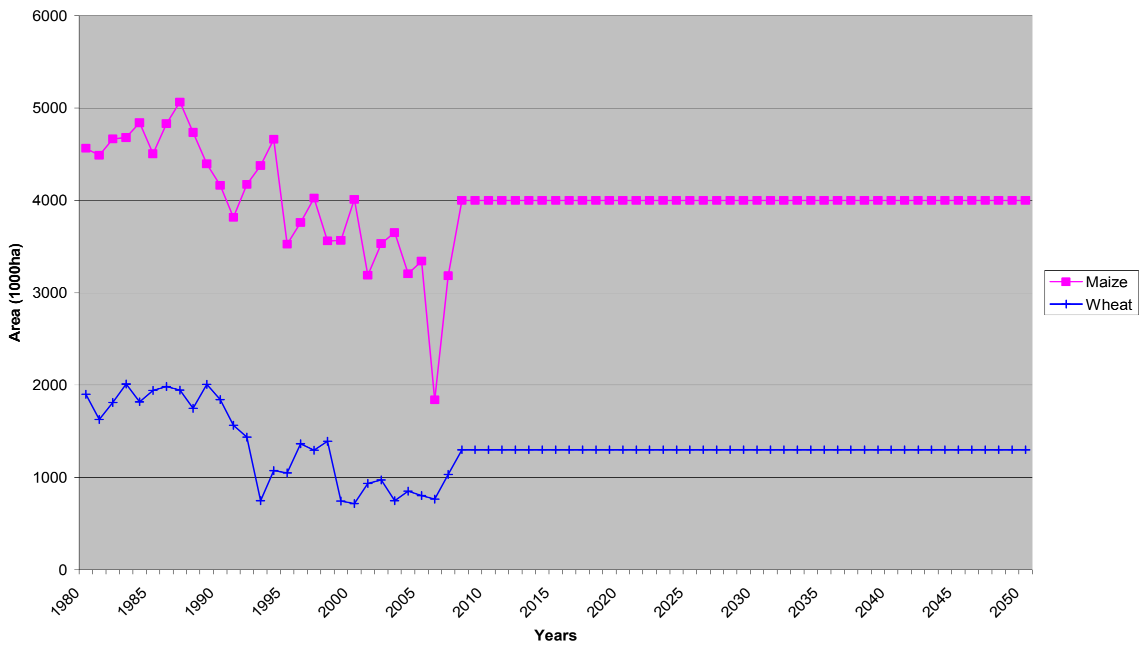


Figure 1: Area for production of maize and wheat (1000ha)

2.5.1.2 Carbon storage

According to Van der Merwe, M. R. & Scholes, R. J. 1998

The carbon content of South African soils is on average low, for three main reasons:

- the majority of soils are sandy, and therefore stabilise little carbon;
- the temperatures are high, leading to high soil organic matter decomposition rates; and
- the climate is dry (600-800 mm rainfall is the norm in dryland crop areas).

The typical range of virgin soil carbon content within the plough layer (0-300 mm) is 0.3-3.6%, with a modal value around 1.2%. The bulk density of agricultural soils has been assumed to be 1.3 Mg m^{-3}, giving a pre-cultivation carbon density(C_0) of 4680g C/m^2 to a depth of 300 mm. The equation describing the change in carbon content is as follows:

$$C_t = C_0 \, t^{-0.21}$$

where C_t is the carbon density in year t after commencing cultivation, and C_0 is the pre-cultivation carbon density.

In the model, calculations are based on the assumption that, in cultivated lands, carbon storage is reduced to 50% of C_{orig} as a result of tilling. 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 (see table below).

Table 11: Coefficients for calculation of C storage in soil

Description	*Value*
Mean original (pre-cultivation) soil C (Corig)	46.8 MgC/ha
Soil C reduction by till (% reduction)	50 %
Exponent of recovery- α	0.21
Soil C after recovery (% final)	80 %

If 't' is the number of years after introducing reduced tillage, then Carbon stored in year 't' is calculated as follows:

$$Cstored_t = C_{orig}*(\%reduction/100) + C_{orig}*((\%final - \%reduction)/100)*(1-(t+1)^{-\alpha})$$

The change in carbon storage during this year is calculated as follows:

$$\Delta C = Cstored_{t+1} - Cstored_t$$

The total change in carbon stored in all lands under wheat and maize as a result of the introduction of reduced tillage, is as follows:

$$\text{Total } \Delta C = \text{Area} * \text{tillage adoption} * \Delta C$$

Finally the total **C** stored:

$$C_{stored} = \sum \Delta C_{stored} - area*C_{orig}*\ \%reduction*(year_t - 1970)^{\alpha} - (year_{t-1} - 1970)^{\alpha}$$

The calculation was updated by extending storage changes to 30 years instead of 10 used by the previous model and by adding calculations up to the year 2050.

2.6 Capital and variable costs requirements to start a no-till system

Before the cost of a system can be calculated, the assumptions must first be noted.

The following assumptions were made in the calculation of the staring cost of a No-till system

- The farmer must be an above average manager.
- The basic No-till planter must be obtained.
- A good sprayer with sufficient capacity must be obtained to apply the herbicide correctly.
- A planter and sprayer can handle 500 ha per year.
- A herbicide application program must be in place.
- In the first year a cover crop must be planted to supply the stubble for the No-till system.
- Sorghum is used as the cover crop.
- The Roundup ready system will be used as the basis for maize production.
- A maize price of R1000 per ton is used.
- In the first year, the maize yield will be 80% of the conventional system crop yield.
- In the second year, the maize yield will be 95% of the conventional system crop yield.
- In the second year, the maize yield will be equal to the conventional system crop yield.
- Budgets for each year and crop must be compiled.
- The effect of inflation will not be included.
- The fixed cost per ha will not be included.
- The starting cost of the No-till system will be the
    - capital lay out of a planter and sprayer;
    - direct cost of the cover crop;
    - loss of income between the conventional roundup ready system and the No-till year one crop systems.

Table 12 gives an estimate of the capital required to buy the planter and sprayer.

Table 12: Capital layout for planter and sprayer

No-till planter	Metasa No-till planter	R300 000
Sprayer	Tecnoma Galaxy sprayer	R150 000
Total		R450 000

According to the assumptions, a planter and sprayer can handle 500ha of maize per year. Taking this into account, the capital cost for the planter and sprayer will be R900 per ha. In year one the farmer will not be able to sell his old equipment as he must still plant with the old equipment. If all the lands are switched over to No-till, there will be some equipment that can be sold. Normally this old equipment doesn't have a market value and will be sold for next to nothing.

In the table below, the direct cost and gross margins for a 3.5 ton maize yield conventional roundup ready and No-till systems, are given. The effect of the lower production was taken into account and the yields were lower.

Table 13: Production cost for different maize systems

Production year 2006/2007	***Product price (R000/ton)***			
System	***Roundup ready system***	***No-till system***	***No-till system***	***No-till system***
Year	Year 1	Year 1	Year 2	Year 3
Yield (to/ha)	3.50	2.80	3.33	3.50
Gross production value (R/ha)	3 500.00	2 800.00	3 325.00	3 500.00
A: Direct allocated variable cost (R/ha)				
Seed	412.40	412.40	412.40	412.40
Fertiliser	555.41	555.41	555.41	555.41
Lime	51.00	51.00	51.00	51.00
Fuel	501.99	250.41	250.41	250.41
Repairs	395.48	281.84	286.14	287.58
Lubricant	25.10	12.52	12.52	12.52
Herbicides	124.92	242.90	242.90	242.90
Pesticides	147.30	147.30	147.30	147.30
A: Total Direct allocated variable cost (R/ha)	**2 213.60**	**1 953.77**	**1 958.08**	**1 959.51**
B: Other allocated variable cost (R/ha)				
Crop insurance (R/ha)	133.00	106.40	126.35	133.00
Part time labour	45.40	45.40	45.40	45.40
Production interest (R/ha)	132.82	117.23	117.48	117.57
B: Total other direct allocated variable cost (R/ha)	**311.22**	**269.03**	**289.23**	**295.97**
C: Total allocated variable cost (A+B) (R/ha)	**2 524.81**	**2 222.80**	**2 247.31**	**2 255.49**
Gross margin (R/ha)	**975.19**	**577.20**	**1 077.69**	**1 244.51**

According to Table 13 the gross margin of no-till in year one is lower than the conventional roundup ready system. In year 2 and 3 the gross margins of the no-till systems are higher than the roundup ready system. The difference between the roundup ready system and the No-till year 1 system is R397.99. This will be the opportunity cost for changing from the roundup ready system to the No-till system.

In Table 14 the direct allocated cost for the production of sorghum is shown. In the calculation the cost of a 5 ton per ha sorghum was used to produce enough stubble for the No-till system. The cost to produce 5 ton of stubble will be R 1099 per ha.

Table 14: The direct allocated cost of sorghum for cover crop

Production year 2006/2007	
Yield (ton/ha)	5.00
A: Direct allocated variable cost (R/ha)	67.20

Seed	239.67
Fertiliser	397.79
Fuel	277.22
Repairs	117.38
Herbicides	1 099.26
A: Total direct allocated variable cost (R/ha)	

Table 15 summarises the cost to start one hectare no-till maize. The total cost to change from a roundup ready system to a no-till system will be R2 397.25 per ha. In effect this means that a farmer must arrange for R2397.25 extra production credit to start this action. The payback time will differ from farmer to farmer and is not included in this calculation. If the assumption is made that the farmer can cover 50 % of the capital layout with the selling of old equipment it will take the farmer nine years to break even. This project must be done with good financial planning.

Table 15: The cost of start one hectare no-till maize

Capital layout for planter and sprayer per ha (R)	R900.00
Direct allocated cost of sorghum as cover crop	R1099,25
Opportunity cost for year 1 in no-till	R379.99
Total capital, direct and opportunity cost for no-till system	R2 397.25

2.7 Methodology for modelling mitigation from land use changes (fire control and savannah thickening)

2.7.1 Fire control

Fires in grasslands, savannas, fynbos and plantation forestry in South Africa are modelled. Six land cover types were considered by the model: Fertile savanna; infertile savanna; sweet grassland; sour grassland; fynbos; plantation. Although a large quantity of CO_2 is generated as result of fires, it is not a net emission (assuming that it is re-absorbed in plants in the next growing season) and only CH_4 and N_2O emissions were calculated. The emissions for each land cover (lc) are calculated as follows:

$$E_{lc} = \sum \text{area}(km^2)/\text{fire return frequency} * \text{fuel load (kg/ha)} * \text{combustion completeness} * \text{emission factor(g/kg)}$$

The parameters used for this calculation are provided in the table below.

Table 16: Data used for calculation of emission from fire

Land cover	*Historical fire return frequency (Yr)*	*Present fire return frequency (Yr)*	*Area (ha)*	*Fuel load (kg/ha)*	*Complete frac (combustion completeness)*
Fertile savanna	6	10	28 285000	1000	0.9
Infertile savanna	3	5	1 2122100	2500	0.95
Sweet grassland	4	4	14 411340	1100	0.9
Sour grassland	2	3	9 607560	3000	0.95
Fynbos	20	15	46046	20000	0.7
Plantation	100	200	1 241300	30000	0.4

The N_2O emissions are calculated using the same equation with different emission factors.

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 (see Figure 2). 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. The costs of complete fire prevention are unaffordable and it is an unrealistic and unnecessary, but fire frequency reduction is an attainable target. For this model mitigation by 50% reduction is assumed.

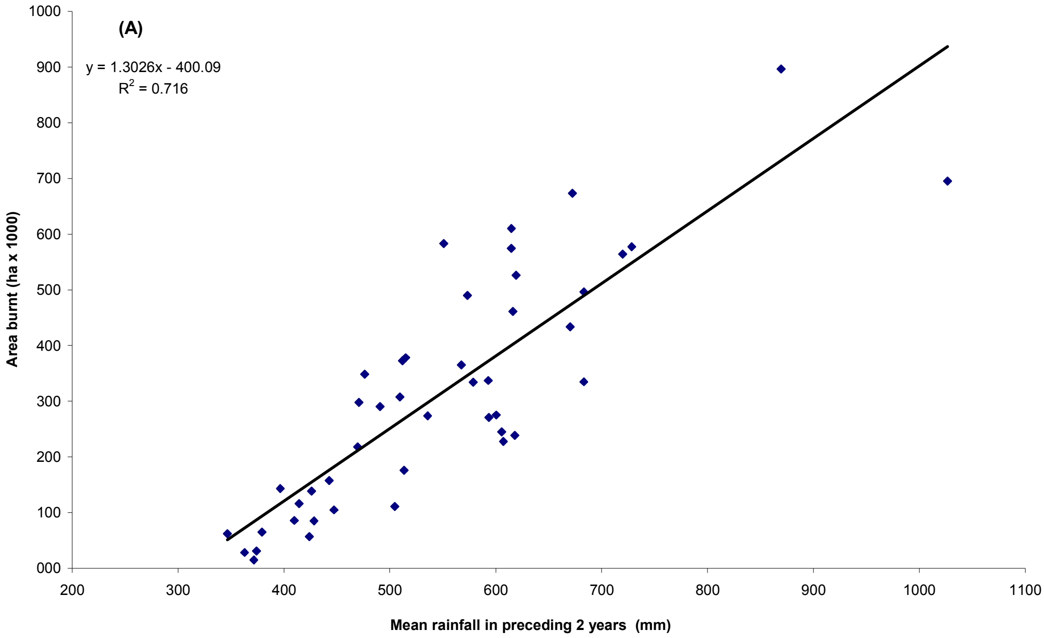


Figure 2: The relationship between mean annual rainfall over the preceding years and the extent of fires in the Kruger National Park
Source: van Wilgen et al (2004)

Unit Cost/ha (UC) of achieving 50% fire reduction is calculated by summarising different components of costs for all land cover (lc) types as follows:

$$UC_{lc} = \sum(UC\ detection*AC\ detection + UCequip*Cequip + Num\ people*AC\ people + Num\ people*cost\ of\ kit$$

Most of the unit costs are expressed as cost per 1000ha

Unit Cost/ha of damaged (UD) caused by fire is also calculated by summarising different components of costs for all land cover (lc) types as follows:

$$UD = Dvegetation*\ fuel\ load*probability\ of\ Dv + D\ livestock*\ probability\ of\ Dl + D\ infrastructure\ *probability\ of\ Di$$

And finally the total control and damage costs are calculated as follows:

$$Control\ costs = \sum area*UC*\ fire\ return\ frequency/(0.5*historical\ fire\ return\ frequency)$$

$$Damage\ cost = \sum area*UD/fire\ return\ frequency$$

2.7.2 Savannah 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. The main reason 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.

Increase in basal/woody area is considered for two land cover types – fertile and infertile grasslands. It is assumed that original woody area in this grasslands are 6 and 8 m^2/ha ($Area_o$)

Firstly the Max woody area is calculated as follows:

$$MaxWA_{lc} = \text{Max Ba} * \text{fire return frequency} / (RT50 + \text{fire return frequency})$$

Where:
Max Ba is maximum tree basal area which is a function of rainfall
RT50 is 50%ile of the fire return frequency

Increase in woody area is calculated as follows:

$$\Delta WA\ (lc) = R * WArea_o * ((MaxWA - WArea_o)/MaxWA))$$

Where:
R is coefficient of savanna growth (assumed 0.04)

Then woody area in year ‘t’ is calculated as follows

$$WArea_t = WA_{t-1} + \Delta WA$$

Finally the increase in CO_2 sequestration (in GgCO2/y) is calculated as follows:

$$\Delta CO2 = \sum(\Delta WA_{lc} * \text{Conv factor} * Area_{lc} * 0.4 * 44/12/1000$$

Where:
Conv factor is conversion for sequestration of C (5.2 Mg/ m^2)
44/12 is conversion from C to CO_2
0.4 represents assumption that only 40% of savanna area would exhibit thickening

The loss of grazing was calculated from an equation derived in Australia, relating grass biomass to tree basal area. It summarises losses for both types of grassland(lc)

$$\text{Loss grazing (Rmillion/a)} = \sum (\text{Normal CC} - (\text{Grass C} + (\text{Grass C} + \text{LSU/ha})\text{\^{}}(\text{Grass K} * WArea_t)) * \text{Income/ha} * \text{Area (lc)})/1000000$$

The Normal CC is calculated as follows:

$$\text{Normal CC} = \text{Grass C} + (\text{LSU/ha} + \text{Grass C})\text{\^{}}(\text{Grass K} * \text{Normal BA})$$

Where:
Grass C is the amount of grass production (expressed in animal carrying capacity units) with maximum tree cover
Grass K is the amount of grass production (expressed in animal carrying capacity units) without any tree cover
Normal BA is tree basal area
LSU/ha is livestock units per ha

It must be noted that LSU/ha should be higher for fertile than infertile savanna given the same rainfall, but averaged over SA the infertile savannas have higher rainfall. Therefore it is assumed 0.1 for fertile and 0.15 for infertile savanna

Table 17: Parameters used for calculation of loss of grazing

Land cover	*Grass k*	*Grass C*	*Normal BA*
Fertile savanna	0.25	0.01	6
Infertile savanna	0.25	0.01	8

2.8 Data for modelling mitigation from waste sector

The most comprehensive national study describing the waste sector in South Africa was the baseline study in 2001 in preparation for the National Waste Management Strategy (DWAF 2001). It classified and quantified the waste generated and disposed of in South Africa. The results of the baseline data collection are presented in the table below.

Table 18: National information on general waste generation in 1997

Source: DWAF (2001: Table 9)

	Information from receipts at landfills	***Information on generation from questionnaires***
Province	***Waste disposed***	***Waste collected***
Eastern Cape	571 000	441 000
Free State	782 000	482 000
Gauteng	4 297 000	1 963 000
KwaZulu-Natal	1 811 000	410 000
Mpumalanga	481 000	353 000
Northern Province	153 000	199 372
NorthWest	354 000	290 000
Northern Cape	262 000	147 000
Western Cape	1 487 070	423 000
Total	**10 245 070**	**4 699 503**

The discrepancy between waste collected and waste disposed shows low accuracy of the available information. While government has implemented a national waste information system to collect regular data on waste disposal to landfill, it will be some time before accurate national data are available.

The estimation of waste received at landfills is inaccurate. Many landfills do not have weighbridges and they are basing their estimations on guesses or on density estimations, which may an order of magnitude out. Many of the landfill sites base their estimates on volumetric measurement on the vehicles coming into the site both in a loose (open trucks) and compacted form (rear end loaders), hence difficult to tie up with estimated densities. There are also periodical insitu topographical surveys of the landfill, but this form of waste estimation also has problems with respect to densities and sometimes the incorrect method of volume calculation due to ongoing settlement in the landfill (S Jewaskiewitz, pers communication 2007).

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 and it can start 6 to 9 months after the waste is put in place. 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 (H2S), mercaptans (R-SH) and ammonia/amines (R-NH2). The mercaptan and amine compounds have particularly strong and offensive odours even at low concentrations.

Typical landfill gas, if permitted to accumulate in low lying, enclosed or confined spaces, may produce an atmosphere that is both explosive and hazardous to life. The CO_2 and VFA components of landfill gas are highly aggressive to concrete, brick mortar and mild steel. Landfill gas will displace oxygen from enclosed spaces making entry to them extremely hazardous. CH_4 is explosive in air concentrations of 5 – 15% by volume.

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. As the landfill uses a soil cover (biocover) in its operations, a portion of the CH_4 is oxidized as it passes through these soil layers and converted to CO_2.

A lot of international research is currently underway looking into biocovers for landfills. This is particularly important with respect to landfills that do not have landfill gas extraction and management systems. There are many such landfills in South Africa including many of the so-called open or controlled dumps or even the smaller permitted landfills where the production of landfill gas is deemed to be too low for the consideration of gas extraction systems. Many of the open dumps are now either being closed or are being encouraged to register with DWAF with the view to being permitted (licensed). In these cases these landfills will become producers of landfill gas. Biocovers are used to oxidize the methane on its way through the capping of the landfill. This can therefore also be considered as mitigation measure.

The existing landfills are running out of available space, therefore new landfills have to be identified and approved through a lengthy, rigorous and frequently contested EIA processes. The provincial governments are reluctant to approve the creation of new landfills in built-up urban areas, which means that landfills will have to be constructed in peri-urban or rural areas. The consequence thereof is that waste has to be transported over long distances, resulting in high energy and resource inputs with associated high costs and increase in emission from transport.

Waste minimization and recycling is an upstream intervention. According to DST (2006):

> In an attempt to reduce an amount of waste going into a landfill, South African Government and related stakeholders have pledged to grow the recycling industry by 30% in 2012. In 2003, 52% waste paper was recycled. South Africa recycles about 20% of glass containers produced per annum and it is estimated that 30% of plastic used for packaging is recyclable. DEAT estimates 85% of beverage cans are recovered and recycled annually in South Africa. It is also approximated that 2% of electronic waste is being recycled in South Africa.

The proposed Waste Management Bill (DEAT, 2006) has placed the waste hierarchy within a life-cycle assessment approach as it states: ‘Every person who undertakes a recovery, re-use or recycling activity must, before undertaking that activity, ensure that the recovery, re-use or recycling of the waste uses less natural resources than disposal’. This implies that only viable, sustainable options to recovery, re-use or recycling of the waste will be considered in future, which are e.g. less resource intensive that e.g. landfilling. The life-cycle assessment is also the approach used in the UK and Europe.

In South Africa only large cities have engineered landfills, with smaller cities, towns and villages having controlled or open dumps. The large sites (with input greater than 30 000 t/a) were studied to determine potential for power generation (DME 2004). It was found that 20 large sites yielded 41 MWe of energy, which is close to 70% of the potential energy for all of the landfills studied. According to the DME study, a total of 57 sites could be considered for power generation out of a recorded 453 sites. These 57 sites were estimated to produce 502 Mm^3 of LFG in 2005.

It can be assumed that for the smaller sites and controlled dumps, which generate remaining 30% of the landfill gas, these emissions can be mitigated by flaring (destroying) the gas, using the gas in thermal applications or oxidising the methane through the use of biocovers.

A comprehensive pre-feasibility study was recently completed by DST (DST 2006) on energy recovery from municipal waste, which suggested some innovative approaches to energy from waste projects. However, 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.

The problem with the diversion of organic wastes away from landfill is that broadly speaking the organic wastes can be divided into two classes: that which can be easily separated (garden wastes etc) and that which is mixed into other wastes. The garden wastes are generally sent to composting operations whereas the mixed wastes can be treated biologically – Mechanical Biological Treatment (MBT), prior to being landfilled. In this way the generation of landfill gas is avoided.

Utilisation of LFG not only produces energy and prolongs the life span of the waste sites, but also allows carbon credits under the CDM to be claimed.

3. Description of mitigation actions and modeling results

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) 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 19 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 3.2 to 3.7.

3.1 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 3.2 to 3.7.

Table 19: Specification of mitigation actions modelled

Mitigation action	*Model parameters*	*Time-scale*	*Ref. goaf*	*Mit. goal*	*Quantity*	*Remaining comment/ qualifications*
Energy supply[2]						
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[3]						
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 improve-ment	% improvement vehicle efficiency	
Hybrid vehicles	20% of private cars are hybrids by 2030 (ramped up from 0% in 2001 to 7% in 2015) Shares of petrol cars reduce to accommodate	2015 2030		7% 20%	% of private cars which are hybrids	
Transport mode shift action: passengers	Passengers shift from private car to public transport, and from domestic air to intercity rail/bus. Currently, 51.8% of passenger kms are by public transport – this will move to 75% by 2050	2050		75%	% 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	

[2] 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).

[3] 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
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 process control, using building energy management systems, improving building shell design, and introducing variable-speed drives.	2015 2030	15%	 30%	Reduction in final energy consumption over base case	In order to reach 30% savings, boiler efficiency improvements must be 40% (base case is 30%). Penetration rates for efficient boilers are as in base case: 2015: 51%, 2030:80%, 2050:100%
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	Increase energy efficiency in the use of electricity and steam by synfuel refineries by 15% by 2015	2015	15%		Refinery efficiency improvement	

Mitigation action	*Model parameters*	*Time-scale*	*Ref. goaf*	*Mit. goal*	*Quantity*	*Remaining comment/ qualifications*
synfuel plants					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 from existing CCS plants	Capture CH_4 emissions from existing CTL plants from 2010	2010		0	CH_4 emissions from existing CTL plants	
Coal mine methane capture	Capture 25% or 50% (at higher cost) of methane emissions from coal mines, starting in 2020, and reaching goal by 2030	2030 2030		25% 50%	Percentage of CH_4 emissions captured from coal mining	
Aluminium: PFC capture from existing plants	Capture of PFCs from existing aluminium plant, starting in 2011, and reaching 100% by 2020	2020		100%	Percentage of PFCs captured from existing aluminium plants	

Mitigation action	Model parameters	Time-scale	Ref. goaf	Mit. goal	Quantity	Remaining comment/ qualifications
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 20 provides descriptions of the new and extended wedges modelled for SBT5.

Table 20: 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.

3.2 Mitigation action in livestock management

3.2.1 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.

3.2.2 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).

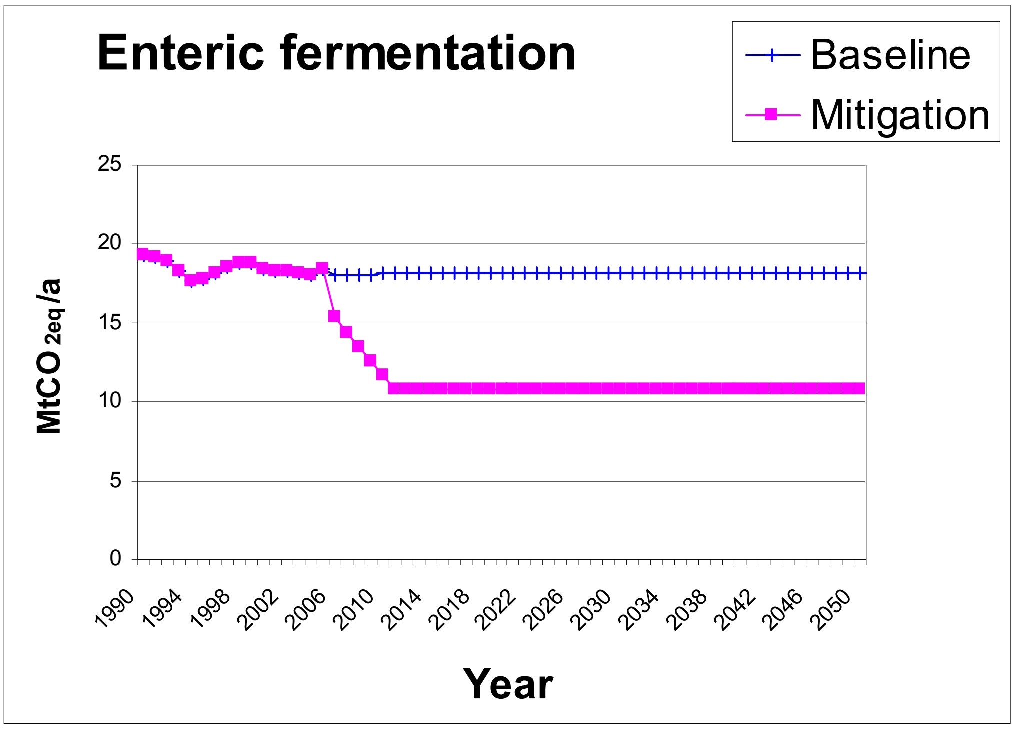
The updated income rates (to keep the baseline consistent these are assumed to be applicable after 2005) were provided by the DoA (J Classen, pers. communication) for some of the categories and for others an increase, using the CPIX index, was assumed.

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

3.2.3 Modelling results for enteric fermentation

The final results of emissions are presented in Figure 3

Figure 3: 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 21: 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.

3.3 Mitigation action in manure management

3.3.1 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.

3.3.2 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.

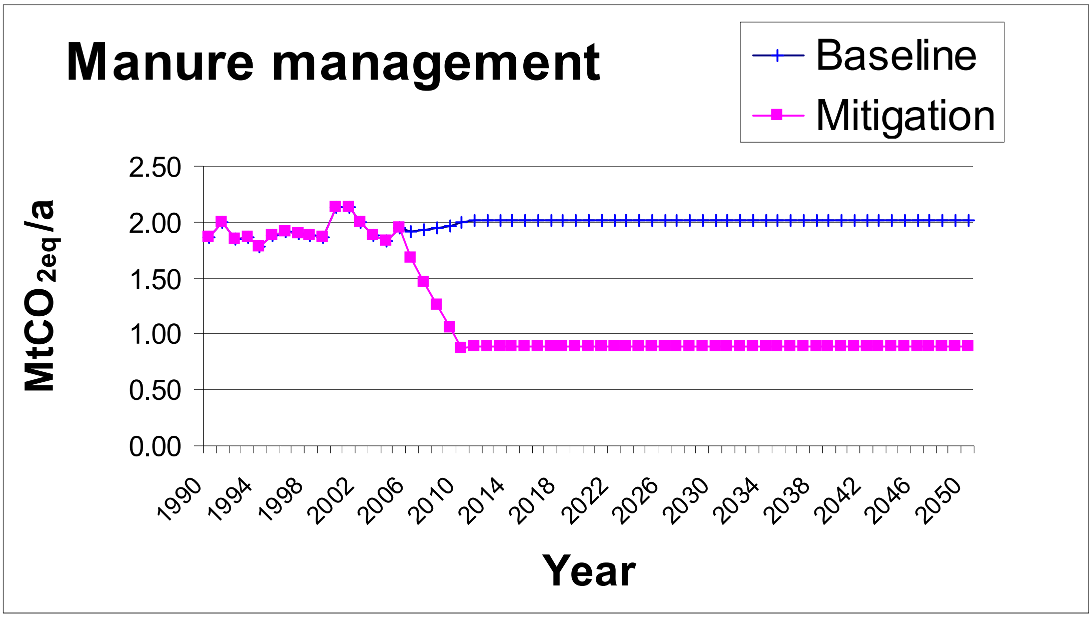
3.3.3 Calculation of costs

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.

3.3.4 Modelling results for livestock manure

The final results of emissions are presented in Figure 4 below:

Figure 4: Baseline and mitigation option emissions from manure management (Mt CO2eq/a)



The financial calculation results are summarised in the table below.

Table 22: 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 23: 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.

3.4 Mitigation action in tillage

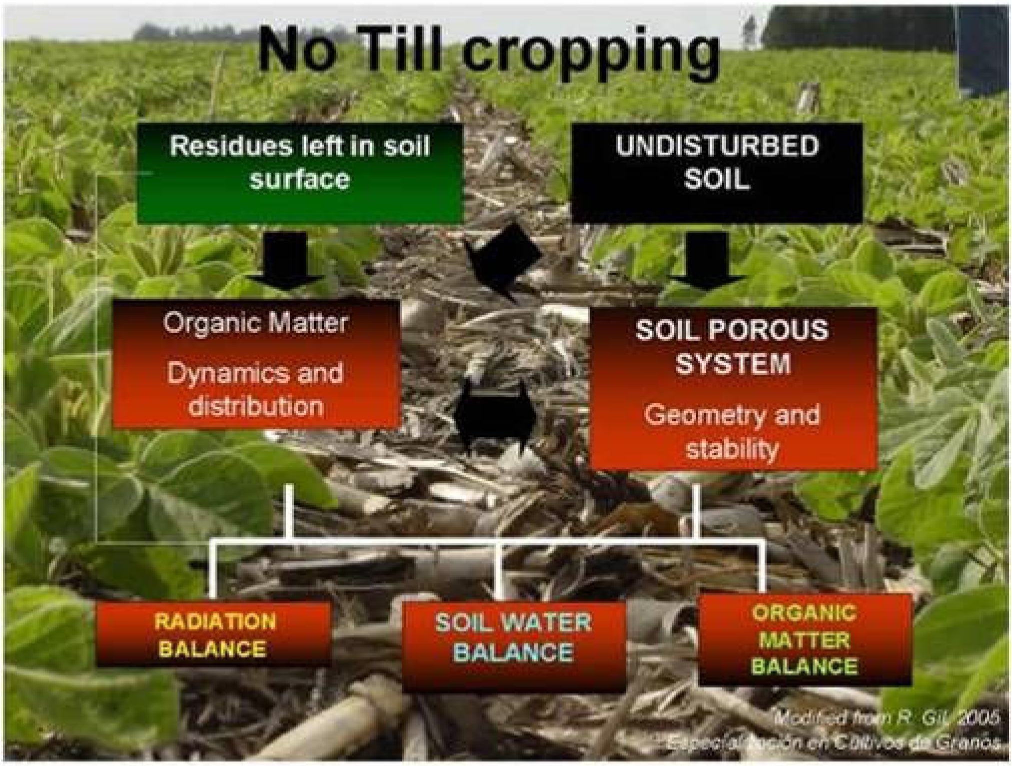
3.4.1 Sector description

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 5: 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.

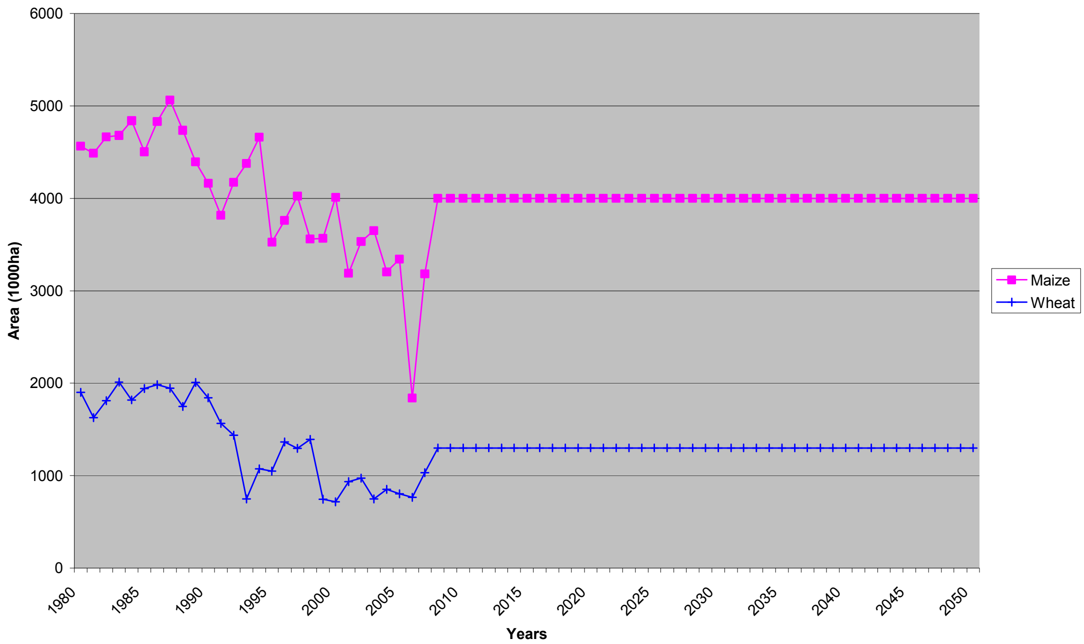
The further details on data sources, assumptions used and the methodology for calculation of emissions are provided in Appendix 10.

3.4.2 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 6 below.

Figure 6: 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:

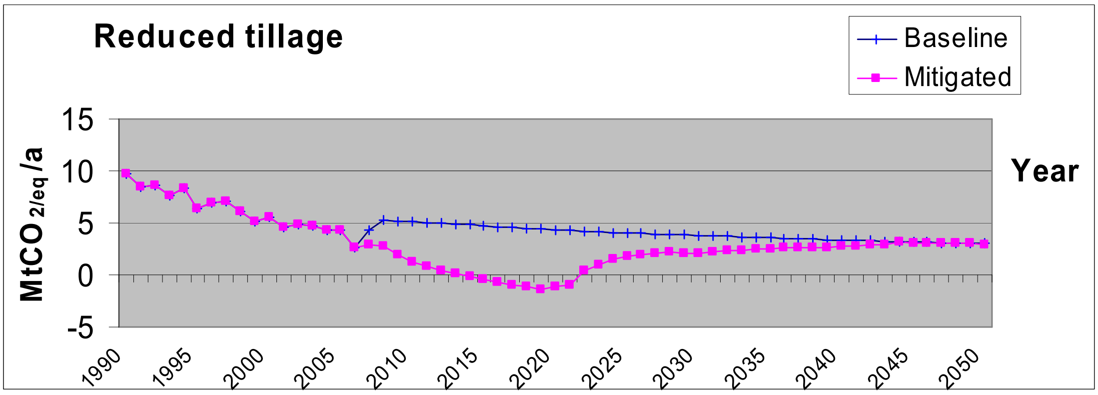
- **In the first scenario it was assumed that reduced tillage can be adopted on 80% of the lands. This scenario represents S4 (or S5) scenario**
- **In the second scenario, the adoption of reduced tillage was much lower (about 30%, and differentiated between wheat and maize), according to the recommendation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

More details are provided in the section below.

3.4.3 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 7 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.

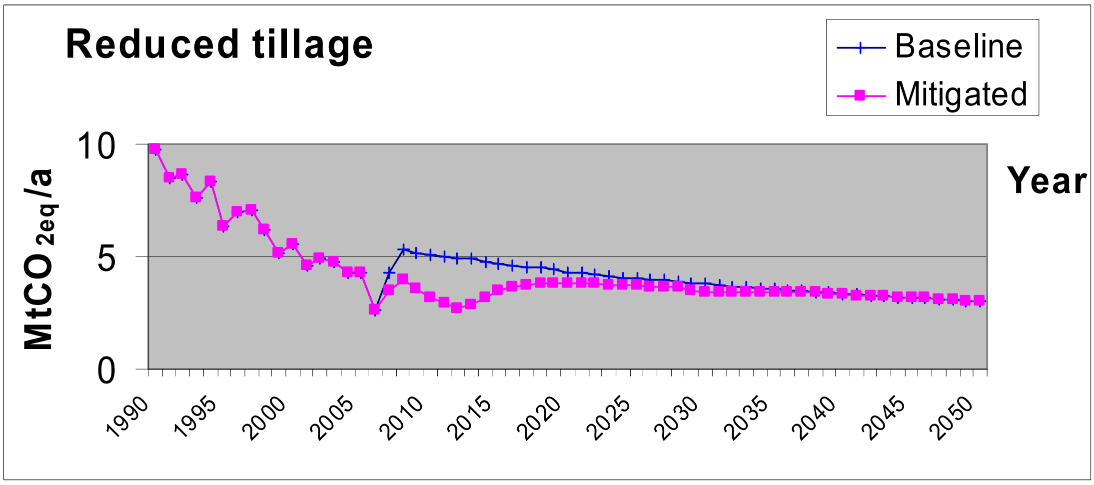
Figure 7: Mitigation by adoption of reduced tillage



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 8: 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 24: 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 25: 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.

3.4.4 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).

3.5 Mitigation actions in waste

3.5.1 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.

3.5.2 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 26 below (Mayet 1993).

Table 26: 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).

3.5.3 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 27: 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.

3.5.4 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.

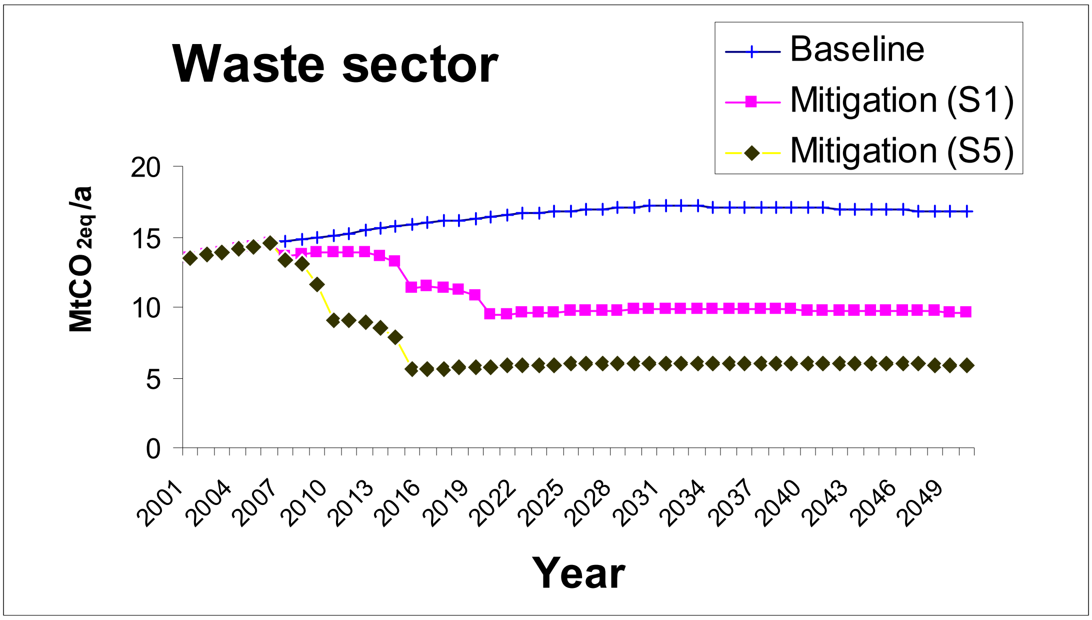
The City of Cape Town is negotiating a contract for composting where R90/t will be paid to remove and then compost chipped garden waste. However this value was not published yet. A simplified assumption was made that the cost of composting is the same as the cost of disposal and therefore no additional 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.

3.5.5 Modelling results for solid waste

The results of the modelling are presented in Figure 9 below.

Figure 9: 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.

3.5.6 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.

3.6 Mitigation actions using fire control and savannah thickening

3.6.1 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.

3.6.2 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.

3.6.3 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.

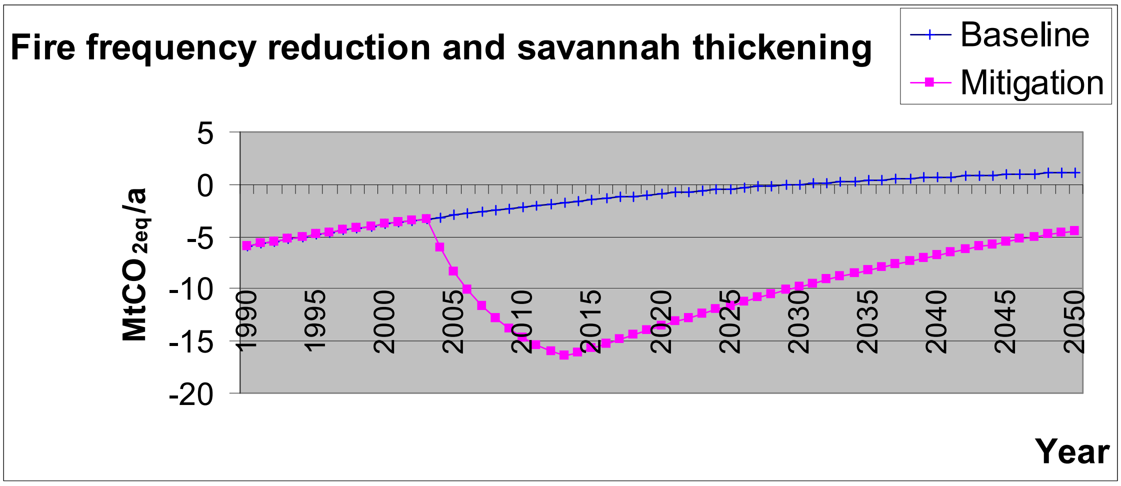
Increase in woody biomass is considered for two land cover types – fertile and infertile savannas. It is assumed that the growth from the original woody biomass to a climatically-determined maximum is function of fire return frequency and of rainfall.

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).

3.6.4 Modelling results for land-use changes

The emission comparison for the baseline and mitigation scenarios is presented in Figure 10. For most of the study period, carbon is sequestered and only at the end are slight emissions projected.

Figure 10: 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 28: 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.

3.6.5 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.

3.7 Mitigation actions in forestry sector

3.7.1 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).

3.7.2 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.

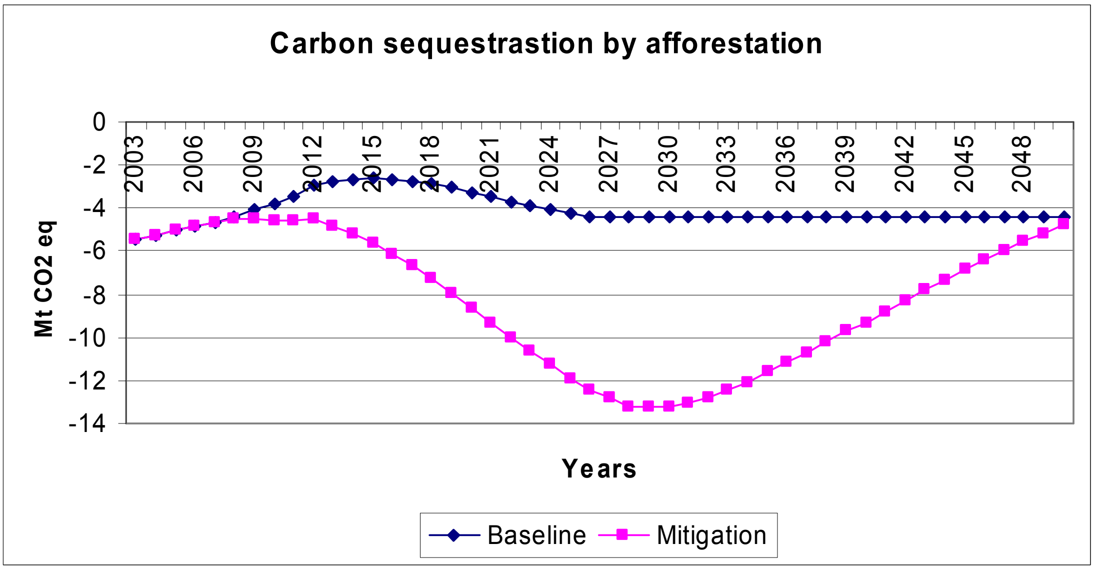
For the mitigation option it is assumed that **the net extension area will increase by 200% from 2008 to 2030 to allow an additional 760 000 ha** (close to the value suggested in DWAF, 2004). Since GDP growth will flatten down to about 3% after 2030 (see Figure 5 in section 3: Key assumptions), the same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

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

3.7.3 Modelling results for afforestation

The modelling results are presented in the figure below.

Figure 11: 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 29: 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

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